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21st International Drying Symposium

Book of Abstracts

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21st International Drying Symposium

Book of Abstracts

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BOOK OF ABSTRACTS

PLENARY LECTURES

#7631
Role of IDS in Global Drying R&D

Arun S. Mujumdar, Hong-Wei Xiao, Sachin V. Jangam

The first conference in the IDS was held in 1978 at McGill University, Montreal, Canada, with the express purpose of international exchange of technical and scientific knowledge and promotion of drying R&D on a global scale via networking and collaboration. Another goal clearly noted in the Preface of the proceedings volume of the first symposium was to encourage tangible academic-industry exchange, knowledge transfer and exchange of knowhow across diverse industrial sectors with significant drying operations. Initially the impetus for drying R&D was provided by the rapidly escalating cost of energy; later the stimulus for drying research was the need to produce high quality products safely at lower cost and higher productivity using innovative dryers and optimal control as well as operation. The success of the IDS series led to the establishment of Drying Technology-an international journal, several international and national conference series devoted to drying and many academic drying research centres around the world. This presetation will give a historical perspective on the establishment and subsequent development of IDS with statistical data and summrize results of a SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis. Prospects for the future of drying R&D and need for research, both basic and applied, will be identified. Role of IDS in promoting networking, international collaboration, innovation, and industry-academia interaction will be discussed.

Keywords: IDS, Technology thougth; Networking; Innovation; SWOT.

#7936
Structure formation by drying

Evangelos Tsotsas

Differently structured dry particles possess different application properties. For example, agglomerates are necessary in order to achieve fast reconstitution in liquid, whereas coated particles are used to control the release of active ingredients. Structured particles can be produced by spraying and drying, namely in spray dryers and spray fluidized beds. Therefore, the lecture will give an overview about the state of our understanding of how structure is created during such processes. And, it will attempt to track frontier and possible future research about new possibilities for structure formation by drying. Some of the questions/topics that will be discussed are:

- Is it possible to coat very small particles by spray drying?
- Can nanoparticles be produced by spray drying with a conventional nozzle at high concentration of the feed?
- Can conventional particle formulation processes be simplified and improved by combination of spray drying and spray fluidized bed technologies?
- Is it possible to produce graded coatings (coatings with gradients of structural properties and/or composition) in spray fluidized beds?
- Can the quality of grading and the thickness of coating be pushed down to the submicron (or even nano) scale by using novel atomization technologies?

Concerning spraying and drying on substrates, the philosophy to be discussed is that respective processes can be seen as additive manufacturing (printing) and they have the potential of producing in a robust and scalable way dry particles with (at least in some cases) similar structural resolution as expensive and difficult to scale liquid phase processes.

KEY NOTES

#7240

Color degradation bio-substrates subject to COLDwave(TM) (joint jet impingement and microwave) drying

Maria Valeria De Bonis, Gianpaolo Ruocco

Drying of bio-substrates such as food can be enhanced when exploiting a variety of simultaneous transport phenomena mechanisms, such as jet impingement and exposure to microwaves.
To this end, a laboratory prototype "COLDwave"(TM) has been exercised to infer on substrate quality departure. Among the various available operating conditions, there are some that address the preservation of color attributes.
As an example, emphasis to pulsed exposure to microwaves would result in less spoiled substrates, while colder air would not necessarily lead to optimal processing, and higher flow rates would increase oxidation and color degradation.

#7293
Understanding fresh food drying: safety/quality, efficiency and energy consumption

Min Zhang

Fresh food drying often has some issues which may conflict with requirements of food safety,quality,efficiency,and energy consumption. High efficiency can lead to low energy consumption and saving drying costs but may cause reduced quality and even problems with safety of the dried foods which may reduce the value of the dried products. So it is very important for the researchers and manufacturers to balance the needs among safe shelf life along with high quality, good efficiency, and lower energy consumption. A comprehensive review of recent developments in this area can provide deep understanding of food drying.Several new drying technologies have been developed to meet these special requirements of efficiency,energy consumption,safety and quality.These highly efficient combined drying methods can protect diverse quality parameters of fresh foods (such as color, flavor, nutrients, rehydration, appearance, uniformity, etc) and safety during an energy-saving drying process. Some novel hybrid drying methods utilizing other latest technologies such as nano-technology, AI technology, technology,NMR and hyperspectral image technology, , can be good choice to be used by Abstract: Fresh food drying often has obvious conflict on safety/quality,efficiency,and energy consumption. High efficiency can lead to low energy consumption and saving drying costs but may cause reduced quality and even safety of the dried foods which may reduce the value of the dried products. So it is very important for the researchers and manufacturers to balance the needs among safe shelf life & enough quality, efficiency, and energy consumption. A comprehensive review of recent developments in this area can be for better and deep understanding of food drying.Some new technologies with combined drying characteristics have been developed to meet these special requirements on efficiency,energy consumption,safety and quality.These high efficient combined drying methods can protect the qualities of fresh foods (such as color, flavor, nutrients, rehydration, appearance, uniformity, etc) and safety during the energy-saving drying process. Some novel hybrid drying methods with other latest technologies like nano-technology,smart technology,NMR & hyperspectral image technology, extreme technology, etc will be discussed. Potential for future applications and research opportunities will be identified for both academia and industry.

#7303
Drying of mangoes applying pulsed UV light as pre-treatment

Thayane Rabelo Braga, Ebenezer Oliveira Silva, Sueli Rodrigues, Fabiano Andre Narciso Fernandes

High intensity pulsed UV Light is a non-thermal treatment used in sanitization of fruits and vegetables. In this work, we have applied high intensity pulsed UV light as a pretreatment for convective air-drying evaluating the benefits of the pretreatment to the drying process and to the nutritional quality of the dried product. Mangoes were subjected to pulses of UV light. The pretreated samples were further dried in a convective oven-drier until 90% of the initial water content has been removed. Drying kinetics, water apparent diffusivity, vitamin B, vitamin C content and total carotenoids content were analyzed. Pulsed UV light showed to be an interesting pretreatment for mangoes given the higher nutritional content of the dried product.

Keywords: mango; drying; ultraviolet; vitamins; kinetics.

#7621
Equipment, mechanism and perspectives of flame spray drying

Ireneusz Zbiciński, Mariia Sobulska, Marcin Piątkowski

The paper presents a novel and still in the early stage of technological development, spray drying method utilizing combustion of flammable component of the spray as an energy source for drying process, i.e. Flame Spray Drying (FSD). Flame spray techniques utilizing the external flame, internal flame and combustion before atomization to produce particles or nanostructured coatings with desired morphology, properties and size distribution for a more efficient use of energy along with a decreased emission of harmful gases to the atmosphere are described. The experiments and theoretical research works on FSD process oriented to control powder properties (bulk density, morphology), particles agglomeration, residence time and safety of the process and modeling of drying kinetics and hydrodynamics of gas and dispersed phase are critically evaluated. A survey of existing equipment for FSD was carried out with analysis of the effect of FSD process parameters and fuel type on the dried powder properties: moisture content, flammable component content, bulk and apparent density, color index and particles morphology.
Complex flow dynamics of discrete phase observed during FSD process at the outward regions of the flame in recirculation zones leading to formation of particles agglomerates, particle puffing or inflation and producing specific morphology of dried particle: hollow particle with a thin shell was discussed.
Comparison of energy consumption between FSD and classical spray drying process was assessed and potential application of the FSD technique in drying of different materials was evaluated.

#7652
Process intensification and process control in freeze-drying

Antonello A Barresi, Roberto Pisano

Widespread use of advanced process control allows reduction of costs, by reducing drying time and energy consumption. The "control of the freezing stage" (by forced nucleation) also appears to be beneficial to process intensification, as it can impact the product structure and modify the product resistance to mass transfer. An alternative way to increase the drying rate is the use of organic solvents as they can lead to larger solvent crystals, hence lower product resistance to vapor flow.
Atmospheric freeze-drying may be a good alternative to vacuum freeze-drying, as a way of increasing process efficiency. A further improvement can be obtained by combining atmospheric or vacuum freeze-drying with new technologies.
A further step towards process intensification is given by continuous plants, as this allows a dramatic increase in throughput and product quality uniformity.

Keywords: freeze-drying; process intensification; controlled nucleation; continuous process.

#7653
Shrinkage during drying of foods: 25 years later

Cristina Ratti

Shrinkage of porous material during drying results from the lowering in the liquid pressure induced by the desaturation process at the interface, elasticity of the still wet material plays an important role in particle deformation and so, while water is evaporating, the space left shrinks. The ideal shrinkage model acknowledges that its extent is equal to the volume of liquid water removed from the dried material. However, often during drying of foodstuffs, shrinkage is not ideal. The shrinkage phenomenon is dependent upon the physical pliability of the material which may be influenced by several intrinsic and extrinsic factors.
Food shrinkage was shown not only dependent on water content, but also on drying conditions. Under extreme drying conditions, the extent of shrinkage is usually lower than under gentle operation variables. How shrinkage could be related to operating conditions was explained 25 years ago based on the Biot number for mass transfer. The 'case hardening', a phenomenon which appears during drying under sturdy air-drying conditions is a clear example of this behaviour. More lately, researchers studying shrinkage of banana and papaya have related shrinkage non-ideality to glass transition, which usually happens at the end of air-drying, when the temperature of the product could be positioned below the glass transition temperature of the product. In these last moments of air-drying, the whole matrix becomes glassy with limited movement, and thus shrinkage could be hindered. Also, the difference in Poisson's ratio values of a food material in glassy and rubbery states, was pointed out from mathematical modelling as the responsible mechanism for slope change and non-ideality in the shrinkage curve at the end of drying. Nevertheless, other researchers stated that the chemical nature of the infused solute (particularly its solubility) is more important than its glass transition temperature to aid in preventing structural collapse during osmotic dehydration of apples. Recently, the presence and concentration of starch and its distribution in the food matrix was studied in relation shrinkage during drying. The substantial increase in mechanical properties of starchy foods as water contents decrease was shown as a major factor in shrinkage non-ideality.
These limited and 'apparently' contradictory results are pointing out the need for more research in the area of food shrinkage and its relationship to phase/state transitions to complete the elucidation of this lifelong research enigma. In this presentation, a description on different possible factors will be presented.

#7725
Innovative microwave technologies for food drying processes

Ana Andres, Ruth De los Reyes, Ana Heredia, Elias De los Reyes

It is well known that microwaves can assist most of food drying processes; but despite its benefits, microwave energy has not yet been exploited to its potential in the industrial applications. Some of the reasons are because available microwave technology (tubes and valves) cannot offer a homogeneous heating, causing hot/cold spots depending on product geometry and distribution in the chamber or tunnel. Particularly in drying processes, when available water decreases, the efficiency of the process will decrease. If the microwave power is not adjusted at this point of the drying process, the electromagnetic field strength increases and thermal runaway, arcing, or plasma formation can be created. Currently, the solid-state microwave heating (S2MH) technology is considered one of the most promising options to avoid the ancient problems preserving the known advantages. The new S2MH features include frequency and phase variability and control, low input-voltage requirements, compactness and rigidity, reliability, and better compatibility with other electronic possibilities (Internet-of-Things). The first notable advantaged is the S2MH system ability to assess feedback from forward and reflected signal. This allows the application to easily measure and track the energy levels being put into the load, which can avoid the mentioned final drying problem, together with many others related to monitoring needs. On the other hand, almost all energy consumption and CO2 generation in drying processes correspond to air heating stage. To tackle this problem, Advanced Materials for Microwaves based Heating (AM2H) have been developed for transducing electromagnetic energy into heat, which is transferred to air by using high contact surface ceramic structures. The aim of this work is to review Microwaves Assisted Drying Processes and to present the advantages offered by two innovative microwave technologies: Solid-State Microwave Heating (S2MH) technology and Advanced Materials for Microwaves based Heating (AM2H).

#7753
Supercritical CO_2 drying of food matrices

A. Zambon, T. M. Vizzotto, G. Morbiato, M. Toffoletto, G. Poloniato, S. Dall'Acqua, M. De Bernard, S. Spilimbergo

This work explore the use of supercritical CO2 drying as alternative technique for the obtainment of pasteurized and high quality dried product. Several tests were conducted on animal, vegetable and fruit matrixes in order to investigate the effectiveness of SC-CO2 drying process at different process conditions. Design of experiment was performed to find the optimal process conditions for vegetable and fruit matrices, using the final water activity of the products as key indicator for the drying efficiency. The inactivation of naturally present microorganisms and inoculated pathogens demonstrated the capability of SC-CO2 drying process to assure a safe product. Moreover, retention of nutrients was compared with conventional drying methods. Results suggest that supercritical drying is a promising alternative technology for food drying.

Keywords: supercritical drying; carbon dioxide; food drying; microbial inactivation.

#7814
Optimal and innovative spray drying of food powder – Product driven process design and scale up considerations

Reinhard Kohlus, Tobias Balke, Annika Linke, Nora Ruprecht

A classical paradigm of spray drying states that scale up based on single drop drying or small scale experiments is inherently difficult, if not impossible. In the last years the understanding of the drying process has been largely improved by sophisticated modelling of CFD simulations. Characteristic drying curves of single droplets by the use of ultrasonic levitators provide product specific insights. This has changed the picture largely. However, in parallel product quality requirements have been increased.

A huge range of different foods are spray dried, including dairy powder i.e. skim milk, whole milk, butter milk, yoghurt, milk protein, whey, instant formula, coffee, egg, yeast, and vegetable powder i.e. tomato and carrots. In addition to these selected high volume products speciality products including encapsulated aroma and edible oils as well as colourants are of high interest, all having specific constraints.

Since more than 10 years, glass transition considerations and sticky point approaches have been established in designing spray drying parameter. In combination with modern CFD simulations and particle tracing approaches, this allows to predict feasible process conditions. Recently, even space resolved reaction rates, i.e. protein denaturation have been taken into account.

Thermal damage is determined by particle temperature, residence time and reaction rate. Particle temperature depends on drying speed which is directly related to local moisture of the drying particle. Reaction speed for most reaction in foods also strongly dependent on moisture or more precisely equivalent water activity. Changes in protein functionality have been found in different applications. Aroma changes are however mainly related to losses of volatiles. In this context, effect of fines return parameters and early drying rates will be discussed.

Due to sustainability and energy saving requirements, high volume processes will be optimized rather by energy saving consideration than by product quality. Regarding energy costs, novel approaches include increasing feed concentration, generating narrow droplet size distributions, process design variations i.e. multistage drying, use of economizer and finally recovery of heat of evaporation i.e. by the use of superheated steam. Most of the techniques also have impact on product quality. Quantitative data based on industrial dairy production allow scenario calculations to compare the effects of different parameters, keeping in mind product constraints. Finally, particle size and residence time of pilot scale products will be compared to industrial spray dried products and the effect will be discussed.

Keywords: spray drying, food powder, reaction rate, scale up, energy efficiency.

#7833
Ultrasound enhancement of osmotic dehydration and drying – Process kinetics and quality aspects

Grzegorz Musielak

The aim of presented studies is to investigate of influence of ultrasonic assistance on both osmotic dehydration and convective drying. A wide range of different materials, as well as several osmotic agents were tested.
The obtained results show that the use of ultrasound always accelerates the investigated processes. The application of ultrasound may reduce the energy consumption of drying. Qualitative studies of dried materials do not give a definite answer about the effect of ultrasound on the quality of the products. Mathematical modelling of the ultrasound assisted drying indicates that so named "vibration effect" plays the biggest role in convective drying acceleration.

Keywords: osmotic dehydration; convective drying; ultrasound; process kinetics.

#7851

Using Life Cycle Assessment methodology to minimize the environmental impact of dryers

A. Léonard, S. Gerbinet

Drying is known as a high energy consuming unit operation, representing between 12 to 25% of the global industrial energy consumption in developed countries. Consequently, drying contributes to several environmental impacts mainly associated to its heat or electricity requirements. One can cite global warming, emission of particles, acidification, photochemical ozone formation, …
Based on a literature review and some dedicated case studies, this work will illustrate how Life Cycle Assessment (LCA) can be used to evaluate the environmental impacts associated to a drying operation. The results will be presended in a way to indicate some eco-design strategies for dryers.

Keywords: drying; eco-design; Life cycle assessment; environmental impact.

#7855
Beyond freeze-drying of biologics: vacuum-foam drying and spray freeze-drying

A. Langford, B. Balthazor, B. Bhatnagar, S. Tchessalov, M.J. Hageman, A. Lukas, M. Plitzko, B. Luy, S. Ohtake

The complexity of biotherapeutics in development continues to increase as our capability in discovery and recombinant technology improves. While safety and efficacy remain the two critical aspects of all therapeutics, ensuring adequate stability is a challenge. Freeze-drying is a commonly-used processing technique to enhance the stability of biotherapeutic products, although the lengthy process time and low energy efficiency have led to the search for, and evaluation of, next-generation drying technologies, including spray freeze-drying and vaccum-foam drying. Both processes result in dosage forms that vary considerably from those produced by lyophilization and possess physical properties that may be deemed superior for their intended applications.

Keywords: vacuum-foam drying; spray freeze-drying; lyophilization; biotherapeutics; stabilization.

#7875

New technique of combined hot air and microwave drying to produce a new fiber ingredient from industrial by-products

Clara Talens, Marta Castro-Giráldez, Pedro J. Fito

The search for solutions to transform the by-products generated by the agri-food sector in high value-added ingredients is a priority. The aim of this research was to develop a microwave coupled with hot air drying technique allowing maximizing profits by reducing time and operational costs and to produce a dietary fiber ingredient with interesting technological properties for the development of healthy foods. The shrinkage-swelling phenomena occurred during drying changed the rehydration properties of the fibre ingredient obtained. An increase in particle size improved the fibre's swelling capacity when hydrated, allowing 50 % fat substitution in potato purees.

Keywords: hot air-microwave drying; orange peel; thermodynamics; GAB model; dietary fibre.

#7897
Power ultrasonic technologies for drying process intensification at low temperatures

Enrique Riera, Juan A. Gallego-Juárez, Roque R. Andrés, Antonio Mulet, José V. García-Pérez, Juan A. Cárcel

Drying intensification has been addressed not only by introducing changes to conventional drying processes but also by combining conventional drying techniques with new technologies such as ultrasound which mainly produce mechanical effects. The ultrasonic vibration makes a microsponge effect in the internal structure that favors the outflow of the moisture to the sample surface by its natural channels. On the other hand, high-intensity airborne ultrasound causes microstreaming at the interfaces that reduces the diffusion boundary layer, increases mass transport, and accelerates diffusion. In addition, the airborne ultrasound introduces pressure variations at air/liquid interface and increases the evaporation rate of the superficial moisture. Therefore, the application of ultrasonic energy offers a great potential to contribute to the drying process. At present, the application of power ultrasound to food drying processing is considered as an emerging, green, promising technology specially for intensification of forced-air drying at lower temperatures. Power ultrasound as a mechanical non-contaminant and non-ionizing radiation plays a relevant role in the need for obtaining safer and higher quality products. The Ultrasonic Systems and Technologies Group (USTG) of the ITEFI-CSIC, the company Pusonics S.L. and the ASPA Group of the UPV have worked together towards introducing novel systems and methods in food drying technology specifically in hot-air drying and in atmospheric freeze-drying. The recent development of a novel family of power ultrasonic transducers with extensive radiating surfaces represents a step forward in the implementation of new power ultrasonic technologies in drying processes. These systems have been successfully used to assist drying of different kind of products at laboratory and semi-industrial level. This work deals with the development, integration and testing of the new ultrasonic technologies and the experimental results achieved. The obtained results confirm that ultrasound application leads to a significant intensification in the conventional processes.

Keywords: Power ultrasound, ultrasonic processing, mass transport, atmospheric freeze-drying.

#7898
Influence of drying on in vitro gastric digestion of beetroot: evaluation of the microstructure

Valeria Eim, Esperanza Dalmau, Juan A. Cárcel, Susana Simal

To better understand the influence of processing on the bioaccessibility of bioactive compounds during digestion, the microstructure of beetroot samples was observed prior to and after 180 min of in vitro digestion, by using scanning electron microscopy. Beetroot samples were subjected to convective drying at 60 ºC and 2 m/s and freeze-drying at -50 ºC and 30Pa. Dried beetroots were rehydrated prior to digestion by immersion in distilled water at 37 ºC during 90 min. To extract quantitative information related to cell size from the visual texture of beetroot, grey level granulometric methods from mathematical morphology were applied.

Keywords: freeze drying; convective drying; scanning electron microscopy; image analysis; image texture analysis.

#7931
Simultaneous wetting and drying; fluid bed granulation and tablet film coating

Ian C Kemp, Alex van Millingen, Houda Khaled, Lewis Iler

Simultaneous wetting and drying occur in processes such as fluid bed (top spray) granulation, Wurster coating and tablet film coating. This gives control challenges, as the spraying and evaporation processes must be carefully balanced and the operating window is significantly narrower than for standalone drying processes. Significant recent advances in modelling have led to effective scale-up and operational strategies. Factors such as flow cessation during filter bag shaking can have a major effect. A design space can be predicted which is often non-orthogonal, and pharmaceutical regulatory authorities have accepted filing submissions using a design space justified by mechanistic modelling.

Keywords: pharmaceuticals; peak moisture content; bed temperature; conduction; design space.

#7932
Electrohydrodynamic (EHD) drying: fundamentals and applications

Alex I Martynenko, Tadeusz Kudra

Following background to the phenomenon of electrohydrodynamics with concise review of basic features like shorter drying time, lower energy consumption and better product quality, the selected key factors affecting EHD drying are examined. These include the geometry of discharge electrodes, effects of air humidity on drying rate, depression of material temperature, and cooling effect of ionic wind.
Examples are given for: (i) prototype EHD dryers of multi-belt types, and (ii) pilot-scale multi-belt EHD dryer in vertical arrangement that can be aggregated into one unit of higher capacity, and vertical cylindrical EHD dryer with vibrated shelves.

Keywords: ionic wind; corona discharge; drying; energy; quality.

#7935
Recent advances in biomass drying for energy generation and environmental benefits

Shusheng Pang

Biomass has been regarded as a renewable resource for future energy and liquid fuels, however, by using biomass as the feedstock, the production costs are higher and the energy conversion efficiency is lower in comparison with traditional fossil fuels. Drying of biomass in a smart way can improve the energy efficiency and reduce the costs. In this presentation, biomass drying technologies and fundamental studies will be reviewed. Effects of biomass drying on thermochemical conversion processes (gasification and pyrolysis) will be examined. Energy and exergy analyses of the biomass drying and the integrated energy processing system will be presented with target for process optimisation.

#7943
Non-Fickian diffusion in biomaterials

Giana Almeida, Patrick Perre

The knowledge of water vapour diffusion in materials is very important in several fields of application (drying, building materials, biofilms…). Regarding the drying process, the value of mass diffusivity, as well as its variations with moisture content, governs the second drying period, which is the most important in terms of drying time, energy consumption and product quality. In the case of biomaterials used for building insulation, this parameter is essential for transformation processes, including drying, but also for the proper design and use of buildings. Concerning biofilms, barrier properties are one of the most important physical properties of these materials to properly ensure a good end use.
Nevertheless, experimental data of mass uptake of some biomaterials showed that did not follow the standard Fickian model. The precise determination of this non-Fickian behaviour showed to be a difficult task since the physical phenomena responsible for such behaviours depend on the biomaterial structure and physical properties. In particular, the abnormal macroscopic behaviour could result from the pore morphology (dual-scale effects), from the nano-structure, from the molecular reorganisation, or a combination of these spatial scales.
This conference proposes a new methodology to quantify the non-Fickian diffusion. Based on a macroscopic formulation of coupled heat and mass transfer with kernel functions, the model parameters, intrinsic characteristic of the product of interest are determined by inverse analysis. Several complementary transient experiments can be analysed simultaneously, which insures the method robustness. Application examples are proposed for different products, including lignocellulosic materials and nanostructured biofilms.

#8265
Nonthermal encapsulation methods – A case study of tomato by-products treatment

Magdalini Krokida

Encapsulation is a process which enhances the stability and maintains the viability of materials that should be protected from external conditions, with variety of application from pharmaceutics and nutraceuticals to agriculture. Various methods for encapsulation have been established, characterized by both advantages and disadvantages. Depending on the operating conditions and the raw materials of each process, products with varying characteristics and final properties are developed. Nonthermal encapsulation methods are of high interest especially in food industry since they are suitable for heat-sensitive food materials (antioxidants, proteins, nutrients, etc.). Electrohydrodynamic processes, along with processes which are basically known as drying methods such as Spray chilling and Freeze drying are the most commonly applied nonthermal encapsulation technologies.

Electrohydrodynamic processes are nonthermal methods to structure fibers and/or capsules. Electrohydrodynamic processes make use of high-voltage electric fields to produce electrically charged jets from viscoelastic polymer solutions which on drying, by evaporation of the solvent, produce ultrathin polymeric structures of varying morphologies. The most interesting advantage of electrohydrodynamic processes is that they can achieve high encapsulation efficiencies without application of heat treatment.

Spray chilling is a microencapsulation technique similar to spray drying, in which cooled air is used for particles solidification instead of heated air to solvent evaporation. This low-cost technology is relatively simple to apply and scale up, and it does not require the use of organic solvents and the application of high temperatures in the process.

Freeze drying is based on the dehydration by sublimation of a frozen product and has been proved to be as a suitable method for the encapsulation of thermosensitive substances. Freeze drying produce products with high quality as the substances are not exposed to high temperatures preserving their initial nutritious characteristics.

The current applying practices, regarding the treatment of tomato processing by-products, include mainly the usage as animal feed and / or disposal. However, being a rich source of natural bioactive compounds, tomato by-products could produce high value-added products for food, cosmetics, or pharmaceutical applications. Towards, these direction suitable nonthermal encapsulation techniques should be applying to encapsulate valuable bioactive compounds such as lycopene.

#8278
Superheated Steam Spray Drying: My new playground

Sakamon Devahastin

Spray drying is among the most widely used techniques to produce powdery products in the food, biotechnological, pharmaceutical and fine chemical industries. Hot air is typically used as the spray drying medium although it is well recognized that such a medium can lead to several undesirable effects that may adversely influence the dried product quality, including oxidative degradation of bioactive compounds, lipid oxidation and browning; fire and explosion hazards may also be cited as another potential problem rendered by the use of hot air at a higher temperature as the spray drying medium. Superheated steam has long been proposed as an alternative spray drying medium as it may lead to several advantageous results, including superior dried particle morphology and less particle-wall stickiness. Use of superheated steam has nevertheless been very limited, due probably to the many technical complications, especially that involving the collection of the dried powdery product. Most superheated steam spray drying studies are therefore computational in nature; experimental studies are mainly confined to the so-called single droplet drying. In this presentation, a brief overview of our work on superheated steam spray drying will be given. The talk will cover all important aspects of the process, ranging from the design and fabrication of a laboratory-scale superheated spray dryer, testing of the dryer and problems encountered during the fabrication and testing of the dryer. Special attention will be given on dried powdery product collection, which represents a challenge due to the steam flow and condensation within the powder collection system. Possible solutions to the aforementioned problems will be mentioned. Preliminary spray drying results will also be shown and discussed.

Keywords: Food drying; Morphology; Particle size; Physical properties; Powder collection; Steam condensation; Yield.

FUNDAMENTALS, MODELING AND SIMULATION

Oral Presentations

#7245

Robust feedback control of continuously operated convective dryers for particulate materials

Carsten Seidel, Christoph Neugebauer, Robert Dürr, Andreas Bück

Convective drying is a common process for the treatment of particulate solids also operated in continuous mode. Continuous operation is characterised by operation in steady-state with constant product throughput and constant product quality. Due to external influences, i.e. seasonal or local variations in the properties of the initial wet material, deviations in the product quality can result, for example over- or under-drying, or on-set of unwanted reaction. In this contribution a new feedback control concept is developed that is robust with respect to variations and uncertainties in the drying kinetics of the material and can reject and attenuate process disturbances.

Keywords: Process control; drying kinetics; robustness; fluidized bed; yeast.

#7252
Mathematical modeling of moisture evaporation in co-current foam spray drying

Maciej Jaskulski, Artur Lewandowski, Ireneusz Zbiciński

Two models of foam drying are presented in the paper: single droplet drying and perfect mixing of phases spray drying models to describe mechanism of drying of droplet containing bubble.
Analysis of drying curves shows that in constant drying rate period and in the falling drying rate period, evaporation rate decreases due to particle shrinkage and increasing of resistance of moisture diffusion inside the solid crust. Increase of gas pressure in the bubble might cause particle breakage.
Slight differences between theoretical and experimental results caused by disregarding broken particles in the simulations proves accuracy of the developed model.

Keywords: spray drying, modeling, foamed materials, particle morphology.

#7321

Heat and mass transfer properties evaluation by linear regression fit of experimental temperature and moisture evolution on analytical solution of Luikov-modified equations

Miguel A Garcia-Alvarado

García-Alvarado et al., [Journal of Food Engineering, (2014): 142, 39-45] modified Luikov equation introducing gas phase moisture as moisture potential and it thermodynamic relation with solid phase moisture and temperature. This modified Luikov equations were analytically solved for 1D rectangular coordinate. Carrots slabs were drying at 50, 60 and 790oC in a tray drier, in which temperature and moisture were followed during time with thermocouples in the center of slabs and weight lost. Carrot thermal diffusivity, moisture diffusivity, heat transfer coefficient and mass transfer coefficient were evaluated from slopes evaluated by linear regression of experimental results in semi-log linear region.

#7371
A mathematical model of spray drying granulation process in formulation

Hiroyuki Kagami

In this study, we apply the drying model of polymer solution coated on a flat substrate to the spray drying granulation process in formulation. In order to apply the former model to the drying of this spherical object, we consider this spherical object to be a stack of solution films applied on the spherical shell and discuss the drying process of each solution film. As a result, we see that the smaller the radius of curvature of the droplet, the more the fine particles tend to be unevenly distributed on the surface of the droplets during drying.

Keywords: model, numerical simulation, spray drying granulation, spherical, droplets.

#7423

Mechanical and thermal segregation of milli-beads during contact heating in a rotary drum. DEM modeling and simulation

Aline Mesnier, Maroua Rouabah, Roman Peczalski, Séverine Vessot-Crastes, Pascal Vacus, Julien Andrieu

The flow mechanics and heat transfer phenomena within a bed of milli-metric size spherical beads rotated and heated by contact in a horizontal drum were simulated by means of commercial discrete element software EDEM. Mono-dispersed and bi-dispersed beds (two particle sizes or two particle densities) were considered. The mechanical segregation index (standard deviation of local bed compositions) and the thermal segregation index (standard deviation of beads temperatures) were calculated for the different types of bed and same operating conditions. The thermal segregation was found to be enhanced by mechanical segregation and was much stronger for bi-dispersed beds than for monodispersed one.

Keywords: rotating drum; particulate solid; segregation; contact heat transfer; DEM simulation.

#7470

The investigation of internal pressure development in convective drying of shrinking and non-shrinking materials using green and fired clay as an example

Anna Adamska, Zdzislaw Pakowski, Robert Adamski

The aim of present research was to measure and analyze the dynamic changes of internal pressure in shrinking vs. non-shrinking materials during convective drying for the use as a possible process control method.
Drying experiments were carried out on wet and fired clay at 50°C and 60°C. In addition, the shrinkage curve was investigated. Experimental measurements show the existence of 4 stages of the process. The comparison of the results for wet and fired clay shows differences in pressure trends.
During drying the internal pressure changes from underpressure to overpressure at the level of 3÷5kPa, what correlates well with transition from the first to the second drying period.

Keywords: ambient pressure drying; clay; shrinkage; pressure evolution.

#7474
Multi-zone & multi-compartment model for dynamic simulation of horizontal fluidized bed granulator

Lisa Mielke, Andreas Bück, Evangelos Tsotsas

Due to the ongoing development and implementation of process control and observation techniques in production processes of particulate products, the research on complexly designed process apparatuses has become of great interest. The work presented in this paper is focused on a model-based study on a multi-chamber horizontal fluidized bed apparatus for fluidized bed layering granulation. The model for the solid phase is extended by a new drying model. Because of the great variety of parameters that influence this complex system a preliminary model-based study on a simplified setup shall show which construction or process parameters influence the product quality.

Keywords: fluidized bed granulation; population balance modeling; surface moisture content; drying.

#7485
Modeling of Dielectric Properties of Durum Wheat (Triticum Durum) in a Frequency Range of 0.6 GHz - 3 GHz

Mohamed Hemis, Vijaya Raghavan

Dielectric properties of durum wheat CWRS (Triticum Durum) were studied to determine the dependencies between thermodynamic properties and dielectric properties of wheat seeds. Several tests were conducted to find the relationships between dielectric properties, moisture content and frequency (0.6 GHz to 3 GHz). Results of dielectric constant, ε', and dielectric loss factor, ε", obtained at different moisture contents were used to establish the value of the parameters in a linear additive model. The obtained models are intended to be used in another study to improve the modeling of heat and mass transfers in microwave assisted hot-air drying process (MW); other experiments were conducted to study the effect of porosity of sample on the dielectric properties of durum wheat. Results show the higher the porosity of the material, the lower is the dielectric constant. Same is true for the dielectric loss factor; this is attributable due to the effects of the inter-granular air on the dielectric properties measurement of powdered seeds.

Keywords: Durum wheat; Dielectric properties; Modeling; Additive model.

#7499
Measuring REA-based drying kinetics through temperature-moisture content relationship

Xiao Dong Chen, Aditya Putranto

The reaction engineering approach (REA) has been proposed and implemented for modeling a number of challenging drying cases. While the modeling is simple and accurate, it is effective to generate the drying parameters. The relative activation energy is the fingerprint of the REA which describes the changes of internal behaviors inside the materials during drying. In this paper, a new method, based on combined heat and mass balance, is proposed and implemented to retrieve the relative activation energy of flat materials. The results indicate that the new approach can be used to retrieve well the activation energy of flat materials. The relative activation energy retrieved by the new approach is independent on the external drying conditions. This new approach can also potentially be used to evaluate the change of surface area of materials during drying

Keywords: reaction engineering approach (REA);, modeling; relative activation energy; mass transfer;, heat transfer.

#7512
Energy analysis and conservation opportunities in spray dryers

Sanjay Kumar Patel, Mukund Haribahu Bade

Dryers are used for removal of moisture from an raw materials (such as effluent) to form a dried solids as per the requirements. For removal of the moisture, energy requirement is huge. Therefore, in this paper, methodology for heat recovery in one of the type of dryers as spray dryers is developed, which is simple and easy to apply. The proposed methodology is illustrated with the help of an example taken from literature. It is observed that the indirect heat recovery method could save energy maximum up to 82 % as compared to literature and 41 % higher than without heat recovery.

Keywords: Spray dryer, pinch analysis, heat recovery, effluent drying, energy saving.

#7536

Implementation of p-controller in Computational Fluid Dynamics (CFD) simulation of a pilot scale outlet temperature controlled spray dryer

Sepideh Afshar, Hasan Jubaer, Lloyd Metzger, Hasmukh Patel, Cordelia Selomulya, Meng Wai Woo

Most of the CFD simulations of spray dryers reported in the literature utilizes a fixed air inlet temperature numerical framework. In this paper, a numerical framework was introduced to model spray drying as an outlet air temperature controlled process. A P-controller numerical framework was introduced which allows the inlet temperature to be automatically adjusted based on the required outlet temperature set point. This numerical framework was evaluated with a simulation of a two-stage pilot scale spray drying system at the Davis Dairy Plant (South Dakota State University) which is used for commercial contract spray drying operation.

Keywords: CFD simulation; Multi-Stage Spray Drying; P-Controller.

#7558
Application of multivariate image analysis to thermal images for in line monitoring of the freeze-drying process

Domenico Colucci, José Manuel Prats-Montalban, Davide Fissore, Alberto Ferrer Riquelme

A new Process Analytical Technology (PAT) has been developed and tested for on-line process monitoring of a vacuum freeze-drying process. The sensor uses an infrared camera to obtain thermal images of the ongoing process and multivariate image analysis (MIA) to extract the information after automatic detection and segmentation of the region corresponding to the product in every vial. A reference model was built, using the information of six batches, and different kind of anomalous events, involving either single vials in the batch or the whole batch, were simulated to test the capacity of the MIA-based monitoring system to promptly identify them.

Keywords: freeze-drying; process monitoring; infrared image; multivariate image analysis.

#7607

A model reduction alternative method to boost simulations of drying of solid foods with simple geometries

Francis Courtois, Emmanuel Bernuau, Daniel Goujot, Hedi Romdhana

To simulate drying of foods, the classical calculation based on finite differences, elements or volumes are quite time consuming, which may be an issue in an optimisation procedure where hundreds or thousands of simulations are necessary. In contrast, a model with coupled heat and mass transfers, based on diffusion and convection, with non-linear properties and boundaries makes an accurate but slow simulator for drying of foodstuffs. In this work, we show that it can be replaced by a simple and much faster, yet accurate, two- or three-compartment model as long as the geometry is simple (sphere, infinite slab or cylinder). Equivalent predictions of mean product temperature and moisture content are obtained by formally linking exchange coefficients (in compartmental model) to transfer coefficients (in diffusion convection model) and fine tuning, once for all, the compartment volume sizes. The resulting simulations are very close with calculation time nearly a hundred times faster.

#7615
The parametric problem of enhanced multiphysics drying by time scale comparison

Francesco Marra, Gianpaolo Ruocco, Giuseppe Titomanlio

Bulk convection drying of substrates in continuous processing can be intensified and optimized by providing exposure to volumetric sources (of multiphysics nature, such as electromagnetic or ultrasound energy).Transient distributions of temperature and moisture in multiple substrates, treated at once, are analyzed in this work by means of a comprehensive numerical model, featuring fluid dynamics effects and custom moisture diffusion and evaporation notations.After proper verification with the correspondent experimental results, geometry and thermal-fluid dynamics dimensionless parameters are defined and scrutinized.It is shown that the exposure to volumetric sources may increase process throughput and improve energy consumption. These good, positive outcomes should encourage operators to embrace multiphysics-enhanced drying technology.

#7616

Feasibility of Vis/NIR spectroscopy and image analysis as basis of the development of smart-drying technologies

Barbara Sturm, Roberto Moscetti, S.O.J. Crichton, Sharvari Raut, Michael Bantle, Riccardo Massantini

Drying is a complex, dynamic, unsteady and nonlinear process that, when not optimized on a system level, may be responsible for (1) significant quality degradation and (2) energy wastage. Consequently, new drying technologies must be designed combining non-invasive at-/on-/in-line advanced measurement and control systems with models cross-linking all relevant aspects of product quality changes and heat and mass transfer phenomena.
This paper presents preliminary results on the use of RGB imaging, NIR spectroscopy and Vis-NIR hyperspectral imaging for real-time monitoring of physicochemical changes of apples and carrots during drying.

Keywords: chemometrics, artificial intelligence, deep learning.

#7643
Modeling of atmospheric freeze-drying for sliced fruit

Akane Horie, Takashi Kobayashi, Kyuya Nakagawa

A mathematical model that simulates atmospheric freeze-drying for apple slices was developed based on the classical mass and heat balance equations. When operated above the glass transition temperature, product shrinkage and micro-collapse due to the glass-rubber transition occurred. So, instead of assuming formation of dried and frozen zones, a glassy matrix with particular vapor pressure was assumed. Apparent vapor pressure of apple slices in the glassy state was experimentally measured and summarized in a diagram, and the values in this diagram were employed for the simulation. This approach well predicted drying kinetics with reasonable accuracy with simplified equations.

Keywords: atmospheric freeze-drying; food; mathematical model; glassy state.

#7756
Thermodynamic model of freeze-drying of poultry breast using infrared thermography

Juan Angel Tomas-Egea, Marta Castro-Giraldez, Pedro J Fito

Food dehydration is one of a main process to preserve meal. In order to optimaze a freeze-drying operation a physic model is needed to well describe the thermodynamic behaviors involved in this process. In this work, a thermographic camera and different physico-chemical determinations are used to monitor many phenomena that occur during the lyophilization of poultry breast. Finally, a non-continuous irreversible thermodynamic model, based on thermal infrared measures and in shrinkage/swelling mechanism, has been developed, wich explains the behaviours produced throughout the meat freeze-drying process.

Keywords: freeze-drying, thermodynamic model, infrared thermography, poultry.

#7886
Mathematical modeling of drying kinetics of cocoa beans in a generalized coordinate system

Jader Rodríguez-Cortina, Sebastián Escobar, Julián Gómez, Luis Daniel Daza, Henry Vaquiro

The sensorial quality of cocoa beans is mainly developed during fermentation, drying and roasting processes. During drying, the temperature, moisture and time must be controlled to ensure chemical reactions responsible of aroma and flavor of good quality chocolate. The modeling and simulation tools can be used to study the behavior of cocoa beans in different drying conditions and, at the same time, can be used to establish operating parameters to improve the final product quality. The present study focused on the development of a mathematical model that appropriately represented the most important physicochemical phenomena that occur during drying. The drying kinetics of cocoa beans were modelled using a mechanistic approach that considers simultaneously coupled mass and heat diffusion, non-constant transport properties, solid shrinkage, and convective mass and heat boundary conditions. The governing equations were expressed in a generalized coordinate system to obtain a one-dimensional model suitable for the geometry of the seeds. To identify the effective diffusivity, model estimations were fitted to data reported in literature for drying kinetics at air temperatures of 40, 50, and 60°C and an air velocity of 3 m/s and a relative humidity of 10 %. The goodness-of-fit statistics were comparable to those obtained from similar models but with a greater number of simplifications in the physical phenomena involved. The proposed approach could be used in optimization problems, including reaction kinetics, and sensitivity analysis because it requires a simpler solving process and a shorter calculation time than some multidimensional approaches.

Keywords: Mass and heat transport, shrinkage, generalized coordinates, effective diffusivity.

FUNDAMENTALS, MODELING AND SIMULATION

Poster Presentations

#7239

Modeling of Particle Behavior in a Wurster Fluidized Bed: Coupling CFD-DEM with Monte Carlo

Zhaochen Jiang, Christian Rieck, Andreas Bück, Evangelos Tsotsas

CFD-DEM approach is applied to investigate circulation motion of particles in a mono-disperse system under both dry and wetting conditions. Good agreement between simulation results and measurement data is observed, in terms of cycle time and residence time in dry condition. The deposition of droplets on the particle surface is modeled by a Monte Carlo approach. The influence of cohesion forces on the macroscopic particle circulation is discussed. In addition, information about coating coverage, the layer thickness and particle size distribution can be predicted by this integrating approach.

Keywords: CFD-DEM; Wurster coater; Monte Carlo; cohesion force; residence time

#7274
CFD model-supported design of monodisperse co-current spray dryers

Maciej Jaskulski, Thi Thu Hang Tran, Evangelos Tsotsas

In this study the operation of spray drying chambers fitted by the multi-stream monodisperse atomizer was simulated by the previously developed CFD model of skim milk spray drying. A series of CFD simulations of skim milk monodisperse spray drying were performed. The influence of different nozzle positions, initial droplet diameters (180 μm and 167 μm) and the way of air introduction (vertical or swirling with 30° or 60° angle) on the drying process were checked. Parameters like drying air and particle residence time, wall deposition, inter-particle collisions, protein thermal deactivation, air velocity and temperature profiles were compared for each case.

Keywords: CFD, spray drying, skim milk, monodisperse atomizers, optimization

#7284
Pore network model of primary freeze drying

N. Vorhauer, P. Först, H. Schuchmann, E. Tsotsas

The pore scale progression of the sublimation front during primary freeze drying depends on the local vapor transport and the local heat transfer as well. If the pore space is size distributed, vapor and heat transfer may spatially vary. Beyond that, the pore size distribution can substantially affect the physics of the transport mechanisms if they occur in a transitional regime. Exemplarily, if the critical mean free path is locally exceeded, the vapor transport regime passes from viscous flow to Knudsen diffusion. At the same time, the heat transfer is affected by the local ratio of pore space to the solid skeleton. The impact of the pore size distribution on the transitional vapor and heat transfer can be studied by pore scale models such as the pore network model. As a first approach, we present a pore network model with vapor transport in the transitional regime between Knudsen diffusion and viscous flow at constant temperature in the dry region. We demonstrate the impact of pore size distribution, temperature and pressure on the vapor transport regimes. Then we study on the example of a 2D square lattice, how the presence of micro and macro pores affects the macroscopic progression of the sublimation front.

Keywords: pore size distribution; transitional vapor transport; pore network model; fractured sublimation front

#7311
Moisture diffusion coefficient estimation in peas drying by means of a modified Hawlader and Uddin method

Carlos Martínez-Vera, Mario Vizcarra-Mendoza

The aim of the present work is to determine the moisture diffusion coefficient in peas applying, in a first step, a methodology previously published in the literature by Uddin et al.[1] for determining constant diffusion coefficients taking in account the volume reduction associated to the drying process. Then, in a second step, refine it by means of an optimization step. The optimization step is justified because the methodology of Uddin et al. is based in a solution of the diffusion equation that is not mathematically valid for the drying-shrinking problem.

Keywords: : moisture diffusivity; drying-shrinking; peas drying

#7315
Effect of gas invasion pattern on drying of porous media

Rui Wu

Drying in porous media is of interest to many research and engineering fields, such as recovery of volatile hydrocarbons from underground oil reservoirs, remediation of contaminant soils by vapor extraction, and water management in gas diffusion layers (GDLs) of proton exchange membrane fuel cells (PEMFCs).

During drying of porous media, the liquid filled zones are gradually occupied by the gas phase. This gas invasion process depends on the structure and wettability of this porous material. In a porous material, the void spaces are composed of pores of various sizes. The large pores are called the pore bodies and the smaller ones the pore throats. At the interface between a large pore body and a small pore throat, there exists a sudden geometrical expansion. Such sudden geometrical expansion increases the resistance to the menisci movement during the two-phase flow, and therefore is called the capillary valve effect. Because of this capillary valve effect, two types of invasion in pore body are revealed, i.e. bursting and merging invasion. To this end, there are three types of gas invasion patterns during drying of porous media. The first is bursting invasion with pore throat to boy, for which gas invasion into pore body is dominated by bursting invasion, and once a pore throat is invaded, it is neighboring pore body will be immediately occupied by the gas. The second is bursting invasion with pore body to throat; in this case, gas invasion into pore body is dominated by bursting invasion, and once a pore body is emptied, its neighboring pore throats will be invaded by gas. The third is merging invasion, for which gas invasion into pore body is dominated by merging invasion. The drying characteristics for different gas invasion patterns are explored and compared.

#7317
Backscattering imaging potential for validating couple heat and mass models for the hot-air drying of Sweet Potato

Daniel Iroemeha Onwude

Validation of drying simulation models is a very important step for the models to be acceptable and applicable in practice. This study investigated the potential of using backscattering imaging to evaluate and validate couple heat and mass transfer models for the hot-air drying of sweet potato. Hot-air drying experiments for 4 mm thickness of sweet potato slices were conducted at 50, 60 and 70 ˚C using a laboratory hot-air oven. Backscattering images were acquired during the drying process. Couple heat and mass transfer models were developed and simulated using COMSOL Multiphysics. The simulation data of the models in terms of moisture and temperature distribution in the sweet potato slices during the drying process were further evaluated based on experimental results. The results showed good correlation between backscattering light intensity, perimeter, and illuminated area with the predicted moisture and product temperature data, having a coefficient of determination $R2 > 0.8$ and root mean square error $RMSE < 0.05$, respectively. There was also significant agreement between the moisture and temperature data obtained using conventional method and the backscattering parameters of illuminated light intensity, and illuminated area, with a coefficient of determination $R2 > 0.92$ and 0.98, respectively. The result of this study demonstrated that backscattering imaging technique can be used to validate couple heat and mass transfer models for agricultural crops. The developed model proved to be accurate and it could be used for further practical applications in agricultural engineering practices that include drying.

#7337

New model for the rehydration characteristics of white yam at different temperatures

A. A. Akinola, S. N. Ezeorah, E. P. Nwoko

A new model describing the variation in the rehydration ratio with rehydration time for yam slices is presented here. Also presented, is a new model for the rehydration kinetics of yam slices. Mass and moisture content rehydration data were collected while rehydrating 3.0 mm thick dehydrated yam slices. Regression analysis established that the mass rehydration data better fitted a two-term exponential equation rather than a second-order polynomial equation. Also, for the rehydration kinetics, the moisture content rehydration data was better fitted to a new empirical model rather than the Weibull, Peleg, and Exponential models.

Keywords: Rehydration Ratio Models; Rehydration kinetic models; Yam; Weibull, Peleg, and Exponential models

#7341
Stochastic modeling of binder-less agglomeration in fluidized beds

Christian Rieck, Andreas Bück, Evangelos Tsotsas

Fluidized bed spray agglomeration plays an important role in the industry, e.g. the food industry. Usually, a liquid containing solid material (binder) with an increased viscosity is sprayed on the fluidized particle bed to induce agglomeration. However, if amorphous particles are to be agglomerated, spraying of pure water may be sufficient. In this case, wetting of the amorphous particles may lead to glass transition at the particle surface creating sticky spots, which may also result in agglomeration. Modeling of agglomeration processes is often done using population balance models, which need a mathematical formulation of the macroscopic process kinetics (aggregation kernel). Operating parameters, such as spraying rate or temperature, are usually not part of the aggregation kernels.

In this study, we present a stochastic modelling approach based on a Monte Carlo method for fluidized bed spray agglomeration due to glass transition. In contrast to macroscopic models, the process is modeled on the single particle scale by a sequence of micro-events and processes, such as droplet deposition, glass transition, binary collisions, breakage, and drying. Simulation results are presented and compared with experimental data on agglomeration of maltodextrin particles.

#7351
Modelling drying kinetics of closed cycle modified atmospher drying of banana fruit

Ihsan Burak Cam, Emrah Eroglu, Handan Basunal Gulmez, Ayhan Topuz, Can Ertekin

Drying is well-known and the oldest food preserving method. In the last few decades, different drying techniques have been developed. Among these techniques, hot air drying is the most widely used one in drying processes of fruits and vegetables.

In the present work, influence of closed-cycle modified atmosphere (CC-MAD) drying on drying kinetics of banana (Musa Cavendish) was investigated. Banana was peeled and cut into circle of 5mm in thickness using laser slicing knife. Sliced banana fruits were subjected to three different drying treatments as CC-MAD at 60˚C with 3 m/s air velocity in 5% oxygen medium, 10% oxygen medium and 21% oxygen (air) medium. Fifteen different drying models used for modelling drying kinetics of banana slices.

Midilli (MR = a exp(-ktn) + bt) model was found best fitting model for CC-MAD in both 5% and 10% drying medium. On the other hand, Wang Sing (MR = 1 + at + bt2) model was the best fitting model for hot air drying kinetics of banana slices.

Keywords: modified atmosphere drying, modeling of drying kinetics, banana.

#7363
Heat and mass transfer properties evaluation from analytical solution of Luikov-modified equations

Saraí Vargas-González, Erik López-Sánchez, Guadalupe C. Rodríguez-Jimenes, Irving I. Ruiz-López, Miguel A Garcia-Alvarado

García-Alvarado et al., [1] modified Luikov's equation introducing gas phase moisture as moisture potential and its thermodynamic relation with solid-phase moisture and temperature as linear relations by stages. This modified Luikov's equations were analytically solved [1] for 1D rectangular coordinate. The results indicate that heat and mass transfer properties define the asymptotic slopes of moisture and temperature kinetics in four semi-log regions. Then, potato slabs were drying at 50, 60 and 70oC in a tray drier, in which temperature and moisture were followed during time with thermocouples in the center of slabs and weight lost. Potato heat conductivity, potato average water diffusivity, heat transfer coefficient in potato-air interface; and water mass transfer coefficient in potato-air interface were evaluated from asymptotic slopes evaluated by linear regression of experimental results in then semi-log region. Results were 0.2957 W/(m.K) for heat conductivity at the three temperatures; 2.23 X 10-10, 2.13 X 10-10 and 1.79 X 10-10 m2/s for average water diffusivity at 70, 60 and 50oC respectively; 55 W/(m2K) for heat transfer coefficient at the three temperatures; and, 0.021, 0.011 and 0.009 m/s for water mass transfer coefficient at 70, 60 and 50oC respectively. These results show that analytical solution of Luikov-modified equations may be used for the heat and mass transfer estimation in solids drying.

[1] García-Alvarado, M.A., et al., Journal of Food Engineering, (2014): 142, 39-45.

Keywords: Luikov equations; analytical solution; solids drying; heat and mass transfer properties.

#7369
Optimization of spray drying of fruit juices with drying aids

Sebastian Linnenkugel

Spray drying of sugar rich foods is a challenging procedure due to their stickiness, causing quality degradation and product hold up in the spray dryer. The phenomena of stickiness is related to the glass transition temperature (Tg) of a system. In the case of fruit juices, sugars and organic acids exhibit very low Tg values limiting the use of spray drying as a drying method. The addition of drying aids is a frequent technique for increasing the Tg of the mixture. In this work a predictive approach is presented which allows to identify the required amount of drying aid without having to rely on trial and error methods, saving time and resources. Two fruit juice concentrates, blackcurrant and white grape, were dried with maltodextrin (MD) DE 10-13 as a drying aid. The glass transition temperatures of the fruit juice and MD mixtures were calculated using a newly derived prediction model. A mass and energy balance of the spray dryer was used to determine the dryer outlet temperature (Tout) depending on the operating conditions. This enabled the safe stickiness region, assumed to be with a Tout-Tg < 25 ˚C to successfully spray dry the mixtures and obtain stable powders, to be identified. The glass transition temperatures of the powders were in a good agreement (± 5 ˚C) of the predicted values. The powders were also studied at different water activities to confirm the prediction method, showing similar results.

Keywords: Glass transition temperature, prediction model, fruit juice powders, spray drying.

#7388

A pore-scale study on the drying kinetics and mechanical behavior of particle aggregates

T. S. Pham, B. Chareyre, E. Tsotsas, A. Kharaghani

SA discrete thermo-mechanical drying model is developed to investigate the interaction between the porous structure and the drying characteristics of dense particle aggregates. The solid phase consists of polydisperse spherical particles in the micrometer range and the void space is constructed by a complementary network of tetrahedral pores. A modified version of the classical invasion percolation algorithm is set up to describe the preferential evaporation of the confined liquid in the pores. Thus, the evolution of the liquid distribution throughout the complex disordered medium can be simulated. In a one-way coupling scheme, capillary forces caused by both fluid pressure and surface tension are computed over time from the filling state of pores and they are applied as loads on each primary particle in the discrete element method. Based on this robust approach the drying kinetics and the mechanical behavior of several different aggregates with various fractions of small and large particles are simulated and quantified.

Keywords: Pore network model; discrete element method; Solid-fluid interaction; capillary force, Convective drying.

#7389
Investigation of 3D particle flow in a flighted rotating drum

Lanyue Zhang, Fabian Weigler, Zhaochen Jiang, Vesselin Idakiev, Lothar Mörl, Jochen Mellmann, Evangelos Tsotsas

To validate the particle motion in flighted rotating drum (FRD), a laboratory FRD was built and operated at 15% filling degree and 10 rpm rotation speed using plastic balls as bed material. The particle tracking velocimetry (PTV) and magnetic particle tracking (MPT) techniques were applied to investigate the particle flow behavior. The 3D particle flow was modeled by Discrete Element Method (DEM) with LIGGGHTS. The height of the barycenter of all overall particles and particle instantaneous velocity were calculated from PTV and DEM data. The 3D time-averaged particle velocity distributions obtained from MPT experiment and DEM simulation were compared.

Keywords: flighted rotating drum; particle motion; particle tracking velocimetry; magnetic particle tracking; DEM simulation.

#7393
Thermo-economic analysis of an efficient lignite-fired power system integrated with flue gas fan mill pre-drying

Xiaoqu Han, Jiahuan Wang, Ming Liu, Sotirios Karellas, Junjie Yan

Lignite is a domestic strategic reserve of low rank coals in many countries for its abundant resource and competitive price. Combustion for power generation is still an important approach to its utilization. However, the high moisture content always results in low efficiencies of lignite-direct-fired power plants. Lignite pre-drying is thus proposed as an effective method to improve the energy efficiency. The present work focuses on the flue gas pre-dried lignite-fired power system (FPLPS), which is integrated with fan mill pulverizing system and waste heat recovery. The thermo-economic analysis model was developed to predict its energy saving potential at design conditions. The pre-drying upgrade factor was defined to express the coupling of pre-drying system with boiler system and the efficiency improvement effect. The energy saving potential of the FPLPS, when applied in a 600 MW supercritical power unit, was determined to be 1.48 %-pts. It was concluded that the improvement of boiler efficiency mainly resulted from the lowered boiler exhaust temperature after firing pre-dried low moisture content lignite and the lowered dryer exhaust gas temperature after pre-heating the boiler air supply.

Keywords: lignite; pre-drying; thermodynamic analysis; thermo-economics.

#7394
Mathematical modeling of the drying of a suspended colloidal drop

Benjamin Sobac, Pierre Colinet, Benoit Haut

The drying of colloidal drops is a complex problem that involves many phenomena. It is of prime importance for a large variety of industrial applications. This problem has received a great deal of attention leading to an extensive literature. However, the drying of such a drop still poses a number of intriguing questions. There is a real necessity to improve our fundamental understanding of the mechanisms involved during the drying, as well as the development of mathematical modeling, to highlight the key parameters and to optimize the drying processes.

In the present study, the problem of the drying of a colloidal drop suspended in an infinite medium is considered. It is assumed that, far from the drop, both the temperature and the humidity of the air are fixed. A mathematical model is built assuming that the problem is controlled by mass and heat transports. A quasi-steady state assumption is considered for the evaporation process (isothermal drop) and hydrophilic interaction between the liquid and the particles is adopted. In the model, three levels of complexity for the dynamics of the colloidal particles are considered in order to describe their diffusion in the drop and their accumulation at the interface, leading to the formation of a crust.

By numerically solving its equations, this model allows tracking the front of densification (growth of the crust) and to calculate the constraints acting on the crust. The impact of the surrounding atmospheric conditions on the drying process is investigated. The results obtained using the different approaches regarding the dynamics of the particles are compared in order to highlight the key phenomena governing the crust formation. In addition, they are used to understand what level of complexity of the modeling should be used for, depending on the system parameters, the quantification of several of its properties (onset of the crust formation, time evolution of its thickness, constraints acting on it…).

When compared to previous works, the originality of this model lies in the consideration of realistic descriptions of the heat and mass transports in the different phases as well as in the fact that it put forward new dimensionless numbers allowing us to highlight the competition between the phenomena involved in the drying of a colloidal drop. The comparison between the approaches regarding the dynamics of the particles brings also valuable results, allowing choosing an appropriate complexity of the modeling, according to the system parameters and the objective of the study.

#7395
Competition between capillary transport and evaporation in a porous medium

Charlotte Van Engeland, Benjamin Sobac, Laurent Spreutels, Robert Legros, Benoit Haut

The interaction between liquids and porous media are ubiquitous in our everyday life and encountered in numerous applications. Fluid transport through porous media driven by capillary forces or by evaporation has been investigated for many years. However, those two mechanisms can occur simultaneously in various situations. Therefore, the present work aims to mathematically model and experimentally characterize the competition between the capillary effects and the evaporation of liquids in homogenous and heterogeneous porous media; the two mechanisms acting antagonistically on the motion of the liquid front.

The 2D mathematical modeling is based on a transport equation governing the liquid flow, including two mechanisms: evaporation and capillary effects. The Darcy's law gives the liquid flux induced by capillary forces. The evaporation process taking place at the liquid-air interface inside the porous medium is characterized by a convecto-diffusion model of the vapor transport into air, including the Stefan flow. The mathematical model highlights three dimensionless numbers. The first dimensionless number is a ratio of gravitational forces to capillary forces. This number characterizes the capacity of the capillarity to raise the liquid up to a certain height. The second dimensionless number corresponds to a ratio of a characteristic time of the capillary rise to a characteristic time of evaporation. The third dimensionless number corresponds to a ratio of a characteristic time of the capillary motion due to the heterogeneity of the medium to a characteristic time of evaporation. Depending on the values of these three numbers, the solving of the equations show that the system considered can exhibit different kind of behaviors.

The mathematical model is compared to experimental results. A first set of experiments consists in tracking the motion of a liquid front in a 2D homogenous porous medium overtime. The porous medium is made of a regular packing of particles arranged in a Hele-Shaw cell and plunged in a liquid reservoir. A parametric study is realized by varying the liquid volatility and the pore size, allowing distinguishing three types of dynamics. In a similar set up, a second set of experiments allows analyzing the stability of a receding evaporation front when it penetrates inside a zone of the cell where there is heterogeneity of the capillary pressure.

#7406

Drying behavior, diffusion modeling of cuminum cyminum L. undergoing microwave-assisted fluidized bed drying

Atefe Babaki, Gholamreza Askari, Zahra Emamdjomeh

In order to conserve cuminum cyminum L. during long storage periods, the drying kinetics of this seed undergoing microwave-assisted fluidized bed dryer at various microwave output power (300, 600 and 900w), air velocity (10, 15 and 20 m/s) and air temperatures (45, 55 and 65^{o}c) were studied. The main aim of this research is developing a mathematical model of mass transfer to investigate the microwave-assisted fluidized bed drying of cuminum cyminum L. seed. In this paper, we tried to discover a good model to evaluate moisture effective diffusivity (Deff).

Keywords: cuminum cyminum L, microwave-assisted drying, mathematical modeling.

#7408
Model of the solutes transfer during osmotic dehydration of vegetal matrices: a proposal

Sahylin Muñiz-Becerá, Lilia Leticia Méndez-Lagunas, Juan Rodríguez-Ramírez, Sadoth Sandoval-Torres

Osmotic dehydration of apple was modeled considering the mechanisms involved in the solutes transfer within the plant matrix: impregnation and diffusion. The model mathematical writing includes the impregnation layer thickness, the diffusion thickness, a water bulk flow and the convective resistance. Apple cylinders were dehydrated at 30, 50 ° C and 30, 50 ° Brix and a motion of 0.15 m/s. The Reynolds number was of 250 for 30°C-30°Bx and 500 for 50°C-50°Bx. Schmidt numbers was of 4000 for 30 ° C-30 ° Bx and 4200 for 50 ° C-50 ° Bx.

Keywords: transfer; solute; impregnation; osmotic dehydration.

#7410
Effect of partition wall on the performance of continuous fluidized bed dryer for lignite

Zhihong Liu

The drying of lignite before burning can improve boiler efficiency. Continuous fluidized beds are widely used for drying, because they can be operated with high efficiency in large scale. In this paper, the drying of lignite in a continuous fluidized bed is investigated numerically. The lignite particles are fluidized by superheated steam and dried by both hot tubes embedded in the bed and steam. Attention is paid to the process of drying in the macro scale of the bed, not on particle level. An Eulerian-Lagrangian approach is used; particles are modelled as discrete Lagrangian points, while the gas phase is modelled as an Eulerian continuum. An imaginary particle represents thousands of actual particles in order to decrease the computational load. Both evaporation and condensation on the particle surface are simulated. Mass transfer of moisture and heat transfer on the particle surface are considered. For simplicity, only free-bounded water in lignite is taken into account. It is assumed that evaporation or condensation occurs on the particle surface. The particles are assumed to shrink during the drying process. Moisture content distributions, temperature distributions and residence time distributions of lignite particles are evaluated. The effect of partition wall on residence time distribution is investigated by compare the numerical simulation with and without partition wall. It is found that the partition wall can improve the residence time distribution and therefore improve the moisture content distribution of products. The influence of wall position is studied; a method to determine the wall position leading to optimal performance is proposed. A relation between moisture content and residence time of lignite particles is confirmed.

#7411

Three-dimensional measurement of internal structure in frozen food materials by cryogenic microtome spectral imaging system

Gabsoo Do, Sadanori Sase, Yeonghwan Bae, Tatsurou Maeda, Shigeaki Ueno, Tetsuya Araki

The objective of this work was to establish a three-dimensional measuring method for the size, morphology and distribution of internal structure such as ice crystals, bubbles and solids content within an ice cream sample by using a cryogenic microtome spectral imaging system (CMtSIS). The 3-D images of ice crystals, bubbles and milk solids were recognized by reconstructing the circles in 2-D images into 3-D spheres; and the Overrun by Volume (ORV) was obtained by incorporating the area of bubbles on integrated image and the volume of bubbles in the 3-D image.

Keywords: Ice crystal, Bubble, Internal structure, Spectral imaging, Micro- to macro-scale, Freeze-Drying.

#7412

Dynamic optimization of the transmission efficiency between the solid state microwave sources and the microwave applicator

S. Zuber, M. Joss, S. Tresch, M. Kleingries

Microwaves are a fast way to dry moist goods through volumetric heating. During the drying process, materials change their electrical properties. As a result, the impedances at the feed port of the applicator will change and the microwave source is not matched anymore. The amount of reflected power increases and the process efficiency reduces. New semiconductor high power sources can perform a dynamic impedance matching. A lab scaled functional model with two sources was designed and realized. For measuring the scattering parameters during the process run, an embedded two-port vector network analyzer was added. Measurement results confirm the feasibility of the concept.

Keywords: Microwave drying, dynamic efficiency optimization, multichannel feed, solid state based microwave source.

#7415
Discrete modeling of ion transport and crystallization in layered porous media during drying

A. Rahimi, T. Metzger, A. Kharaghani, E. Tsotsas

In this work, an isothermal pore network model has been utilized to investigate ion transport and crystallization in layerd porous media during drying. Said network consists of two distinct layers each with a different pore size distribution. One-dimensional approximation at the throat level describes transport phenomena for liquid, vapor, and dissolved salt. An explicit time stepping scheme has been used to obtain fluid pressure fields and ion concentration. Various simulations are carried out which indicate the effect of mean pore size disparity in the top and bottom layer, as well as the effect of drying rate on final crystal distribution.

Keywords: pore network modeling, composite material, drying porous media, crystallization, ion transport.

#7416
Simulation and control of a batch fluidized bed dryer

Bruno Worliczek de Camargo, Rodrigo Cesar Frizzi, Carlos Alexandre Moreira Silva, Bruno Faccini Santoro

On a daily basis people have contact with food and pharmaceutical drugs, and the amount of water contained in these particles is strictly connected to the product quality. It is mandatory to dry such particles in order to reduce storage and transportation costs, also increasing its shelf-life. Using fluidized beds assures that the solid particles will be perfectly mixed, providing homogeneity during the drying process and improving the process' efficiency energetic-wise. The present paper focus on the comparison of different control strategies (predictive and feedback) through the development of a simulation of a batch drying process with the drying gas velocity as the manipulated variable and final moisture content of the solid particles as the controlled variable. The model chosen to describe the drying dynamics was proposed by Li and Duncan (2008) and combined with simplifications proposed by Villegas et al. (2010) in order to describe satisfactorily the behavior of moisture content and temperature of pharmaceutical drug particles in a batch fluidized bed dryer. For the feedback control structure, tunings rules were considered accordingly to an approximation of the system dynamics as a first order plus time delay transfer function. For the predictive strategy, a linear model predictive controller (MPC) was designed using the same model as before to relate gas velocity and particles moisture. The main difference is that MPC allows the natural inclusion of constraints on both manipulated and controlled variables. In the present case, there is a mandatory constraint on the particles temperature, to represent the possibility of degradation of chemical compounds of the drugs at high temperatures. The results show that a proportional only controller achieved a significant larger error when trying to follow a changing set-point. On the other hand, there were no significant differences between PI and PID. The predictive controller was able to both track the set point and respect the temperature constraint.

#7417

Dependency of continuum model parameters on the spatially correlated pore structure studied by pore-network drying simulations

Xiang Lu, Abdolreza Kharaghani, Evangelos Tsotsas

Pore-network simulations are carried out for monomodal and bimodal pore structures with spatially correlated pore-size distributions. The internal and surface relationships between the partial vapor pressure and saturation as well as the moisture transport coefficient for these model porous structures are identified from the post-processing of the corresponding pore-network model solutions. The simulation results show that the deviation of the partial vapor pressure from the saturation vapor pressure in the presence of liquid – which is referred to as non-local equilibrium effect – in the bimodal pore structures is less pronounced than in the monomodal pore structures. For the monomodal pore structures the moisture transport coefficient profile is not unique over the entire drying process, whereas this profile depends marginally on the drying history of the bimodal pore structures. Finally the ability of the continuum model to predict the results of the pore-network simulations for multiple realizations of the pore space is assessed.

Keywords: Scale transition, Moisture transport coefficient, Pore structure, Discrete model, Continuum model.

#7421

Use of a multi-vial mathematical model to design freeze-drying cycles for pharmaceuticals at known risk of failure

Bernadette Scutellà, Ioan Cristian Trelea, Erwan Bourlés, Fernanda Fonseca, Stephanie Passot

Freeze-drying is a dehydration method suitable for the stabilization of heat-labile pharmaceutical products, such as vaccines. Due to the vial-to-vial variability of heat and mass transfer during the process, the value of the critical process parameters (e.g., product temperature, sublimation rate) may be different between vials and batches often present significant product quality heterogeneity. The aim of this work was the development of a dynamic, multi-vial mathematical model making it possible to predict risk of failure of the process, defined as the percentage of vials potentially rejected by quality inspection. This tool could assist the design of freeze-drying cycle.

Keywords: lyophilization; vaccines; heat and mass transfer; mathematical modeling; design space.

#7422

Comparison between the finite differences, finite volume and finite element methods for the modelling of convective drying of fruit slices

Adriana María Castro, Edgar Yesid Mayorga, Fabian Leonardo Moreno

Three numerical methods, finite differences, finite volume and finite element, were compared to know their convenience in the simulation of convective drying of fruit slices. The mathematical treatment, the stability, the convergence and the sensibility were analysed for each method. The data of the simulations were compared with the data of feijoa dried at 60°C, 5 mm of thickness and air velocity of 0.5ms-1. The error was 7%, 13% and 17% for finite element, finite volume and finite differences respectively. The method selection depends on the software, the required data precision and the use of the model.

Keywords: mathematical model; convective drying; numerical methods.

#7454

Experimental and numerical study of flighted rotating dryers: assessment of number of flights and granular material on the design loaded

Marcos A. S. Barrozo

Rotary dryers are widely used in various industries, due to their versatility in operating with a wide range of materials. However, the rotary dryers are a significant capital item for many industries. Their thermal efficiency is strongly dependent on the correct design and operation. Numerous research efforts have focused on characterizing the dynamics of rotary dryers, but the design of these devices is complex and still is dictated by the "experience" of engineers and empirical factors. The rotary drum is said design loaded when it is in the condition that there is the greater interaction between the particulate material and the flowing air, which is interesting for drying process. So, in this study, it was evaluated the rotational speed that lead to the design loading condition using a rotating drum operating with different numbers of flights and granular materials. In addition, it was also analyzed the effect of the number of flights on the last unloading flight. A simulation study was also performed using an Eulerian model. The results shown that the Eulerian approach was able to predict the fluid dynamics behavior in various operating conditions. From the experimental and simulated results, it was possible to verify the effect of the number of flights and granular material in the design loaded condition.

#7455

The role of boundary conditions on the dynamics of green coffee beans in a rotated dryer

M.V.C. Machado, I.A. Resende, R.M. Lima, R.J. Brandão, M.R. Pivello, S.M. Nascimento, C.R. Duarte, Marcos A.S. Barrozo

Coffee drying and roasting are usually performed in rotated dryers; therefore, the study of particle dynamics in this equipment is of great relevance to improve their efficiency and hence the quality of the final product. Thus, this work aimed to investigate experimentally and numerically the dynamics of coffee beans in a rotary dryer. The Euler-Euler model was employed to reproduce the particle velocity profile in the rolling regime under different boundary conditions. The results shown that the lower specularity coefficient (0.01), which characterizes the smooth wall and free slip condition, reproduced the bed behavior that most resembled the experimental one. On the other hand, the other coefficients (0.1 and 1.0) showed an increasing deformation in the bed surface, different from the observed experimental behavior. It was also verified that, as the filling degree increases, the bed surface deformation becomes more pronounced.

Keywords: coffee; rotated dryer; simulation; specularity coefficient.

#7464
Lattice Boltzmann modeling and simulation of isothermal drying of capillary porous media

Githin Tom Zachariah, Debashis Panda, Vikranth Kumar Surasani

Modeling of dring of capillary porous media is difficult due to the complex and coupled heat and mass transfer that occur at dynamic liquid-gas-sold interface. Thus far, drying was simulated using either continuum models or pore-network models, both of which have limitations. In this work, the Lattice Boltzmann Method (LBM) is used to simulate the drying in porous media. The LBM is ideal for such simulations as it can incorporate complex effects in a simple way to exhibit realistic fluid-gas interface during drying of capillary porous media.

Keywords: Lattice Boltzmann Method; Capillary Porous media; Drying, Pore Network.

#7471
Air impingement drying of foods: modelling and experimental approach

Tidjani Bahar, Virginie Boy, Yves Lemée, Anthony Magueresse, Thomas Lendormi, Patrick Glouannec, Jean-Louis Lanoisellé

Thermal drying of foods is still a major challengebecause foods are heat sensitive and it is needed to optimize the energy consumption of the process to obtain high quality dried products. Impinging jets are commonly used in numerous industrial drying operations involving rapid drying of materials in the form of continuous sheets or relatively large, thin sheets, or even beds of coarse granules. Numerous studies have demonstrated the benefits of impingement jets in heat transfer applications, including drying. Currently, it is of growing interest to apply impingement jets to the drying of foods. The present work is intended to develop, on one hand a numerical mathematical model in order to predict heat and mass transfers in the product (hereafter called "product model") and on the other hand, an "airflow model" to estimate the boundaries conditions through an average heat transfer coefficient. The innovative aspect of the work comes from bringing together both models.
For the product model, equations were adapted from previous studies. A system of non-linear unsteady-state partial differential equations solved by using finite elements methods was established. The following assumptions were: heat and mass transfers are one-dimensional; water vapour flux in the food is negligible; physical and thermal properties are constant; the shrinkage is not taken into account. The external heat and mass transfers are proportional to, respectively, the temperature and the vapour pressure difference between the surface of the product and draining air; the food is viewed as infinite slabs. The boundaries conditions were as follows: at the food/air interface no accumulation occurs; the convective heat flux exchanged at the surface of the food is equal to the amount of heat requires to evaporate the moisture at the surface to which is subtracted the heat transferred by conduction through the food; no mass and heat is transferred across the bottom surface of the product.
An experimental study was carried out using a gel made of carboxymethylcellulose (CMC) to simulate water-rich foods. A prototype of air impingement dryer was used in which the air was injected through triangular nozzles punched of rectangular slots. Temperatures and heat transfer coefficients were measured and used to test the "product model" from 40°C to 70°C and from 1 to 17 m s-1. A good analogy was observed between simulated results and experimental data for average moisture and core temperature. The airflow model is in the validation phase.

Keywords: Drying; Air impingement; Modelling; Heat and mass transfer; Food.

#7475
Drying kinetics of cellulose nanofibers suspensions

Belal Al Zaitone

Cellulose nanofibers (CNF) is used in various pharmaceutical applications due to its unique characteristics i.e., biodegradability, mechanical and biological properties. CNF is often produced by spray drying process, knowledge of the drying kinetics in terms of mass and heat transfer on the scale of single droplet is important for process development and model validation.

Acoustic levitator was used to study drying process of CNF suspension at different air temperatures and initial CNF concentrations. The unique property of acoustic levitation to hold single droplet contactless in the air, enables to study particle morphology during drying process, calculate evaporation rate and estimate particle porosity. Results show that packed particles result at lower initial concentration and temperature has a moderate influence on mean porosity of CNF dried particles.

Keywords: acoustic levitation; droplet; drying kinetics; Cellulose Nanofibers.

#7491

Evaluation of color change and browning index values in bananas dried under modified atmosphere by computer vision technique

Ihsan Burak Cam, Handan Basunal Gulmez, Ayhan Topuz

In foods, the appearance is a key criterion in making purchasing decisions. Computer vision-based image analysis offers rapid, accurate, non-contact and non-destructive analysis of food materials. The images obtained with this technology, especially allowing the entire surface of the food to be seen at the same time, are much more accurate than the mechanical measuring systems taken only from a specific area.In this study, the color changes and browning index values of bananas were analyzed by using image processing techniques after the drying processes in the modified atmosphere in different nitrogen concentrations. The dried products were placed in a homogeneously illuminated photo cabinet (Mondo Photobox 60, China). The photo cabinet is illuminated by two 45 cm white LED light sources at 6500 K color temperature to prevent the formation of the product shade and is a light-tight cube measuring 60 cm x 60 cm x 60 cm. The products were imaged with a digital camera (Nikon D3100, Germany) and images were analyzed in computer software (Matlab, USA). With computer software, the color values of the product images are converted into L, a, b color values from R, G, B values. The camera was calibrated to provide L, a, b values with the photogrammetric calibration plate. Browning index (EI) and total color change (ΔE) values were then calculated.According to the results, except for the L value which expresses the brightness level of the dried samples, the other findings differ statistically from the drying atmosphere. The L value determined as 67.32 ± 5.14 in fresh bananas decreased at the same level (20%) as a result of all applications. The minimum change in a value, determined as -3.19 in fresh samples, was at 10% oxygen ambient. This was followed by drying in 5% oxygen environment. However, these changes in L, a, b values were not found to be statistically different in terms of the browning index and color change calculated from L, a, b values between drying mediums.

#7497

Convective air drying of brown seaweed Bifurcaria bifurcata in thin layer configuration

Santiago Arufe-Vilas, Jorge Sineiro, Francisco Chenlo, Ramón Moreira

Air drying kinetics of Bifurcaria bifurcata brown seaweed at 35, 50, 60 and 75°C were determined. Experimental drying data were modelled using two-parameter Page model (n, k). Page parameter n was constant (1.28) at tested temperatures, but k increased significantly with drying temperature from 35 to 60ºC and was invariant at higher temperatures (up to 75ºC). Drying experiments allowed the determination of the critical moisture content of seaweed (1.6 ± 0.2 kg water (kg d.b.)−1). Mass transfer coefficients during constant drying rate period and effective coefficients of water diffusion during falling drying rate period were evaluated, assuming cyclindrical geometry and considering volumetric shrinkage.

Keywords: algae, diffusivity, drying kinetics, modelling, shrinkage.

#7498

Microwave drying of food materials modeled using the reaction engineering approach (REA): lumped and spatial model

Aditya Putranto, Xiao Dong Chen

Microwave drying is one of the common method implemented for process intensification. A reliable mathematical model is useful for process design, optimization and troubleshooting. In this study, the reaction engineering approach (REA) in its lumped and spatial format is developed and employed to model the microwave drying of green peas. In lumped format, the REA is implemented to describe the overall drying kinetics. The relative activation energy is generated from one accurate drying run and combined with equilibrium activation energy evaluated according to the final sample temperature and humidity. Combining the heat balance, the REA in lumped approach results in average moisture content and temperature which match well with the experimental data. For the spatial model, a set of equations of conservation of mass of liquid water, water vapor and heat is implemented. The local evaporation/condensation rate is employed to link the equation of conservation of mass of liquid water and water vapor. The same relative activation energy as the one for lumped model is implemented to describe the local rates inside the green peas. While benchmarking towards the experimental data, a good agreement is shown. The spatial profiles indicate that the highest moisture content, concentration of water vapor and temperature are located at the core of the samples. This is also confirmed by the highest local rates at the center of the samples.

#7505
Single droplet drying of detergents. experimentation & modeling

Borja Hernandez, Luis Martin de Juan, Mariano Martin, J. Enrique Julia, Rosa Mondragon, Leonor Hernandez, Juan Carlos Jarque, Sergio Chiva

In this work we evaluate the single droplet drying of detergent. Experimental data are used to validate a theoretical multistage model. The experiments are performed with 5 different detergent formulations with various composition of salts, organics and moisture content. They are carried out by means of an acoustic levitator together with the use of image analysis. The drying curve obtained shows 3 stages. First, an external surface drying stage is seen. A second stage is controlled by the diffusion through the pores to the surface. At the same time, the particle is heating up until the pressure generated by the internal vapour phase opens the pores. In a third stage, once the pores have opened, the drying is controlled by the boiling temperature. Since the stage of external diffusion control is observed, the modelling of detergent droplets cannot be performed with the use of a single Constant Drying Curve (CDC) or the use of a Reaction Engineering Approach (REA) as it has been assumed recently. Thus, in this work we develop a model based on several from the literature to capture all three stages. It includes the use of Nesic and Vodnik (1991) or Darvan and Sommerfeld (2014) for the modelling of the two first stages, together with the use of a Hecht, J. and King, C.J. (2000) or REA for the last stage. The selection of the model depends on the software application used, considering the possibility to be implemented for CFD codes of spray drying simulation, and the accuracy desired.

Keywords: Detergents, Modelling, Single droplet.

#7506
Global sensitivity analysis of operating conditions on the convective drying of paddy rice

Henry Vaquiro, Jader Rodríguez-Cortina, Oscar Rodríguez-Barragán, Susana Simal, José Bon

At an industrial level, hot-air drying is one of the most important post-harvest treatments for paddy rice to attain moisture contents that ensure the storage, processing and commercialization of grains. The modeling and simulation tools can be used to study the behavior of paddy rice in different drying conditions, in such a way that they allow to establish operating parameters to improve the process. In addition, a sensitivity analysis of simulations could be used to evaluate which drying conditions are most significant for process performance and product quality. The objectives of this work were to simulate the drying kinetics of paddy rice and to study the effect of hot-air temperature (between 35 °C and 50 °C), velocity (between 0.1 m/s and 1.0 m/s) and absolute humidity (between 0.007 kg/kg (dry basis) and 0.029 kg/kg (dry basis)) on the drying time by means of a global sensitivity analysis based on variance. A mathematical model was formulated considering the geometry of the rice grain as an ellipsoid of revolution on the major axis. The governing equations in prolate spheroidal coordinates were used to describe the one-dimensional mass and heat diffusion inside the product. Moisture and temperature-dependent transport properties, convection heat and mass transfer at the grain surface and symmetrical distribution of moisture content and temperature inside the solid were considered. The global sensitivity analysis allowed the quantification of the effect of the hot-air conditions, and their interactions, on the required drying time (RDT) simulated by the diffusion model. RDT was defined as the time required to reach an average moisture content lower than 0.12 kg/kg (wet basis). Results suggested that internal and external resistances to transfer phenomena controlled the water diffusion because the hot-air temperature, and its interaction with the absolute humidity, exhibited the greatest influence on RDT (total-order-effect indices greater than 77%) under conditions that cover from 10% to 80% relative humidity of the drying air. In contrast, the influence of the hot-air velocity on RDT was very low (sensitivity indices lower than 4%). The use of global sensitivity analysis could contribute to identify the most influencing variables on diffusion mechanisms, offering an alternative approach to prioritize input variables regarding to process efficiency and to suggest model simplifications based on model response on practical conditions.

#7521
Hybrid solar-gas-electric dryer optimization with genetic algorithms

H. El Ferouali, M. Gharafi, A. Zoukit, S. Doubabi, N. Abdenouri

To promote the hybrid solar dryers for use even under unfavorable weather and to overcome the intermittance state issue, the energy consumption should be optimized and the response time should be reduced. This work concerns a drying chamber connected to a solar absorber where the air can be heated also by combustion of gas and by electric resistance. To optimize the control parameters, an evolutionary optimization algorithm simulating natural selection was used. It was combined with a predictive model based on the artificial neural networks (ANN) technique and used as a fitness function for the genetic algorithm (GA). The ANN is a learning algorithm that needs training through a large dataset, which was collected using CFD simulation and experimental data. Then a GA was executed in order to optimize two objectives: The energy consumption and the t95% response time in which the drying chamber temperature reaches its set point (60°C). After optimization, a 30% decrease of the t95% response time, and 20% decrease of the energy consumption were obtained.

Keywords: hybrid solar dryer; artificial neural network; temperature regulation; energy consumption; genetic algorithm.

#7523
Multivariable modeling of an innovative hybrid solar-gas dryer

A. Zoukit, H. Elferouali, I. Salhi, S. Doubabi, N. Abdenouri

The main goal of this paper, is to propose a multivariable control model (MM) issued from CFD study of an innovative hybrid solar-gas dryer to simulate the drying chamber temperature in three modes of operation: Solar mode, Gas mode and hybrid mode. There is an indirect heating of drying air instead of direct heating inside the drying chamber. The air temperature obtained by CFD is still closed to one obtained by multivariable model (MM) with an RMSE under 2.31. the proposed multivariable model leads to a quick output parameters estimation related to each clilmate conditions and so, to an easy control of a hybrid solar dryer.

Keywords: Hybrid dryer; Multivariable model; solar dryer simulation; solar dryer control; Least square methods.

#7527
Identification of moisture transport mechanism in gypsum during convective drying

R. Adamski, A. Adamska, Z. Pakowski

Gypsum is a popular building material. Drying and rewetting of gypsum is a process of practical importance. This work presents the experimental results of kinetic of drying, heating and internal pressure development in rewetted gypsum cylinders. Analysis of the observed changes is presented. Additionally sorption isotherms, permeability and dependence of Young's modulus on moisture content were measured. These data will be used in the model of the process under development.

Keywords: internal pressure, permeability, Young's modulus.

#7534

Numerical and experimental study of a modular solar dryer coupled to a parabolic trough solar concentrator for agricultural product

Noureddine Benaouda

A numerical and experimental study has been carried out to investigate the performance of a modular solar dryer using a parabolic trough collector to produce the required heat for drying agricultural products. The modular solar dryer consists of a parabolic trough solar collector, a water-air heat exchanger and a drying chamber. The solar concentrator system has been constructed and tested without tracking device. The parabolic trough solar concentrator was oriented north-south and tilted from the horizontal at an angle equal to the latitude of the location (Algiers latitude b=36°). Tomato slices have been used in this study. The drying experiments have been performed for two air flow velocities and several air drying temperature in order to determine the drying velocity and the characteristic drying curve. A drying program based on thermal and mass balances on components of the cabinet dryer was developed and implanted in the TRNSYS software. Mathematical models describing the other components of the drying system are included in the TRNSYS library. Simulations are carried out for meteorological data of Algiers (Algeria). The results show that the parabolic trough solar collector gives drying air temperature in the range 60-90°. The air drying temperature, drying efficiency and collector system efficiency increases with increasing the flow rates of the air and water. The simulation results are in good agreement with experimental data. The discrepancies between experimental and numerical results are inferior to 8%. The drying duration required for reducing moisture from 80% to 10.5 % (Wet basis) is less than five hours and the drying efficiency is about 80%.

#7538
Inline quality control of product properties produced using fluidized bed agglomeration

Michael Jacob

The industrial-scale production of innovative products requires state-of-the-art technologies. Fluidized bed processes offer almost unlimited possibilities in terms of optimized particle design and the functionalization of products.
For instance, spray agglomeration makes products easier to handle and more safe, better to dose, better in homogeneity. Using fluidized bed agglomeration technology, stability, functionality and processability can be significantly improved. Main fields of applications are the food, feed and pharmaceutical industry as well as fine chemicals, where high performance products are needed.
To ensure optimal processes and reproducible product properties fluidized bed plants have to have powerful integrated control strategies.An automatic property-based control system for fluidized bed granulation requires research into a complex and validated process and product model. To link input data (e.g., material properties, quantities, temperatures, pressures, ...) with product parameters (e.g., bulk density, composition, homogeneity, morphology, particle size, humidity, etc.), the concept of artificial neural networks is used. For this purpose, innovative measuring systems have to be integrated into the system and used for the independent product property-based control of the granulation conditions
The paper shows actual status of research activities at Glatt using a case study of fluidized bed agglomeration of products to be further processed by tableting.
Based on a number of test based on "Design of Experiment" (DoE) a process model was developed to predict particle growth kinetics based on inline process data. A laboratory scale unit (ProCell-Labsystem /Glatt Germany) was used for experimental work. All relevant process and product data were electronically collected and processed using artificial neural network to derive a validated process model.
Parallel to inline measurements also conventional analytics were carried out. Results were used to evaluate the quality of inline data and to determine additional bulk properties.
The case study demonstrates the potential of inline measurements and data processing to be used to detect process deviations and as part of model predictive control strategies.

Keywords: agglomeration, fluidized bed, PAT, neural networks.

#7539
Simulation of a Fluidized Bed Characteristics using DEM-CFD Coupling

Preeda Prakotmak

This paper presents a coupled multiphase computational fluid dynamics and discrete element method (CFD–DEM) approach to simulate the behavior of fluid–particle interactions and flow characteristics of fluidized bed. The motion of discrete particles with ellipsoidal particle is described by dense discrete particle model (DDPM) on the basis of Newton's laws of motion applied to individual particles and the flow of continuum fluid by the CFD based on the local averaged Navier-Stokes equations. The influence of inlet air velocity on the particle motion and collision behavior is investigated. Here, the motion of individual particle is based on the contact force between particles and the fluid force acting on the particles. The simulation results showed that the minimum fluidization velocity (Umf) increased with the increase of static bed height. Higher superficial flow velocities gave rise to larger and more plentiful bubbles throughout the bed which led to higher rates of mixing and decreased in total bed dead zones. The particles were observed to be well-mixed after 4 s of fluidization. The number of contacts between the different layers of particles indicated the mixing efficiency. The simulation results demonstrated that pressure-drop formation was observed near the distributor and at the center of the column. These observations have achieved a general understanding of phenomena which take place inside the bed during fluidization.

Keywords: CFD, DEM, Fluidized bed, Multiphase flow.

#7553
Modeling of kinetics of drying process of polycaproamide granules considering its sorption properties

Maria Konstantinovna Kosheleva, Olga Roaldovna Dornyak, Marina Sergeevna Maklusova

The object of research is a fiber-forming polymer - polycaproamide. The process of drying of polycaproamide granules, after aqueous extraction of low-molecular compounds from them, is an important stage of producing of polyamide fiber nylon and largely determines the quality of the target product. To obtain a high-quality fiber, the drying of the granules should provide a sufficiently high degree of its dehydration. The average final moisture content of the material should be no more than 0.1%. With a low moisture content, the drying process slows down, so the calculation of the kinetics of dewatering of granules can not be carried out using a constant effective mass-transfer coefficient (moisture diffusion). In this paper we present a calculation technique for determining two local parameters of mass transfer: the water diffusion coefficient in polycaproamide (as a liquid) and the so-called criterion for phase transitions, which depend on the moisture content of the material and are determined by its sorption properties. The report presents the results of numerical calculations illustrating the development of two-dimensional fields of moisture content, temperature, pressure and vapor concentration in the vapor-gas phase for cylindrical granules in convective drying. To describe the processes of heat and mass transfer during the drying of granules, a nonstationary nonlinear 2D model is used that includes transport equations averaged over the microvolume of the material: the liquid phase transfer equation; heat equation; equation for vapor-gas phase pressure; equation for the concentration of the vapor component. The nonstationary nonlinear conjugate mathematical model is studied numerically. A feature of the presented model is the possibility of an analytical calculation of the local mass transfer coefficients of a liquid, taking into account the sorption properties of the material, the permeability coefficient and the local values of humidity and temperature.Determination of the local coefficients of moisture transfer is carried out on the basis of the formulas obtained in the analysis of a more general mathematical model of heat and mass transfer carried out based on the mechanics of multiphase systems developed in the works of R.I. Nigmatulin, and S. Whitaker. The structure of the samples was investigated by three independent methods in order to obtain the most complete idea of it and to compare the obtained characteristics. The isotherms of the sorption of polycaproamide were obtained experimentally on a vacuum sorption plant with Mac-Ben-Bakr weights. Comparison of the results of mathematical modeling of heat and mass transfer in the granule and data of the laboratory experiment on the kinetics of polycaproamide granule drying showed good agreement between the calculated and experimental data. The constructed mathematical model allows to form energy-efficient resource-saving regimes for drying granules of polycaproamide.

Keywords: convective drying, mathematical modeling, polycaproamide.

#7563
Computational fluid dynamics simulation of spray dryers: transient or steady state simulation?

S. Afshar, H. Jubaer, B. Chen, J. Xiao, X. D. Chen, M. W. Woo

Self-sustained fluctuating airflow behaviour in spray drying chambers is in essence an unsteady phenomenon requiring the transient CFD simulation framework. There is currently, however, a mixture of steady state and transient CFD simulations of spray dryers practised and reported in the literature. The choice between steady state and transient approach significantly affects the computation time of the simulation and subsequently the adoption of this approach by industry. This paper firstly examines in detail the bottleneck in computation time of the transient simulation approach. Based on past reports, this review paper then presents a discussion and provides several recommendations on the use of steady state and transient simulation approach for spray dryers.

Keywords: CFD simulation, spray drying, transient, steady state, fluctuation.

#7571
Semi empirical models for drying of agricultural products by used structured artificial neural network

Kornél Bessenyei, Zoltán Kurják, János Beke

We compared a semi empirical and an empirical model. The empirical model is a multilayer ANN. The semi empirical model is a custom multilayer ANN. It is a structured model, and we define the structure by hand before the training of the network. The influence of the neuron numbers on the accuracy of the models was also investigated by statistical approach.

We found that the custom multilayer ANNs developed like this, are suitable for modelling the drying process of agricultural materials. They also provide the ability to improve the applicability of the empirical models. Furthermore, the semi empirical model has a higher sensitivity on neuron number applied.

Keywords: drying; energetics; artificial neural network; semi-empirical model.

#7574
Drying characteristics and kinetics of hybrid tomato (EVA-F1) using different drying methods

Olajide Sobukola

The drying characteristics and kinetics of hybrid tomato (EVA-F1) produced under screen house were investigated using sun, infra-red (150, 250, 300 and 400 W) and microwave (120, 250, 420 and 520 W) drying methods. Eight thin layer models were used to analyze the tomato drying kinetics. The drying characteristics results showed that a higher power levels contributed to the drying process. Drying methods also had significant effects on the drying characteristics and kinetics. The Demir model best simulated the tomato dewatering process in all drying methods. Moreover, the microwave drying process obtained the fastest drying kinetics with the highest apparent diffusion coefficients and lowest activation energy followed by infra-red and sun drying processes in decreasing order.

#7575

Numerical simulation of evaporation of heptane droplet as a precursor material to form wax complexes in a single droplet drying (SDD) by suspension method

Oluwafemi Ayodele George

Wax solutions are excellent complexes in many applications such as coating to maintain the water contents in fruits. They also serve as slip agents in furnitures, etc. Furthermore, evaporation rate of each constituent in the mixture is a key factor that determines the performance of the coated surface. Due to high volatilities of the constituting organic solvents and high freezing point of wax, experimental investigations have however, been very cumbersome. On the other hand, mathematical modelling allows evaporation of wax solution to be studied in great detail. As a pilot exercise, the authors in this study have conducted numerical simulations on heptane droplet evaporation using single droplet drying (SDD) by glass filament suspension. The computational fluid dynamics (CFD) simulation is conducted in COMSOL Multiphysics with appropriate implementation of the necessary boundary conditions. The Arbitrary Lagrangian-Eulerian (ALE) procedure embedded inside Navier-Stokes ensures interface tracking as well as visualization of the droplet evolution. The fluid flow, temperature profile and local evaporation rate have been investigated. The developed model will serve as a guide for numerical investigation of evaporation rate of wax solution.

#7578

Artificial intelligence techniques modeling for predicting moisture content of luffa slices during air impingement drying process

Liu Ziliang, Deng Li-Zhen, Wang Jun, Gao Zhen-Jiang, Liu Yan-Hong, Xiao Hong-Wei

In current work the hot air impingement drying kinetics of luffa slices with initial moisture content of 95% (w.b) was investigated under different drying temperatures (55, 60, and 65 oC), air velocities (6, 9, and 12 m/s) and sample thickness (6, 9, and 12mm). Results showed that the drying temperature, air velocity and sample thickness have a significant effect on drying rates of luffa slices. Three artificial intelligence techniques, general regression neural network (GRNN), extreme learning machine (ELM) and least square support vector machine (LSSVM) are employed for predicting moisture content of luffa slices during drying process. GRNN, ELM and LSSVM have been applied as regression techniques. The drying time, temperature, air velocity and sample thickness are served as the input layer features of GRNN, ELM and LSSVM models and the moisture content as output feature. The performance of GRNN, ELM and LSSVM models is compared based on mean relative error (MRE), coefficient of determination (R2) and computing time (t). The simulation results indicated that the developed GRNN, ELM and LSSVM models can be effective for moisture content prediction. While the ELM model can show better accuracy and generalization than the GRNN and LSSVM model.

#7584

Experimental and numerical studies of the drying of aqueous solvent polymer supported by a thin polymer film

Pascal Le Bideau, Patrick Glouannec, Anthony Magueresse

Water based polymers tend to substitute organic solvent polymers for environmental reasons in many industrial sectors and for various applications (varnishes, adhesives, sensitive sensors…). As a result of this substitution, an added energy input is necessary to dry these products. Theses ones are often temperature sensitive, semi-transparent and present large shrinkages during the drying step. Thus, to avoid risks of degradation and guarantee the product quality, it is essential to correctly control the energy inputs as intensifying the production. In this perspective, a combination of various heat transfer modes provides an interesting way to improve the production.
The aim of this work is to apprehend experimentally and numerically the thermal and hydric behaviour of an aqueous solution deposited on a PET (Polyethylene terephthalate) polymer film, during drying by convection or infrared radiation.
Two specific drying devices developed in the laboratory for thin-layer product are used to track mass and product temperatures evolutions. One experimental laboratory setup enables to dry the product with short-wavelength infrared emitter associated to natural convection. Another one device combining short-wavelength infrared radiation and forced convection is used to intensify the heat and mass exchanges. In the same way, the heat fluxes absorbed by the solution and the polymer film are estimated as function of the solution thickness by the means of a fluxmeter.
A numerical model is developed to predict moisture contents and temperature variations. The thickness variation is also computed in considering a linear shrinkage with the water content. The first numerical results are encouraging and in accordance with experimental observations.

Keywords: Heat and Mass Transfer, Aqueous solution, Modelling, Experiment.

#7585
Estimation of kinetics parameters in forced convection drying with Markov Chain Monte Carlo method

H. R. B. Orlande, N. Gnanasekaran, M. V. De Bonis, G. Ruocco

The prediction of the residual moisture in water-saturated substrates that are subject to convective drying is at stake to evaluate drying performance. One of the most efficient description of evaporation, yet well suited to inclusion in Computational Fluid Dynamics framework, is the Arrhenius-type drying kinetics. Unfortunately, this kinetics is based on empirical coefficients whose evaluation constitutes sources of uncertainties for the results obtained with a forward simulation of the model, i.e. based on the integration of conservative differential equation for momentum, water and energy.

In the present work, an approximate one-dimensional model has been applied for the residual moisture of water in slices of a model food. Then, an inverse method was applied to estimate the unknown parameters involved in the kinetic evaporation term.

The inverse problem solution was accomplished using Markov Chain Monte Carlo method (MCMC) with Metropolis-Hastings sampling strategy. In parallel, the solution to the standard forward model was obtained by solving simultaneous partial differential diffusion equations whose integration accounts for air velocity, humidity and temperature. A good agreement was found between the estimated parameters by the MCMC method and the values used to generate the simulated measurements (forward method).

#7596

Rotary wheel atomizer study using computational fluid dynamics, analytical solutions and full-scale testing

Tórstein Vincent Joensen, Maximilian Kuhnhenn, Mads Reck, Cameron Tropea

Feed atomization is the single most influential process for the end product quality in spray drying. The output of the atomization, namely the droplet size distribution, influences every downstream aspect of the powder production process, ranging from drying chamber depositions to cyclone and bag filter efficiency and further on to packing and, of course, final powder characteristics.
Rotary atomizers are often used in industrial spray drying, as they are highly durable and easy to operate. This study provides a fundamental understanding as well as validated tools for simulating all fluid dynamic aspects of rotary atomization, thus providing a basis for the development of a new generation of atomizers. First, the study considers distribution of the feed inside the rotating wheel as well as the internal flow from the center to the edge of the wheel. The internal flow of representative atomizers has been simulated using Computational Fluid Dynamics (CFD), and the results have been validated experimentally based on integral quantities.
Next, this study investigates the flow of feed out of the atomizer, including the film, rivulet and ligament formation, as well as the subsequent atomization process associated with the atomizer outflow. A comparison of the initial outflow shape as analytically predicted, simulated by CFD, and visualized experimentally using a high frame rate camera, shows that the exit flow can be well predicted, in particular the exiting rivulet width. The resulting droplet size distributions for various operating parameters have been measured experimentally using the phase Doppler technique. Finally, a comparison between the resolved droplet size distribution of the CFD simulations and the measured droplet size distribution will be presented.
Based on this study and the validated tools developed, it is now possible to simulate the effects of various parameters, e.g. changes of the atomizer wheel geometry or feed properties, like viscosity, on atomizer wheel performance characteristics such as energy consumption, durability and droplet size distribution. This then allows atomizer designs to be improved or optimized.

Keywords: spray drying, rotary atomizer, atomization, CFD, experimental validation

#7598
Mathematical model of heat and mass transfer during drying of food material with shrinkage effect incorporated

I. O. Ajiboshin, O. A. Olafadehan, R. A. Bello

Drying is one of the oldest methods of food preservation. It is a heat and mass transfer process for reducing moisture content in food material. The mode of heat and mass transfer process is very complex and involves shrinkage of the food material. Modelling of the process is important for optimisation and energy efficiency. In this research work, modified governing equations of heat and mass transfer during drying of food material were developed. Shrinkage effect was taken into consideration to study its influence on drying process. Mathematical model of the modified simultaneous heat and mass transfer (SHMT) equations was proposed for prediction of temperature and moisture distributions during drying of food material. The model was applied to hot air drying of cassava root. Numerical scheme of Crank-Nicolson's approximation of finite difference method was used to solve the coupled heat and mass transfer equations. Simulated results showed that the proposed model can be used to predict temperature and moisture distribution inside the material as function of both position and drying time during hot air drying at any temperature. It also showed that shrinkage phenomenon is as integral part of food material drying process.

Keywords: Drying; Shrinkage; Heat transfer; Mass transfer; Food material

#7606

Application of process analytical technologies and artificial intelligence to monitor and control a fluidized bed coating process

C. A. M. da Silva, O. P. Taranto

The chemical, food, and pharmaceutical industries have extensively used fluidization operation in many cases, due to its very attractive features that enable effective contact between the solid and fluid phase, which reflects the generation of high heat and mass transfer rates. However, the bubbling fluidization regime, which is the starting condition of the processes involved in this operation, is often affected by operating conditions. Elevated temperatures, the excessive moisture content of the particles and introduction of liquid into the fluidized bed may lead to instabilities in the fluid-dynamic regime and cause the partial or total collapse of the bed, reducing the process efficiency. The maintenance of stable conditions of the fluidization regime for particle coating processes in fluidized beds is of fundamental importance to ensure a favorable coating efficiency and to avoid zones without movement and agglomeration of particles in the bed, because these undesirable factors compromise the mixing between the phases and therefore the quality of the final product. Within this context, the use of a monitoring system and real-time control of particle coating processes is highly desirable to allow operation in stable fluidization regimes and to ensure a uniform coating film and good condition of flowability of the solids. This work aimed to apply the Gaussian spectral analysis methodology of the pressure fluctuation signals, for the development of control systems based on artificial intelligence (Fuzzy Logic), to monitor the stability of fluidization regime particle coating process. Experiments were carried out with 0.60 kg of microcrystalline cellulose, 70C in the plenum chamber, 6.0 and 10.0 mL/min were used for the coating suspension flow rate, based on Eudragit L30D55. Comparisons between the fluid dynamic conditions of the processes with and without control were analyzed for operations in fluidized bed laboratory scale. To assess early stages of unwanted agglomeration, a monitoring in-line probe (Parsum IPP70) was used. With the application of this automated system, it was possible to associate the stability of fluidization with a high degree of agglomeration. The process stopping point could be set at 420 μm (initial in 360 μm) and after this median particle size, the coating mechanism takes place simultaneously with the agglomeration one. The monitoring parameters of the system were able to identify the initial phase of defluidization, as well as it was possible to control the process by using Fuzzy Logic and to stabilize the operation for high rates of the coating suspension atomized onto the bed.

#7614
Mathematical modeling of thin-layer drying of longan in hot air tunnel

Bhuchiss Tanwanichkul

Longan is a subtropical fruit widely grown in Asia whereas the largest producers are Thailand, Vietnam and China. In Thailand generally, the harvest period of longan is in the end of rainy season having high humidity. Therefore, this will easily leads to rot of harvested longan, which highly affects to the storability, transportation, and shelf life. This paper aims to determine the mathematical model of thin layer drying of longan in hot air dryer tunnel. Thin layer drying characteristics of longan were conducted at three drying temperature of 55, 65, and 75°C with average thickness of layer is about 15 mm under average wind velocity 1.0 ms-1. Twelve thin-layer drying model were investigated. Non-linear regression analysis was used to determine model parameters, while coefficient of determination (), reduced of chi-square (), root mean square error (RMSE), and sum of residuals are generated were examined to determine goodness of fit in models. The experimental result was shown that the Midilli drying model is the best fit of Longan in different drying temperature. The effective moisture diffusivity () was obtained using Fick's diffusion equation and its mean values ranged between 9.47´10-10-20.00´10-10m2s-1 as the drying air temperature increased from 55°C to 75°C. The activation energy of diffusion of Longan was calculated as 35.60 kJ/mol. Predicted moisture ratio agreed well with experimental values.

#7623

The paramateric problem of enhanced multiphysics drying by time scale comparison

Francesco Marra, Gianpaolo Ruocco, Giuseppe Titomanlio

Bulk convection drying of substrates in continuous processing can be intensified and optimized by providing exposure to volumetric sources (of multiphysics nature, such as electromagnetic or ultrasound energy).Transient distributions of temperature and moisture in multiple substrates, treated at once, are analyzed in this work by means of a comprehensive numerical model, featuring fluid dynamics effects and custom moisture diffusion and evaporation notations.After proper verification with the correspondent experimental results, geometry and thermal-fluid dynamics dimensionless parameters are defined and scrutinized.It is shown that the exposure to volumetric sources may increase process throughput and improve energy consumption. These good, positive outcomes should encourage operators to embrace multiphysics-enhanced drying technology.

#7646

Image Segmentation and 3D reconstruction for improved prediction of the sublimation rate during freeze drying

Luigi C Capozzi, Andrea Arsiccio, Amelia C Sparavigna, Roberto Pisano, Antonello A Barresi

In a freeze drying process, the freezing step determines the pore size distribution within the product, which, in turn, affects the sublimation rate. Traditionally, pore analysis is carried out on SEM images by means of a manual, time-consuming approach. Here, an image segmentation technique was used to automatize this process and improve its reliability. A 3D structure of the cake was then reconstructed from the distribution of the super-pixels. We show that the approach herein proposed can remarkably improve prediction of the sublimation rate with respect to traditional methods.

Keywords: Freezing; Freeze-Drying; Image Segmentation; 3D Reconstruction.

#7658

Mathematical relationship between glass transition temperature and water activity of cellular and non-cellular food systems

Thanh Khuong Nguyen, Seddik khalloufi, Cristina Ratti

Cellular and non-cellular-solid food systems were used to obtain experimental data of aw and Tg as a function of moisture content during drying. GAB, Gordon-Taylor, and Khalloufi-Ratti models were used to obtain the state diagrams of the four food systems investigated. The results suggest that the GAB and Khalloufi-Ratti models can successfully be used to capture the experimental data. In terms of plasticizing effect, it seems that cellular and non-cellular systems have comparable values. Although the number of food samples explored in this study was limited, it is suggested that the chemical composition could have more impact on Tg and stability than the presence of cell structures.

Keywords: Isotherms; Glass Transition; Cellular and Non-Cellular Food Systems; Modeling.

#7659
Mathematical approach and its experimental validation to predict the porosity profiles during drying

Seddik khalloufi

Water activity (aw) and glass transition temperature (Tg) are relevant concepts to predict the stability of food products. In the open literature, several mathematical models have been reported to describe aw and Tg as a function of moisture content during drying. There have been also some attempts to directly express Tg as a function of aw. When available, these mathematical expressions can be used to build a state diagram which produces valuable information on critical zones of a given system. It has also been suggested that the cellular architecture could affect the stability of food systems and that this could be due to the presence of two phases (the sugar-rich phase and the cell wall-rich phase). In this contribution, cellular (carrot, potato, and mushroom) and non-cellular-solid (Maltodexrin DE19 and DE36 with agar) food systems were used to obtain experimental data of aw and Tg as a function of moisture content during drying. The sorption isotherms were represented by the Guggenheim-Anderson-de Boer (GAB) model and Tg as a function of moisture content was expressed by the Gordon-Taylor equation. The Khalloufi-Ratti model was used to mathematically correlate Tg to aw. The state diagrams of the five food systems investigated were obtained and discussed in this study. The results suggest that the GAB and Khalloufi-Ratti models can successfully be used to capture the experimental data for both cellular and non-cellular systems. In terms of plasticizing effect of water, it seems that cellular and non-cellular systems have comparable values. Although the number of food samples used in this study was limited, this contribution suggests that the chemical composition of food systems could have more impact on their Tg and stability than the presence of cell structures. Further investigations with diverse food systems are required to confirm this preliminary finding.

Keywords: Isotherms, Glass Transition, Cellular and Non-Cellular Food Systems, Modeling.

#7668
Modeling sorption isotherms and isosteric heat of sorption of roasted coffee beans

Gentil Andres Collazos-Escobar, Nelson Gutiérrez-Guzmán, Henry Alexander Vaquiro-Herrera, Erika Tatiana Cortes-Macias

The aim of this work was determine the sorption isotherms in roasted beans of specialty coffee at temperatures of 25, 30 and 40 °C and water activities between 0.1 and 0.8 using the dynamic dew point method. The experimental sorption data were modeled using 12 different equations to represent the dependence of equilibrium moisture content with aw and temperature. The net isosteric heat of sorption was determined from the experimental sorption data using the Clausius-Clapeyron equation. The Weibull model satisfactorily modeled the effect of the temperature on the hygroscopic equilibrium in roasted coffee beans (R2adj=0.902 and RMSE = 0.00550 kg·kg-1d.b.). The net isosteric heat of sorption increase with increased moisture content.

Keywords: water activity; sorption properties; equilibrium moisture content; hygroscopicity.

#7669
Modelling the water sorption isotherms of warionia saharae and determination of sorption heats and drying kinetics

F. Amel, A. Cheriti

The hygroscopic equilibrium of Warionia saharae was studied, which allowed getting an idea of the equilibrium water content relative to a given humidity. The results of this study made it possible to have the sorption curves. The results of this study made it possible to obtain the sorption curves necessary for know the storage conditions of the plant and the study of its drying kinetics. The static gravimetric method was used to determine sorption isotherms of Warionia saharae leaves at 30and 40 ◦C and in the range of water activity varying from 0.063 to 0.898. The Gab, Peleg models was found to be the most suitable for describing the sorption curves. The isosteric heat calculated by applying the Clausius–Clapeyron equation .The desorption isosteric heat was higher than the isosteric heat of adsorption and both decreased continuously with increasing of the equilibrium moisture content. The experimental results obtained allowed us to determine the temporal evolution of the drying kinetics as a function of the moisture content. The curve of the evolution of the water content as a function of time shows the absence of the phases product temperature and constant drying rate

Keywords: Sorption isotherm, isosteric heats, modelling, kinetics, Warionia saharae.

#7681
Multiphase transport model for microwave freeze-drying of porous media with prebuilt pores

Wei Wang

A multiphase transport model based on the local mass non-equilibrium assumption was formulated to verify the effect of initially porous frozen material on microwave freeze-drying of liquid. A wave equation was derived to express the real-time distribution of electrical field strength in porous material, and an error function form of adsorption-desorption equilibrium relationship was adopted to describe the hygroscopic effect of material. Governing mass and heat equations as well as wave equation were solved numerically on the software of COMSOL Multiphysics. Simulation results showed excellent agreements with the experimentally measured drying curves for initially saturated and unsaturated frozen materials. When the solid material in liquid has a large loss factor, microwave plays a major role in heating. When it is quite small, dielectric substrate needs to be employed in support to microwave heating. Electrical field distribution was obtained during simulation and evolution of microwave energy absorption by the material was discussed. According to ice saturation and temperature distributions, mechanisms of mass and heat transfer inside the material were analyzed.

Key words: microwave freeze-drying; dielectric substrate; loss factor; drying curve; mass and heat transfer.

#7682
Hybrid cylinder dryer for the drying of sheet-form materials with hot air

Sung Il Kim, Sang Hyun Oh, Won Pyo Chun, Ki Ho Park, Byoung Hyuk Yu

In this paper, we introduce a novel energy-efficient dryer that uses hot air as a combined heating method of heat conduction and convection heat transfer. The dryer consisting of rotary cylinders and arched jackets is structurally different from conventional dryers. We designed and built a hybrid 4-cylinder dryer for sheet-form materials. The energy consumption to evaporate unit water is about 930 kcal/kg moisture from the experimental results of a hybrid 4-cylinder dryer. The hybrid 4-cylinders dryer has a compact structure with about 1/3 of the size of a conventional dryer for the drying of sheet-form materials.

Keywords: Dryer; Hot Air; Sheet-form; Energy Efficiency; Hybrid.

#7702

Thermodynamic properties and moisture sorption isotherms of two pharmaceutical compounds

A. Zammouri, M. Ben Zid, N. Kechaou, N. B. Mihoub

This investigation examines and compares the water sorption isotherms and the thermodynamic properties of two pharmaceutical preparations (Hypril and Azix) intended to be manufactured with the same process plant and equipment. The moisture equilibrium isotherms were determined at 50, 60 and 70 °C using a gravimetric technique. Five isotherm models were explored for their fitting to the experimental data. Azix showed sigmoid type II isotherms while Hypril showed type III isotherms according to the BET classification. All investigated models fitted well the water sorption isotherms of Hypril. By contrast, only GAB and Adam and Shove equations gave appropriate fit to the experimental data of Azix. For both formulations, the isosteric heat and the differential entropy decreased sharply with the increase of equilibrium moisture content to minimum values and thereafter remain constant. In the case of Azix, the integral enthalpy decreased with equilibrium moisture content while the integral entropy increased until reaching a constant value. Contrariwise, Hypril showed decreasing of the integral enthalpy and entropy with the equilibrium moisture content.

Keywords: sorption isotherm, enthalpy, entropy, spreading pressure, pharmaceutical formulations.

#7703
Comparison between bubbling and turbulent regime for the simulation of batch pharmaceutical powders fluidized bed drying

A. Zammouri, N. B. Mihoubi, N. Kechaou

This investigation examines and compares the water sorption isotherms and the thermodynamic properties of two pharmaceutical preparations (Hypril and Azix) intended to be manufactured with the same process plant and equipment. The moisture equilibrium isotherms were determined at 50, 60 and 70 °C using a gravimetric technique. Five isotherm models were explored for their fitting to the experimental data. Azix showed sigmoid type II isotherms while Hypril showed type III isotherms according to the BET classification. All investigated models fitted well the water sorption isotherms of Hypril. By contrast, only GAB and Adam and Shove equations gave appropriate fit to the experimental data of Azix. For both formulations, the isosteric heat and the differential entropy decreased sharply with the increase of equilibrium moisture content to minimum values and thereafter remain constant. In the case of Azix, the integral enthalpy decreased with equilibrium moisture content while the integral entropy increased until reaching a constant value. Contrariwise, Hypril showed decreasing of the integral enthalpy and entropy with the equilibrium moisture content.

Keywords: sorption isotherm, enthalpy, entropy, spreading pressure, pharmaceutical formulations.

#7704
CFD modelling of particle residence time in spray drying towers

Borja Hernandez, Luis Martin de Juan, Mariano Martin, Victor Francia

Spray drying towers are used for the manufacture of particulate dried materials. Previous work demonstrates that the deposition of material at the walls has large influence on the structure of the vortex employed in swirl units. Being neglected in CFD modelling for decades, it has led to substantial errors in the description of the flow patterns and the drying process. Our previous work demonstrates that the effects of deposition in the flow structure can be predicted with the appropriate use of wall functions. In this work, we extend the methodology to study the momentum interaction with the disperse phase. For the first time, a CFD model is validated with the residence time of the particles in a spray drying tower independently from heat and mass transport under different operation conditions. The CFD model uses two-way coupling and the BBO equation for the modelling of particle-air interaction. Meanwhile the particle-wall interactions are modelled with the restitution coefficients. The experiments recently presented are extended to validate under different nozzle positions, various Reynolds numbers, particle size distributions and materials (glass ballotini and detergent dry powders). The CFD model predicts the mean residence time distribution for all the experiments. However, the distributions of the residence time are only predicted for the glass ballotini. The detergent powder shows large deposition in the experiments (in some experiments only 20% of the initial mass used is recovered) so that further models such as transient deposition may be required in further steps.

Keywords: CFD, residence time, Spray drying.

#7712
Multi-area temperature and humidity independent control of belt dryer

Xianlong Yu

Hot-air flow field during drying of a multi-tier conveyer drier with has been mathematically studied in order to optimize flow field distribution. The drying chamber was divided into separate areas by adding windscreen. Each area can complete the independent cycle heating of hot-air under certain temperature and humidity conditions by automatic control system. Furthermore, in order to solve the uneven distribution of airflow, the Air distribution box was used to adjust gas flow rate in drying chamber. The air distribution box was optimized with the method of numerical simulation for flow field which had different parameters spoiler. The optimal parameter of spoiler was obtained which offered an optimum model that the variance coefficient of flow velocity is 10% in different locations of the drying chamber.

#7715
Modeling and simulation of intermittent drying of high moisture foods

Ana Paula Filippin, Érika Fernanda Rezendes Tada, João Claudio Thomeo, Maria Aparecida Mauro

This study aimed at the modeling and simulation of intermittent drying to be applied to highly deformable moist foods such as apples. Mass transport modeling considered two stages: the first at 95, 85 and 75ºC air temperatures, and the second at 60ºC. The shrinkage was correlated with the sample moisture and included in the model that was solved by the finite differences method. The first stage temperatures affected the water diffusivity in the second stage. This model was suitable for simulating the water profiles during the two-stage intermittent drying, showing an efficient fitting to the experimental data.

Keywords: thermal intermittence; coefficient diffusion effective; shrinkage; apple drying.

#7726

The aggregation rate constant of the discrete population balance model in hot melt fluidized bed coating process

W. Xin, Y. Yan, X. Qing, W. Long

During hot melt fluidized bed coating, particle agglomeration leads to non-uniform particle size. In this study, Population Balance Model (PBM) is used to establish the conservation of the size of particles in the system. In order to solve the population balance model, it is discretized. The aggregation kernel of the particles can be described by the Equi-partition of Kinetic Energy (EKE) kernel based on the gas dynamics theory. The EKE kernel is incorporated into a discrete population balance (DPB) model, and the effective aggregation rate constant is obtained by fitting with the experimental data.

Key words: Hot melt fluidized bed, PBM, DPB, EKE kernel, Aggregation rate constant.

#7733
Study of the hot air drying process of chicken breast by non-invasive techniques

Juan Angel Tomas-Egea, Marta Castro-Giraldez, R.J. Colom,, Pedro J Fito

Food drying is one of the main unit operations for food preservation and it is based on the difference of chemical potential between the product and a fluid with lower chemical potential. The objective of this work was the development of a thermodynamic model of chicken meat drying process using infrared thermography; also the viability of using dielectric spectroscopy as a monitoring system was analyzed. A thermodynamic model has been developed to predict the expansion/contraction phenomena of poultry meat throughout the drying process. Moreover, it was demonstrated that permittivity is a non-destructive method to monitor the evolution of drying process.

Keywords: Poultry meat, hot air drying, permittivity, infrared, drying kinetics.

#7737

Intensification of the convective drying process of Salvia Officinalis: simulation and optimization

José Bon, Jebri Monia, José Tarrazó, Susana Simal, Gabriela Clemente

The current study deals with an innovation in the hot air convective drying process consisting of the application of two consecutive drying steps. Temperatures ranging between 60 and 80°C for times between 200 and 600 seconds were applied for the first stage, and from 40 to 80°C for the second stage. Salvia Officinalis, an aromatic, medicinal Mediterranean plant with remarkable antioxidant properties, was selected. A management of the process regarding the antioxidant capacity of Salvia Officinalis extracts and energy consumption was carried out: (i) Artificial Neural Networks were applied to model the evolution of the antioxidant capacity and moisture content of the product in the drying process; (ii) A genetic algorithm and a multi-objective genetic algorithm were selected to optimize the drying process, considering the antioxidant capacity and/or the energy consumption in the objective function. The results showed that the optimum values depended, logically, on the controllable variables values (hot air temperatures and drying times), but also on the uncontrollable variable values (room air temperature and relative humidity and the product's initial mass and moisture content).

#7752
Thermodynamic and spectrophotometric study of tiger nut pasta

Marta Castro-Giráldez, María Eugenia Martín-Esparza, Ana Albors, Pedro J. Fito

In this work, tiger nut pasta was formulated and dried at low temperature (40 °C, 1.5 m/s) during different drying times (10, 20, 40, 80, 140 y 200 min). Mass, volume, water content, water activity and permittivity (Hz-MHz) were determined before the treatment, immediately after drying and after 24 hours of storage (packaging and tempering at 4°C). Controlling the drying air conditions, the volumetric deformations and the physicochemical properties of the paste during the drying, a thermodynamic model was developed including the development of a sorption isotherm and a transport kinetic model, which allowed the development of drying control algorithms of tiger nut pasta.

#7755

Pulsed multiphase flows - Investigation of the influence of flow conditions and particle properties on the heat transfer in gas-solid flows

Arne Teiwes, Michael Jacob, Maksym Dosta, Stefan Heinrich

Although the benefits of pulsating multiphase flows and the concomitant opportunity to intensify heat and mass transfer processes for e.g. drying, extraction or chemical reactions have been known for some time, the industrial implementation is still limited. This is particularly due to the lack of understanding of basic influencing factors, such as amplitude and frequency of the pulsating flow and the resulting particle dynamics. With the goal of process intensification and targeted control of sub-processes or even development of completely new processing routes for the formation, drying or conversion of particulate solids in pulsating gas flows, the basic understanding of occuring transport processes becomes more and more important. In the presented study, the influence of flow conditions and particle properties on particle dynamics and the resulting heat transfer are investigated. With the help of flow simulations and the unilaterally coupled modeling of gas-particle micro-processes, parameter dependencies are highlighted, which provide a basis for the later model extension to mass transfer and phase transformation processes, e.g. occur during "pulse-combustion-drying" or the spray pyrolysis according to the APPtec-method of Glatt Ingenieurtechnik GmbH.

#7763
Control of fluid-dynamic regime in spouted bed wetting process using spectral analysis

J. J. Butzge, C. A. M. da Silva, O. P. Taranto

Spouted bed dryers have been widely used in many industrial processes, especially in chemical, food and pharmaceutical industries. One of the main advantages of these dryers are high rates of heat and mass transfer. However, such characteristics are related to the maintenance of stable spouted regime, which is rare and difficult to control during the drying of pastes, due to the high moisture content from liquid atomization. One way to overcome these problems is to apply process control. The aim of this work was to maintain a stable dynamic regime of particles during water atomization onto the spouted bed. Spectral analysis of pressure fluctuation signals was used to monitor the fluid dynamic regimes and a PID process control strategy was implemented. Glass beads were used as inert particles and distilled water was the atomized liquid. The open-loop experiments performed in a wet bed allowed to evaluate the dominant frequency behavior during stable and unstable spout conditions. Twelve combinations of the mass of solids (1.0 and 1.5 kg), particle size (2.6 and 3.1 mm) and liquid water flow rate (13, 16 and 19 mL/min) were studied. The initial moments of the fluid-dynamic regime transitions were identified by the dominant frequency of the power spectrum. The dominant frequency was able to monitor and control the wetting process. The set-point range of the control system was defined based on the stable spouting regime (7.8 and 8.4 Hz). Conventional PID tuning methods were used to determine the parameters of the controllers, which provided stable performances of the manipulated variables, air flow rate and atomized water flow rate. The PID controller parameters to the frequency converter (KC = 0.048 V/%, tI = 249 s, tD = 37.5 s) were obtained by the application of Åström and Hägglund method, while the reaction curve method provided preliminary PID controller parameters to the peristaltic pump (KC = -1.1 V/%, tI = 500 s, tD = 13.5 s). The wet control (closed-loop) improved the fluid-dynamic conditions in comparison to the process without control. Although equivalent amounts of liquid have been added to both processes, the spouted regime with control was kept stable, while fixed bed regime was achieved without control. The methodology used in this work demonstrated good potential for applications in the drying of real slurries, conducted in spouted beds. Conventional controllers (PID) could overcome the scale-up problems of maintaining stable spouting regime, avoiding fluid-dynamics instabilities.

#7767
Flat plate solar air heater with helical integrated fins for drying processes

Maytham A. Al-Neama, Istvan Farkas

In this study, an experimental investigation was carried out on solar system consists of many main components; solar air collector, drying chamber and air blower. Manufacturing and an analysis of two active double-pass solar air collector integrated with unfinned and helical finned absorbers have been carried out. The helical fins increased the standers solar collector (unfinned) efficiency by about 6%. In five hours for 2 kg of apple slices drying, the final weight of the dried product is 1.237 kg using an unfinned solar collector, while 1.039 kg using helical finned solar collector.

Keywords: solar drying, air heater, thermal performance, helical fins.

#7812
Modelling of amorphous to crystalline transformation in a drying droplet/particle

Muzammil Ali

Spray drying is widely applied in the pharmaceutical industry for the formulation of particulate materials such as solid dispersions, excipients, active pharmaceutical ingredient (API) as well as co-dried materials (API with excipient). It has a distinct advantage of converting pumpable feed into dry powder in a single unit operation. In spray drying, the atomised droplets typically range from 10 to 500 μm in diameter and comprise dissolved solute in a solvent. The droplets undergo rapid evaporation of solvent upon contact with a turbulent hot gas flow, favouring the formation of amorphous particles with a higher dissolution rate compared to the crystalline form. However, amorphous particles can be unstable and transform to the crystalline form when exposed to high temperature and humid conditions, which reduces its efficacy. Furthermore, the distributions of particle size, densities and moisture contents also influence the product performance. By optimising the input operating conditions and feed composition in the spray dryer, it is possible to control the dried powder attributes.

The present work is focused on the modelling of the amorphous to crystalline transformation in a particle undergoing drying. A diffusive transport equation based on a droplet drying model is numerically solved in a solute-fixed coordinate system using the fully implicit backward difference method to predict the solute/solvent concentration profiles within the droplet/particle. To evaluate the amorphous to crystalline transformation during drying, a distributed approach is used for predicting the glass transition temperature variation within the particle. The rate of crystalline transformation in the particle is considered to be a function of the difference between the particle temperature and the glass transition temperature. A strong variation of the glass transition temperature and the consequent crystalline transformation is predicted within the particle. The overall transformation rate is a maximum once the entire droplet is converted into a solid particle. The results are validated with data available in the literature on drying and crystalline transformation in a single particle for lactose. The model can be incorporated in a spray drying process to predict the influence of dryer operating conditions on the moisture content, crystallinity and stability as well as thermal degradation and product yield.

#7820
Theoretical analysis of HPD for performance optimization

Bhaskar Thorat

Electricity operated tray dryers are commonly used by small and medium scale industry. These systems are popular because of its simplicity, variable capacity and simple utility i.e. electricity.
The challenge of electricity operated tray dryer is its high cost of operation. Typically it consumes 1 unit of electricity per Kg of water removal. In Indian context, it costs $0.2 per unit or per Kg water removal. This high operating cost makes electrical dryers ineffective for multiple applications including food where operating cost of drying makes final cost of dehydrated food too expensive to be competitive in market.
The present paper focuses on increasing efficiency of HAD (Hot Air Dryer) by converting it into a HPD (Heat Pump Dryer) where COP is increased from 1 (in case of electrical dryer) to around 3 (in case of HPD). The lab level trials of HPD has shown that efficiency and quality varies considerably based on operating parameters mainly temperature and relative humidity. It is observed that temperature and relative humidity are so crucial to define food quality and microbial load that in certain conditions food degrades before drying. Hence, efficiency and quality need to be analyzed together.
This paper focuses on temperature and relative humidity aspects of HPD in terms of efficiency analysis. The mathematical model of drying kinetics and heat transfer associated with HPD is built into check how temperature and relative humidity variations affect efficiency of HPD. The optimum parameters are identified and experiments are carried out to check for quality aspects.
The theoretical analysis clearly shows that certain temperature and relative humidity combination is preferred so far as food quality aspects are matched.

#7825

Use of hemispherical-shell geometry to describe the osmotic dehydration of white mushroom considering its shrinkage

Irving Israel Ruiz-López, Julio Emmanuel González-Pérez, Karen Hariantty Estévez-Sánchez, Juan José Luna-Guevara, Carlos Enrique Ochoa-Velasco

The aim of this study was to model both the dynamic and equilibrium mass transfer periods for water and osmotic solute between product and solution during osmotic dehydration (OD) process of white mushroom pilei (10 and 25 g NaCl/100 g solution, 40, 60 and 80°C). Water and solute are considered to move within the product by a diffusion mechanism based on Fick's second law, while product is considered to have a hemispherical-shell geometry with shrinkage occurring in the radial direction. Evolution of size and shape characteristics was followed with image analysis. The diffusion model was numerically solved with the methods of lines and fitted to experimental data to estimate water and solute diffusivities. Water loss at equilibrium ranged from 0.2 to 0.6 g water/g fresh product, while corresponding values for solute gain were between 0.02 and 0.2 g NaCl/g fresh product. Results demonstrate that the inclusion of shrinkage in OD model is necessary to obtain reliable values of mass transfer properties.

#7827
Drying of sugarcane bagasse in a partially filled horizontal drum

Érika Fernanda Rezendes Tada, Andreas Bück, Fernanda Perpétua Casciatori, João Cláudio Thoméo

One-phase model have been reported to describing the simultaneous heat and mass transfer in a horizontal drum partially filled by sugarcane bagasse with attention to the loss of water promoted by the increase of temperature. Mass and energy balances were written in MatLab language and solved by finite difference method. Predicted temporal and spatial profiles of moisture content and temperature are shown. Experimental tests were carried out in a horizontal drum and the temporal profiles were obtained. Great adjustments between experimental and predicted data were observed, indicating that the model is able to describe the transport phenomena in this system.

Keywords: horizontal drum; heat and mass balances; sugarcane bagasse; solid-state fermentation process.

#7838
CFD modeling of air flow distribution in customized withering trough for tea processing

Ashutosh Namdeo Chavan, Ashis Kumar Datta

Withering is one of the most important and primary step in tea processing. It brings physical as well as chemical changes in freshly plucked tea leaves which affect the quality of tea. Customized withering trough developed at IIT Kharagpur is used to study the effect of different operating parameters like air flow to overcome non-uniform withering of tea leaves. CFD modeling is done using ANSYS Fluent software to study uniform air flow distribution in plenum chamber of withering trough considering three different types of vane arrangements viz. straight inclined vane, elliptical downward vane, and elliptical upward vane. The study showed that straight inclined vane leads to relatively more uniform air flow than other two types of vanes. Simulation results later compared with experimental measurements are found in good agreement with each other.

#7841

Moisture content modeling and effective moisture diffusivity determination during convective solar drying of blackberry (rubus spp) and basil (Ocimum basilicum L.)

Anabel López-Ortiz, Octavio García-Valladares, Isaac Pilatowsky-Figueroa, Juan Rodríguez-Ramírez

The goal of reducing energy consumption (EC), losses and waste (FL) in the food processing is a challenges in the worldwide. The use of active solar greenhouse dryers (GHD) for EC and FL reductions has increased due to its capacity, and low operating costs. In this work the effective diffusivity (Deff) and the moisture content modeling were analized for basil (Ocimum basilicum) and blackberry pulp (Rubus rosoideae) dried in a conventional stove (CD) and an GHD coupled to an additional air solar heating system (SCHa). The loss of water and the drying rate in food materials dehydrated in the GHD is consistent with the increment or decrement of temperature during the solar day. The Deff values for basil and blackberry pulp was ranged between -1.1044x10-7 and -3.9167x10-9. The solar energy obtained in the GHD supplied the heating requirements. In general, the Page's model was the best fit for the drying kinetics for basil and blackberry pulp.

Keywords: Solar Collector for air heating, solar energy, variable conditions.

#7847

Drying characteristics and mathematical modelling of the drying kinetics of oyster mushroom (Pleurotus ostreatus)

A. A. Satimehin, M. O. Oluwamukomi, V. N. Enujiugha, M. Bello

This study was conducted to determine the drying characteristics of oyster mushroom (Pleurotus ostreatus) at 50, 60 and 70 °C. Pleurotus ostreatus were cleaned and dried in a laboratory cabinet dryer. The drying data were fitted to six model equations namely Newton, Pabis and Henderson, Logarithmic, Two-term diffusion, Wang and Singh, as well as Modified Henderson and Pabis equations. The goodness of fit of the models were evaluated by means of the coefficient of determination (R2), root mean square error (RMSE) and reduced chi-square ($\chi 2$). The Logarithmic model best describes the drying data and could be used to predict its drying behaviour.

Keywords: oyster mushroom; thin-layer drying; characteristics; modelling.

#7857

Mass transfer modeling during convective drying of white mushroom pilei using the prolate-spheroidal coordinate system

Irving Israel Ruiz-López, Julio Emmanuel González-Pérez, Karen Hariantty Estévez-Sánchez, Carlos Enrique Ochoa-Velasco

A mass transfer model based on the prolate spheroidal coordinate system was proposed to describe the water removal during convective drying of white mushroom pilei (Agaricus bisporus). The dimensionless form of the model was numerically solved with the method of lines under negligible external resistance to mass transfer. In addition, average drying kinetics were calculated from the volume integration of local moisture values. Drying experiments were conducted at 50, 65 and 80°C with an air velocity of 2 m/s. The contours of transversal product slices, obtained from digital images, were averaged to extract relevant dimensional characteristics of the dried samples. Mass transfer model was also solved considering flat-slab and hemispherical-shell geometries. Prolate spheroid shape, which closely resembles geometry of the white mushroom pilei, was found to be the most suitable, achieving a satisfactory reproduction of drying curves. Results demonstrate that the inclusion of shrinkage in drying model is necessary to obtain reliable values of water diffusivity.

#7877
Thermodynamic model of Ca(II)-alginate beads drying by spectrophotometry

Patricio R. Santagapita, Marta Castro-Giraldez, Maria Victoria Traffano-Schiffo, Pedro J Fito

The purpose of this work was to study the drying process of Ca(II)-alginate beads with/without sucrose, monitored by infrared thermography (IRT), in order to describe the critical points and the transformations suffered by the systems. Beads were obtained by the drop method and the drying process was performed at 40 ºC and 1.5 m/s. IRT was measured by a thermal imager Optris PI® 160. Mass, aw, xw and volume were also obtained. It was demonstrated that IRT is a good monitoring tool, able to analyzed heat transfer in colloidal systems. A thermodynamic model able to predict the mechanical phenomena of the beads throughout drying process has been developed.

Keywords: encapsulation; thermodynamic; spectrophotometry; drying; beads.

#7884

On the importance of heat and mass transfer coupling during characterization of hygroscopic insulation materials

Patrick Perre, Arnaud Challansonnex

The present work is focused on mass transfer characterization of hygroscopic materials used for insulation, such as Low Density Fibreboards. Due to their particular morphology, these panels present a very high mass diffusivity in the connected gaseous phase and a very low thermal conductivity. This combination of properties exacerbates the coupling between heat and mass transfer in transient state.
Based on experimental data obtained with an original set-up and relevant simulations performed using a comprehensive physical formulation, a throughout vision of this question is proposed in the present study. In particular, we emphasize on:
- The impressive change in core temperature in terms of magnitude and duration,
- The great impact of the internal temperature gradient, which slows down mass diffusion,
- The dramatic error on mass diffusivity value if the coupling is ignored.

Keywords: experiment; identification; modelling; RH at back-face; transient state.

#7885

A physical interpretation of the use of fractional operators for modelling the drying process

Patrick Perre, Ian Turner

Fractional order derivatives provide useful alternatives to their integer order counterparts due to their ability to model memory and other properties of the porous medium, such as nonlocal behaviour. These phenomena are driven by the constrained interactions within the complex and non-homogeneous microstructures evident at the pore scale.
In this work, we investigate the suitability of time and space fractional operators for modelling drying processes and provide a physical interpretation of these operators. At first, the concept and the general formulation in the case of a 1-D finite domain is summarised. Then a selection of simulations allowed us to analyse the physical effects of these operators on the solution. In particular, we elucidate:(I)the ability of these operators to break the fundamental relationship between mean square displacement and time in the simple example of diffusion in an open space, (ii) the caution to be taken with the formulation of boundary conditions and source terms to obtain consistent balance equations, (iii) the effect of fractional in space diffusion as a way to alter the MC profiles compared to standard diffusion, therefore potentially avoiding the dependence of the diffusivity on the variable

Keywords: Fractional Calculus; Transport in Porous Media; Finite Volume Method; Matrix Transfer Technique; Matrix Functions.

#8266
Designing an effective and optimized freeze-drying process for complex pharmaceutical formulations using "Temperature-Ramp" approach

Getachew Assegehegn, Edmundo Brito-de la Fuente, José María Franco Gómez2 Franco, Críspulo Gallegos

Freeze-drying, despite being cost-intensive drying process, is a well-established drying method used in pharmaceutical and biopharmaceutical industries. Its main purpose is to convert liquid formulations, which otherwise are unstable, into stable solid forms without compromising their pharmaceutical as well as therapeutic properties. The cost of the freeze-drying process can significantly increase if it is not properly designed and optimized. The design of freeze-drying processes is often approached by iteratively changing process parameters in a trial and error experimental plan. Consequently, this requires much longer time and often the resulting process is far from being optimized. The purpose of this study was to develop an approach that allows developing an effective and optimized freeze-drying process by examining formulation characteristics and different process parameters. A model multi-API complex pharmaceutical formulation was prepared for this purpose. Thermal analysis (DSC) was used to characterize the frozen formulation. The freeze-drying process was performed with a laboratory scale freeze-drier, in which product temperatures of front and center vials were measured using thermocouples. A novel experimental approach, known as "Temperature-Ramp", was utilized to study the effect of chamber pressure and shelf temperature on sublimation rate and heat transfer uniformity during drying. The results from the "Temperature-Ramp" experiments were scientifically analyzed to select chamber pressure and shelf temperature yielding the most optimized freeze-drying process. This study demonstrated that the "Temperature-Ramp" approach is an excellent method for a rational design of an effective and optimized freeze-drying process in a few steps for pharmaceutical formulations regardless of their complexity.

#8350

Theoretical and experimental investigation of temperature and moisture distributions and changes in nutritional quality during Intermittent Microwave

Imran Khan, Nghia Duc Pham, Azharul Karim

Intermittent microwave convective drying (IMCD) is an advanced drying system where a unique volumetric heating mode is facilitated. However, the physical phenomena of IMCD system and its effect on nutritional quality are not well understood yet. The aim of this research is to develop a coupled IMCD and quality prediction model and experimentaslly validate it. A coupled 3D mathematical model considering Maxwell's equation for electromagnetic heating, and reaction kinetics for predicting quality was developed and validated. COMSOL Multiphysics, engineering software was used to solve the developed model. It is found that IMCD significantly affect the nutritional quality during drying of apple tissue.

Keywords: Food material; Microwave; heat and mass transfer; Quality; 3D modelling.

#8353
Diffusion in organic double layer coatings

Sebastian Marius Raupp, Paul Kitz, David Siebel, Philip Scharfer, Wilhelm Schabel, Frank Kleine-Jäger

The field of organic electronics offers a broad variety of applications and has a big growth potential. The devices consist of several thin organic layers. State of the art is that these thin layers are deposited by vacuum evaporation. To lower the prices of the devices, wet film deposition techniques are favorable in terms of throughput and material efficiency.
A challenging issue for the wet film deposition of organic multilayers is intermixing. Intermixing is likely to occur due to high solvent contents (typically ~99% in organic electronic coating fluids) and the use of small molecules, resulting in high diffusion coefficients. The zones of intermixing which can be tolerated as well as the layers themselves are in the range of several nanometers.
In our work we develop a model to describe the intermixing of organic double layers. With the model the influence of drying conditions (variation of heat and respectively mass transfer coefficient) as well as solubility issues on the intermixing of the two layers can be described. The model is validated by experimental investigations with the inverse micro Raman spectroscopy (IMRS). Polymer double-layers are knife coated and the distribution of the single components within the double-layer is measured over time. This method is applied to different polymer-polymer-solvent systems, while changing composition to investigate the influence of solvent content on interdiffusion and drying behavior. Chain lengths of polymers are varied as well, as an increase of polymer chain length is expected to slow down interdiffusion kinetics.

Keywords: Diffusion, Raman spectroscopy, solution processed, knife coating, modelling, drying in organic coatings.

#8366
Temperature profiles in model food cylinders during microwave-vacuum heating

Nazmi İzli, Sundaram Gunasekaran, Ahmet Polat

The field of organic electronics offers a broad variety of applications and has a big growth potential. The devices consist of several thin organic layers. State of the art is that these thin layers are deposited by vacuum evaporation. To lower the prices of the devices, wet film deposition techniques are favorable in terms of throughput and material efficiency.
A challenging issue for the wet film deposition of organic multilayers is intermixing. Intermixing is likely to occur due to high solvent contents (typically ~99% in organic electronic coating fluids) and the use of small molecules, resulting in high diffusion coefficients. The zones of intermixing which can be tolerated as well as the layers themselves are in the range of several nanometers.
In our work we develop a model to describe the intermixing of organic double layers. With the model the influence of drying conditions (variation of heat and respectively mass The temperature distribution in two-percent agar gel cylinders was investigated during microwave heating under vacuum both experimentally, using a thermocouple, and theoretically according to the Maxwell's equations and the Lambert's law. The sample temperature increased with heating duration (2, 4 and 6 min) almost unaffected by the vacuum level (5.33, 8.00 and 10.67 kPa). The temperatures were slightly higher at both the sample center and edges than in the middle. These measured temperature profiles were more accurately predicted by the Maxwell's equations than by the Lambert's law, especially for heating durations of 2 and 4 min. A general linear model developed to predict sample temperature as a function of heating duration, vacuum level, and measurement location (the distance from sample center) was highly satisfactory ($R^2>0.991$) for all measurement conditions investigated.

#8545
Mathematical modelling of fluidised bed for drying heat sensitive compounds

Behdad Soltani, Timothy A.G. Langrish, John M. Kavanagh

We have developed a mathematical model for the fluidised bed drying of yeast to predict the bed temperature, exhaust air humidity, moisture content and drying time, and have validated the model by testing on a pilot-scale fluidised bed. The mathematical model has included mass and energy balances for the air and the solid bed, and the model has used GAB isotherm to estimate the drying kinetics. The range of experimental conditions covered inlet air temperatures from 40 to 80°C and bed temperatures from 10 to 60°C, while the moisture content decreased from 96 to 4% and the bed mass ranged from 400 to 600g. The comparisons between the model predictions and the experimental observations showed good agreement with 1.5°C and 2% differences in the bed temperature and the moisture content, respectively. The tested conditions were different inlet air temperature, mass flow rate and bed masses.

DRYING PRODUCTS

Oral Presentations

#7247
Effects of different drying conditions on curcumin concentration in turmeric

Qixin Li, Robert H Driscoll, George Srzednicki

Turmeric (Curcuma longa), belongs to Zingiberaceae family. The rhizomes contain bioactive compounds of the curcuminoids group (natural phenols). They are used in food and pharmaceutical industry. The aim of this research was to acquire dried turmeric with high total curcumin content. In this study, optimum turmeric drying conditions and new extraction techniques were explored. Fresh turmeric samples were subjected to constant vs changing drying air temperatures and pre-treatment (blanching). Changing drying air temperature and use of non-blanched turmeric slices resulted in the highest concentration of curcumin. Ultrasonic extraction instead of soxhlet extraction improved the extraction efficiency and decreased extraction time.

Keywords: Turmeric, Curcumin; Drying; Blanching; Extraction.

#7318
Electrically enhanced drying of white champignons

Ivanna Bashkir, Tadeusz Kudra, Alex Martynenko

Effects of convective cross-flow of air in electrohydrodynamic (EHD) drying on drying rate of 5 mm slices of champignons have been investigated. Electro-convection issued from discharge electrode (42 needles arranged into 6×7 rows with 2×2 cm spacing, 18 kV DC voltage and 3.5 cm gap) provided average ionic wind velocity of 1.0 m/s flowing perpendicularly to the surface of champignons slices, while forced air stream at atmospheric pressure 1000 kPa, superficial velocity 1.0 m/s, temperature 22-24°C, and relative humidity 25-40%, was blown parallel to the surface of champignons slices. To study interactions between forced air cross-flow and electro-convection, the experimental protocol was designed, exploring three cases in various combinations: (1) Sole EHD, (2) air cross-flow, and (3) EHD with simultaneous air cross-flow. The case # 3 was found to be the most efficient, resulting in □10.2 g/h of water evaporation whereas drying rate was 6.6 g/h (# 1) and □3.6 g/h for (# 2). Such numbers imply that these effects are additive. In some combinations the effect of air cross-flow was the same (3.6 g/g), but electro-convection was significantly suppressed to 3.2 g/h likely because air stream removed surface water, which reduced charge transfer and electro-diffusion.

In trials with different initial moisture content it was found that drying kinetics followed exponential decay in the wide range of initial moisture contents from 4.9 to 12.0 g/g (db). Drying rate due to forced air convection was found to be independent of moisture content, whereas drying rate due to electro-convection significantly depended on the moisture content. For example, the EHD drying rate of fresh-cut champignons slices with initial moisture content 10.74 g/g was 0.237 g/h, while the slices after two days in the cooler (initial moisture content dropped to 4.92 g/g) it was 0.418 g/h. Also, it was found that electro-convective drying could not remove all residual water. At the end of drying the equilibrium moisture content attained 0.2 - 0.3 g/g (aw~0.3).

It appears that performance of EHD drying depends also on the product porosity as water can exist as free in open pores or be trapped in closed pores. In some experiments we observed rotation of champignon slices in the plane perpendicular to ionic wind. It happened at the end of drying when slices were light enough to be lifted by electrostatic force and dragged by the vortex. This phenomenon could be attributed either to the effect of DC electric field on polarized water molecules trapped in closed pores, or it could be electrostatic effect of ionic wind on charged porous body. Also, the hypothesis that EHD has both linear and rotational (vortex) components require further investigation.

#7319

Influence of drying conditions on process properties and parameter identification for continuous fluidized bed spray agglomeration

Gerd Strenzke, Ievgen Golovin, Maximilian Wegner, Stefan Palis, Andreas Bück, Achim Kienle, Evangelos Tsotsas

Agglomeration is a particle formulation process in which at least two primary particles are combined to form a new one. The growth of agglomerates depends on interactions of particles covered with wet spots that generated by depositions of binder droplets. This work experimentally compares the influence of external feed rate and sprayed binder content on product properties and process stability with internal separation at different drying conditions. Due to the identification of parameters a populations balance model (PBM) is developed. The PBM includes the agglomeration kernel function, which characterizes the kinetics, i.e. the rate at which primary particles build agglomerates.

Keywords: spray fluidized bed agglomeration; drying; continuous process; internal separation; population balances.

#7323
Encapsulation of krill oil by spray drying

S. Takashige, A. H. Dwi, A. Sultana, H. Shiga, S. Adachi, H. Yoshii

An oil from Pacific krill (Euphausia pacifica) has a high content of PUFAs and phospholipids. The sediment was formed with homogenization of krill oil and maltodextrin (MD; dextrose equivalent (DE) = 19) solution using sodium caseinate, gum arabic, hydrolyzed whey protein or modified starch as a surfactant. Quillaja saponin could form the emulsion without the sediment. MD (28.5 wt%) was solubilized with distiller water (50 wt%) and mixed with krill oil (20wt%) and Quillaja saponin (1.5 wt%). The homogenized solution was spray-dried using Okawara-L8 spray dryer with a centrifugal atomizer. Spray-dried powder was evaluated in the oil-droplet size and surface-oil content.

Keywords: krill oil, emulsion, Quillaja saponin, spray drying, PUFAs.

#7328
Thin layer drying behaviour of fermented cocoa (Theobroma cacao L.) beans

Saheeda Mujaffar, Aveena Ramroop, Darin Sukha

To assess the impact of a rest interval and bean turning on the thin-layer drying behavior of fermented cocoa beans, beans of mixed Trinitario varieties were dried in a cabinet oven at three temperatures (40, 50, 60°C) using three drying regimes, namely; continuous drying, intermittent drying (drying for 8h with a rest period of 16h), and intermittent drying with turning of beans. Moisture content, water activity, pH and colour attributes were measured and sensory evaluation of the cocoa liquor carried out on selected samples. Drying curves were constructed and drying rate constants (k) and effective diffusivity (Deff) values determined.

Keywords: Oven-drying; Fick's Law; Rate constant; Diffusion coefficient

#7332

Microencapsulation of pumpkin seed oil by spray dryer under various process conditions and determination of the optimal point by RSM

Mansoureh Geranpour, Zahra Emam-Djomeh, Gholamhassan Asadi

The objective of this research was to microencapsulating the pumpkin seed oil (PSO) by the spray dryer and also investigating the effects of some process conditions on physicochemical properties of PSO microparticles. Inlet drying air temperature (140-180 °C), aspirator rate (55-75%), and peristaltic pump rate (5-15%) effects were studied. Moisture content (%W.b.), Microencapsulation Efficiency (MEE, %) and Peroxide value (POV, meq/kg sample) considered as model responses. Consequently, the ideal drying state for microencapsulation of PSO as a result of optimizing by Response Surface Methodology (RSM) determined with the aim of minimizing the Moisture content and POV and maximizing the MEE.

Keywords: Microencapsulation; spray dryer; pumpkin seed oil; optimization; RSM

#7356
Nano spray drying of pharmaceuticals

Cordin Arpagaus

Spray drying plays a crucial role in the processing of pharmaceutical products such as pills, capsules, and tablets as it is used to convert drug containing liquids into dried powdered forms. Nano spray drying is in particular used to improve drug formulation by encapsulating active ingredients in polymeric wall materials for protection and delivering the drugs to the right place and time in the body. The nano spray dryer developed in the recent years extends the spectrum of produced powder particles to the submicron- and nanoscale with very narrow size distributions and sample quantities in the milligram scale at high product yields. This enables the economical use of expensive active pharmaceutical ingredients and pure drugs. The present paper explains the concept of nano spray drying and discusses the influence of the main process parameters on the final powder properties like particle size, morphology, encapsulation efficiency, and drug loading. Application results of nano spray drying for the formulation and encapsulation of different drugs are reviewed.

Keywords: nano spray drying; pharmaceuticals; drug encapsulation; particle size; powder.

#7376

Acceleration of freeze drying by microwave application and by stabilized foamed matrices containing sensitive biomolecules with optimized retention of physiological activity

Peter Kubbutat, Ulrich Kulozik

To increase the shelf life of biogenic substances like proteins, antibodies, immunoglobulins or micro-organisms and to improve handling, such biomolecules are often preserved by freeze-drying, mainly in the presence of sugars as protectants. Freeze-drying has been well established as a very gentle process, maintaining high physiological activity of the substrates. However, it is highly time- and energy-consuming, and thus, often constitutes the main capacity bottleneck of the whole production chain. In order to change this situation, it is aimed at developing a new drying method allowing for the production of high-quality biogenic products in significantly reduced time.

Microwave freeze-drying offers the advantage of heating products volumetrically instead by contact heating. Consequently, heating happens more homogeneous and drying time is decreased drastically as compared to conventional freeze-drying. Nevertheless, microwave-related effects like edging, hot spot formation or heat accumulation may impair product quality. To overcome these problems and to further reduce drying time, the substrates to be dried can be incorporated into an aerated, protective matrix containing sugars as protectants. Surface active agents enable foam formation, whereas sugars promote foam stabilization and protection of the biomolecules.

Therefore, the aim of this study was a comparison between freeze-drying and microwave freeze-drying of biomolecules. Additionally, differences in the drying performance of solutions and aerated matrices were focused on. Owing to the larger surface area of an aerated product in comparison to a solution, it was expected that foams would dry faster due lower resistance to water vapor mass transfer. Furthermore, the hypothesis was that the heat stress per volume should be lower for the aerated matrices. Therefore, a higher nativity or activity of the biomolecules can be expected.

It was found that the application of microwaves during freeze-drying in pulsed mode allowed for a reduction of drying time from 32 h to less than 2 h. Despite this drastic reduction in drying time, no differences in physiological activity between freeze-drying with or without microwaves were detected. A certain the reduction of drying time was also achieved for the foamed matrices, but the impact of microwave heating was found to be the dominant effect for acceleration. However, due to less volumetric heat stress during foam drying, the physiological activity of the biomolecules contained in the matrix remained considerably higher in comparison to drying of the unfoamed solution. Concluding, fast and gentle drying of biomolecules is achievable using aerated matrices in combination with microwave assisted freeze-drying.

#7377
Evolution of "Chili" Tunisian landrace durum wheat sprouts properties after drying

Sarra Jribi, Hela Gliguem, Andras Nagy, Nagy Gabor Zsolt, Lilla Szalóki-Dorkó, Zoltan Naàr, Ildiko Bata-Vidàcs, Sarra Marzougui, Zsuzsanna Cserhalmi, Hajer Debbabi

Sprouting is a green technology contributing in improving cereals and pulses nutritional properties. However sprouts have a high water content limiting their shelf-life. This research focused on the impact of drying technology on physico-chemical, functional and nutritional properties of Tunisian landrace durum wheat (Triticum durum)"Chili" sprouts for their use as a functional ingredient. Three technologies were evaluated: lyophilisation, micro-wave vacuum drying and oven drying at 50°C. Sprouted seeds flour properties were significantly ($p<0.05$) affected by the drying methods used. Lyophilisation led to the highest preservation of bioactive compounds followed by micro-wave vacuum drying. The way of evolution of physico-chemical and functional properties depended on drying method used.

Keywords: Sprouts; drying; functional properties; bioactive compounds.

#7384
Cellulosic fibre drying: fundamental understanding and process modeling

Sabyasachi Mondal, Puja Agarwala, Suvankar Dutta, Vishvas Naik-Nimbalkar, Pratik Pande, Sunil Dhumal

Process modeling of conveyer dryer for cellulosic fibre drying demands many fundamental insights. Present study highlights detailed cellulosic fibre drying aspects like mass transfer correlation relating mass transfer rate with process conditions, normalized drying curve and critical moisture content. Cellulosic fibre drying follows falling rate period, where rate of mass transfer decreases with moisture content. Conveyer dryer process model for commercial cellulosic fibre drying was developed and validated successfully. Moderate drying strategy derived based on developed process model and drying fundamentals was deployed at commercial scale which helped in reducing the moisture variability.

Keywords: Cellulosic fibre, Conveyor dryer, Process Model, Sherwood number, Moderate drying.

#7387
Effects of pretreatment and drying methods on the quality of Amaranthus viridis leaves

Kehinde Adekunbi Taiwo

Leafy vegetables have also been found to alleviate the problems of micronutrients malnutrition that dominant in tropics. Amaranthus leaves contain 17.5 to 38.3% dry matter as protein of which 5% is lysine. They supply dietary fibre and are important sources of essential vitamins, minerals and trace elements. Particularly important are the antioxidant vitamins A, C, E and also contains phytochemicals (polyphenols, saponins, tannins and oxalates). The leaves of Amaranth viridis are high in moisture content and thus deteriorate rapidly. The objective of drying vegetables is to extend their availability for consumption or marketing purposes. The study evaluated the drying characteristics of Amaranth viridis leaves under different conditions, determined the physicochemical properties (Bulk density, pH), mineral composition (Ca, Na, Mg, K, P and Fe), vitamin C, and proximate composition (moisture, fat, fibre, ash, protein and carbohydrates) of the dried leaves and evaluated the sensory characteristics of the dried leaves.

The amaranth leaves were washed in water, sliced and divided into four portions. The first portion was unblanched. The second, third and fourth portions were blanched with 0.003% EDTA, 0.5%NaCl, and hot water respectively (70 ^{o}C, 3 min). Each of the portions were further divided into three each. The first and second portions will be oven-dried at 50oC and 70 ^{o}C while the third portion was sundried. The dried samples were milled and packed for analysis.

Sundried samples and samples blanched with EDTA had higher protein, fibre and ash content compared the other samples. Samples blanched with NaCl had higher mineral contents (Ca, Fe, Mg, K and Na) than samples blanched in EDTA, hot water or unblanched. Use of salts minimized nutrient loss to a maximum of 16%. pH and bulk density decreased as drying temperature increased. Vitamin C content was higher in sundried or unblanched samples. Blanched/chemically treated leaves had higher sensory scores for color but the unblanched or hot water blanched samples had higher scores for taste.

#7392
Drying of a synthetic human mucus: experimental study and modelling

Alexandra Buess, Benoit Haut

Despite the important research that has been done to help demystifying the complexity of the lungs, there is still need for a better understanding of the respiratory system. This would gain insights into the causes and possible treatments of pulmonary diseases such as asthma or cystic fibrosis (CF). This work mainly focuses on the mechanisms controlling the evaporation process of the human mucus. Knowing how the human mucus interacts with its environment under normal respiratory conditions and how its properties change during this interaction is a fundamental aspect within pulmonary research. An experimental in vitro study was established where synthetic human mucus of different hydration level were dried, to a certain extent, in a closed environment, with air of controlled temperature, humidity and velocity. During the drying process, the rate of evaporation and possible sol-gel phase transition were observed using a weighing device and an infrared camera. Changes in other physical properties such as the viscosity of the synthetic human mucus were measured before and after the drying. The results of the experimental study show that the evaporation rate of the mucus has a complex dependence upon its hydration level and the characteristics of the air. These results were consolidated and implemented in a previously developed computational tool aiming at characterizing the heat transfers and the evaporation of the water in the bronchial region of the lungs. This computational tool was further used, combined with literature results, to analyze the dynamics of the mucus balance in a healthy lungs, i.e. how the mucus balance is established in the different generations of the lungs, according to the different phenomena controlling this balance (water evaporation, absorption or replenishment by the epithelium and mucocilliary transport). The results show that the evaporation has a significant influence on this balance, especially in the first generations of the lungs. As a further step, this modelling approach should be extended to analyse the dynamics of the mucus balance in unhealthy lungs, in order to give new insights into some pulmonary diseases, such a cystic fibrosis.

#7400
Study and optimization of freeze-drying cycles of a model probiotic strain

Pierre Verlhac, Séverine Vessot-Crastes, Ghania Degobert, Claudia Cogné, Julien Andrieu, Laurent Beney, Patrick Gervais

This work is based on the experimental study of the freeze-drying process to understand the impact of numerous factors on the survival rates of a model probiotic strain of Lactobacillus casei type. With the aim to find out if cell density in the matrix and survival rates are linked, we have studied the location of the cells after freeze drying inside a porous matrix composed of a lactose basis with a polymer, the polyvinylpyrrolidone (PVP) in various amounts. The best survival rate were obtained at slow freezing rate for a formulation containing 5% (m/V) of lactose and 5% (m/V) of PVP.

Keywords: Freeze-Drying; Freezing; Probiotics; L. Casei ATCC 393.

#7520
Enhancing antioxidant property of instant coffee by microencapsulation via spray drying

Desi Sakawulan, Richard Archer, Chaleeda Borompichaichartkul

This study is aimed to improve the antioxidant property of instant coffee by using microencapsulation technique and spray drying. Concentrated coffee extract was mixed with Konjac glucomannan hydrolysate (KGMH) and Maltodextrin (MD). The mixture of coating material and coffee extract was then spray dried at 160 - 180 °C inlet air temperature and at 85-90 °C outlet air temperature. KGMH can preserve retention of phenolic compounds, DPPH scavenging activity and antioxidant activity of FRAP ($p<0.05$ of instrant coffee better than other treatment.

Keywords: Hydrolysed Konjac Glucomannan; Spray Drying; Microencapsulation; Instant Coffee, Antioxidant.

#7537
Ambient temperature drying of therapeutic protein solution with use of microwave

Takaharu Tsuruta, Takuma Ogawa, Ryosuke Abe, Hirofumi Tanigawa

High quality drying of therapeutic protein-solution is important in medical and pharmaceutical processing. Freeze-drying is mostly used, but it takes a long drying-time and causes damages of protein structures. In order to improve the drying quality, we propose a microwave vacuum drying performed at ambient temperatures under low-pressure conditions. We are focusing on the Parma-Zyme method for the evaporative drying of protein solutions such as egg white or lysozyme with vitrification. Circular dichroism (CD) spectroscopy is used to detect protein conformation changes due to the drying, and it is found that the ambient temperature drying can preserve the protein conformation.

Keywords: Microwave vacuum drying; Freeze-drying; Therapeutic protein; Egg white; Lysozyme.

#7544

Immobilization of Candida rugosa lipase on eco-friendly supports by spouted-bed technology: Use in the synthesis of isoamyl caprylate

Tales Alexandre Costa-Silva, Ana Karine Furtado Carvalho, Claudia Regina Fernandes Souza, Larissa de Freitas, Heizir F Castro, Wanderley Pereira Oliveira

Candida rugosa lipase (LCR) was immobilized on low-cost supports (by-products) and dried using a spouted-bed system. The yields of immobilized derivatives were in the range 61.5–78.7%. Lipase immobilized on rice husk showed the best results, presenting 94.1% of the original activity, followed by sugarcane bagasse (90.3%) and green coconut fiber (87.3%). Moisture content in the obtained powders varied between 4.7 and 5.6% and the water activities were in the range 0.21–0.35. Among all the tested biocatalysts for aroma production the lipase immobilized on rice husk showed the highest activity towards the formation of isoamyl caprylate (62.40 g.L-1).

Keywords: Spouted bed dryer; Enzyme dehydration; Enzyme immobilization; Enzyme stabilization; Aroma production.

#7593

Recent developments in functional bakery products and the impact of baking on active ingredients

Lu Zhang, Remko M. Boom, Xiao Dong Chen, Maarten A.I. Schutyser

Active ingredients can be supplemented into a bakery product to produce functional food. However, the preservation of the functionality of these active ingredients during baking remains a challenge for food industry. A deeper understanding of the underlying interactions between functionality and baking is highly desired for developing innovative functional bakery products with significant health benefits and high product quality. In this work, recent advances in the development of functional bakery products are reviewed. The interactions between the baking process and the functionality of the supplemented active ingredients are discussed and the perspective of future research is addressed.

Keywords: baking; active ingredients; probiotics; inactivation kinetics; functional food.

#7624
The effect of drying on the mechanical properties and structure of biodegradable films

Gabriela Silveira da Rosa, Sai Vanga, Yvan Gariepy, Vijaya Raghavan

The aim of this study was to investigate the effect of convective and vacuum drying on properties of biodegradable films. The film-forming solutions were prepared with bovine gelatin and carrageenan. The films solutions were dried in convective and vacuum dryers at temperatures of 40, 50 and 60 oC. The results of convective drying kinetics of biofilms showed a constant drying rate period followed by a falling drying rate period. The results of thickness showed dependence with moisture content present in films.Carrageenan films showed promising results, with high values of tensile strength and elongation for convective drying at 60 oC.

Keywords: gelatin; carrageenan; drying; biofilm.

#7629
The effect of pre-treatment on the texture of cranberries subjected to hybrid drying

Konrad Nowak, Magdalena Zielinska

Hot air drying of cranberries is time-consuming, mainly due to the presence of the natural wax surface layer, which is a barrier to heat and mass transfer processes. The hybrid convective-microwave-vacuum drying seems to be good alternative for drying of different food products. Also, the use of different methods of pretreatment before drying may significantly shorten the drying time. Nevertheless, they may also significantly change the material properties and result in various mechanical properties of dried berries and acceptable/unacceptable texture of final products. Thus, the aim of this study was to investigate the effect of sonication, freezing/thawing, and microwave-vacuum pre-treatment on the textural properties of osmo-dehydrated cranberries, osmo-convective dried and osmo-convective-microwave-vacuum dried cranberries. Six methods of pre-treatment, namely: (i) sonication (S), (ii) convectional freezing (F), (iii) convectional freezing preceded by sonication (SF), (iv) convectional freezing preceded by microwave-vacuum pre-treatment (MWVF), (v) cryogenic freezing (N), (vi) microwave-vacuum pre-treatment (MWV) were used before hybrid drying. To compare, raw, non-treated berries (R) were also subjected to drying. Texture Profile Analysis (TPA) was performed to evaluate textural properties of cranberries. Hardness, gumminess and chewiness of raw berries were 63.69 ± 1.92 N, 14.42 ± 0.63 N and10.23 ± 0.54 N, respectively, while hardness, gumminess and chewiness of raw berries subjected to hybrid drying were 18.30 ± 0.71 N, 0.68 ± 0.04 N and0.45 ± 0.03 N, respectively. N and MWV treatment had the most significant effect on the textural properties of non-dried berries. S treatment was found to be ineffective method of modification of textural properties of both non-dried and dried cranberries. Both F and N freezing treatment applied before drying caused dried fruits much harder, gummy and chewy than those dried without treatment. Hybrid drying preceded by MWV treatment produced berries with the lowest hardness, gumminess and chewiness. MWV treatment applied prior to convective freezing (F) of berries significantly affected the efficiency of convective freezing of texture modification of non-dried, osmo-dehydrated and hybrid dried berries. Dried berries subjected to MWVF treatment were few times harder (101.05 ± 8.20 N), gummy (4.22 ± 0.35 N) and chewy (2.07 ± 0.14 N) than other berries.

#7647

Influence of drying temperature and harvesting season on phenolic content, antioxidant activity and antiproliferative capacity in cancer cell models of olive (Olea europaea) leaf extracts

María Losada-Echeverría, Amani Taamalli, Vicente Micol, María Herranz-López, David Arráez-Román, Enrique Barrajón-Catalán

Poplyphenols are natural compounds that are associated with numerous health benefices. Olive leaf extracts are especially rich in polyphenols and have shown relevant biological activities as antioxidant and antitumoral activities.
Extraction techniques, including drying, have demonstrated their influence in extract composition and/or activities, but comparative studies are still scare or incomplete. In the present study, olive leaves were harvested in the different seasons and subsequently dried under different temperature conditions (25, 40, 60, 80, 100 or 120 ° C) before the extraction process, which was performed using the supercritical fluid extraction technique. The obtained extracts were then tested for their chemical composition and antioxidant and antitumoral activities. Chemical composition was analyzed by HPLC-Ms-TOF, antioxidant activity was measured using up to three different methods (FOLIN, TEAC and FRAP) and antitumoral activity was tested in three different tumoral cell lines form human breast and colon cancer origin. All data were analyzed using different statistical approaches to obtain the putative relationships between all the variables and their significance.
Results showed that there were different correlations between harvesting, chemical composition, drying temperature and biological activities and pointed out the high relevance of drying procedures on biological activity of natural compounds and extracts.

#7674

The effects of reducing the fat content and using of microparticulated protein on the physical, reconstitution and morphological properties of spray dried cheese powder

Muge Urgu, Figen Kaymak-Ertekin, Nurcan Koca

Cheese powder finds widespread use in instant soup mixes, beverage mixes, bakery (biscuits, cracker, cake), sauces, snacks, potato chips, pizza and pasta to improve both the flavor and mouthfeel of food products. They are more convenient to use than regular cheese due to their long shelf life and stability during long term storage. In recent years, production of reduced fat dairy products has increased because of increasing consumer trend. Hence, it has become necessary to produce low-fat cheese powder and to create the scientific background.

Fat is an important compound in dairy products because of the major role on the functional and rheological characteristics besides its emulsifying effect. In the previous study, it was determined that the low-fat cheese emulsion had higher viscosity and poorer flowability compared to full-fat emulsion, and the use of microparticulated protein in emulsion decreased the viscosity values resulting in a pumpable emulsion with higher drymatter. In this study, it was aimed to evaluate the effects of fat reduction and microparticulated protein use on the physical, reconstitution and morphological properties of powder.

Three different white cheese powders (full-fat, low-fat and low-fat with microparticulated protein (Simplesse)) were produced by spray drying. In cheese powder production, firstly white cheese emulsions were prepared and then cheese slurry was dried using pilot plant spray drier at 174°C of inlet drying temperature, 354 kPa of atomization pressure and 68°C of outlet drying temperature. After production, quality parameters such as densities (particle, bulk and tapped bulk), reconstitution properties (solubility, dispersibility, wettability), free fat content and particle morphology were investigated.

The moisture contents and water activity values of all powders were lower than 3% and 0.2, respectively. The cheese powder produced using low-fat cheese had significantly lower free fat and solubility values, and it became wettable in shorter time compared to full-fat counterpart. The use of microparticulated protein affected the powder chracteristics in different ways. The values of dispersibility, wettability and free fat of powder with microparticulted protein were in between the values of full-fat and low-fat powders, but it had higher density values. The surface of low-fat powder were usually wrinkled due to the high casein content and low level of surface fat. Addition of microparticulated protein altered the morpholoy of powder and reduced the particle size and the wrinkle formation, which was similar to full-fat powder. In sensory panel, the flowability of all powders were observed as almost the same.

#7687
Hot-air drying of garlic slices enhanced by surface contacting ultrasound

Yang Tao

This abstract was aimed at studying the effect of surface contacting ultrasound treatment on the convective drying kinetics and quality properties of garlic slices. For this purpose, garlic slices were dried at different ultrasound intensities (216.8, 902.7 and 1513.5 W/m2) and temperatures (50, 60 and 70 oC). Surface contacting ultrasound significantly accelerated the garlic drying process. Compared with non-ultrasound treated samples, the drying time of garlic samples sonicated at 1513.5 W/m2 was shortened by 35.0% at 50 oC, 48.5% at 60 oC and 50.0% at 70 oC. A diffusion model considering shrinkage pattern was numerically solved to simulate the mass transfer process. According to the modeling results, both water effective diffusivity and external mass transfer coefficient were enhanced when garlic samples contacted ultrasound directly during drying. Meanwhile, internal water diffusion was more affected by contacting ultrasound. Regarding quality properties, the differences in contents of thiosulfinate and total phenolics and antioxidant capacity among hot-air dried garlic slices with and without contacting ultrasound processing were small. However, contacting ultrasound had a positive effect on the preservation of organosulfur compounds in garlic slices during drying. The browning problem of garlic products during hot air drying was also alleviated if contacting ultrasound treatment was performed. Moreover, no over-heating problem was observed during surface contacting ultrasound assisted drying within the selected experimental range. Overall, surface contacting ultrasound can be a promising technology to enhance the convective drying process of garlic slices and improve the quality of dried garlic products.

#7694

Investigation of influence of pre-treatment and low-temperature on drying kinetics, sorption properties, shrinkage and color of brown seaweeds (Saccharina Latissima)

Ignat Tolstorebrov, Trygve Magne Eikevik, Inna Petrova, Yulia Shokina, Michael Bantle

Drying kinetics of Saccharina latissima (raw and blanched) at low temperatures (10.0, 25.0 and 38.0 °C) was studied. The effective moisture diffusivity coefficient varied due to temperature alterations in the range between 1.4 and 4.5 10-10 m2/s for raw and 0.91 and 2.56 10-10 m2/s for blanched seaweeds. Significant changes in structural properties and chemical composition resulted in a much longer drying time of blanched seaweeds, when compared with raw. Drying temperature of 38.0 °C resulted in more brown color, when compared with other samples. Sorption characteristics of dried raw seaweeds depended on salt content and showed high accumulation of moisture at relative humidity of air of 80.0 %. The blanched seaweeds showed linear accumulation of moisture within increasing of relative humidity of drying air from 20.0 to 80.0 %, but high level of hysteresis was determined between sorption and desorption isotherms. The shrinkage development within dewatering of blanched and raw samples was also studied.

Keywords: brown seaweeds, drying kinetics, sorption isotherms, color.

#7722
Microencapsulation of curcumin by spray drying and its stability

Özgün Köprüalan, Işıl İlter, Saniye Akyil, Mehmet Koç, Figen Ertekin

Curcumin, an active ingredient in turmeric, is an important yellow-colored natural substance used in foods. Curcumin, a pigment that is soluble in organic solvent, has low solubility in water and is sensitive to heat, light and oxidants. Low stability to environmental conditions and water-solubility limit the use of curcumin in foods. Microencapsulation technology is a method to solve these problems and to improve the solubility and stability of the curcumin structure.
In this study, physical and chemical properties of microencapsulated curcumin powder produced through spray drying and its stability under light and dark conditions with different temperatures (4, 25 and 50°C) and different pH values (3.5, 4.6 and 7) were investigated. The effect of core material to wall material ratio (1:5, 1:10), inlet temperature of spray drying (180°C, 190 °C) and coating materials ratio (carbohydrate to protein) (25:75, 50:50, 33,3:66,7) were also examined on microencapsulated curcumin powder. The results revealed that the microencapsulated powder produced 1:5 core to wall materials ratio had the lowest moisture content, water activity, bulk and tapped density, highest solubility, wettability, hygroscopicity, b* and Chroma values and microencapsulation efficiency. When compared the effect of coating materials on microencapsulated curcumin powder, the powder obtained with maltodextrin and whey protein isolate had lower moisture content, dispersibility, wettability, hygroscopicity, a*value and Hue value . Although the microencapsulation efficiency values of maltodextrin and whey protein isolate, as coating materials were lower than those of gam arabic and whey protein isolate, their results for physical properties were better. In terms of curcumin storage stability, microencapsulated curcumin powder produced with 1:5 core to wall materials ratio, 49.5 % maltodextrin+49.5 % whey protein isolate as coating materials and 190°C inlet temperature of spray drying showed better stability under 4°C and dark conditions.

Keywords: Curcumin, Spray Drying, Microencapsulation, Stability, wall materials.

#7723
Drying of insects and larvae: towards valorization into high-value functional proteins

Hedi Romdhana, Samir Mezdour

The current global context of food market and protein consumption is dominated by a degradation of the environment, an increase of the density of population and a rarefaction of the agricultural and natural resources available for their productions. In spite of the deep interest for insects, as natural resources rich in proteins with high efficiency on their productions, scientific and technological steps have to be raised before to be incorporated as protein ingredients in human food formulation or even in animal feeds

Concerning transformation, insects must undergo a series of treatments in order to make them fit for industrial use. Of utmost importance is the need to master the quality and supply of the raw material (selection, development stage, insect diet), as well as operating conditions necessary to obtain end-products showing the desired features

The drying process is a necessary step to stabilize the fractionated insects or to standardize them before industrial treatment.However, the drying step is often a real bottleneck for the whole production line. This limitation of productivity, combined with the decisive impact on the quality of the dried insects, requires research and development efforts that are still substantial.

The drying process has also the particularity of being one of the strongest consumers of energy, because it is carried out in the majority of the cases by the thermal way. It is therefore essential to optimize the operating conditions of drying in order to obtain a better quality of the finished product and a high-energy performance. For example, the control of the drying temperature is important for thermosensitive products such as insect larvae. High temperature may improve the dryer efficiency (ratio of the heat of evaporation to the heat put into the dryer), but may cause also thermal degradation or burning of the drying product.

The overall objective of this study is (a) to conduct experimental characterization of the drying of pressed larvae using a lab scale rotary dryer, and (b) to develop a mathematical model for a co-current rotary dryer, to predict the temperature and the moisture profiles of the drying gas and the feed pressed larvae along the length of dryer. Ultimately, this study will provide a basic tool for simulating the drying of insect larvae and for optimization purposes.

#7744
Stabilization of encapsulated probiotics from the bacterium Lactobacillus casei by different drying techniques

Elsa Maritza Acosta-Piantini, M. Carmen Villaran, J. Ignacio Lombraña

The main objective of this work is to encapsulate and dry the bacterium probiotic Lactobacillus casei applying three different drying techniques (lyophilization, fluidized bed and flash freeze drying) as well as to evaluate their viability during storage in the dark at 20ºC and 34% relative humidity for 28 days. In addition, to compare viability of the bacterium processed with flash freeze drying with cryoprotectant (skim milk) and without cryoprotectant.
In the case of flash freeze drying, the final level of viability shows the potential of this drying technique with much less operating costs than lyophilization.

Keywords: Encapsulated, probiotics, lactobacillus, casei, drying.

#7770
Comparative study of the drying of extracts proceeding the olive by means of liofilization and spray-drier

Elia Ana Sirvent, Luis Torró, Carmen Veciana

Currently there is a growing demand for ingredients with natural antioxidants. In particular, the polyphenolic extracts under study come from the olive sector (olives, bone, leaves, brines ...), which is why they have a high antioxidant power.
Throughout the production of polyphenolic extracts, variables such as humidity, antioxidant activity and total polyphenols are controlled to standardize the production of these extracts. All of them in addition to the tests to determine the biofunctionality of these extracts.
Once the extraction process is ready, the need to preserve the stability of the antioxidant compounds is considered. The high reactive capacity of the extracts with antioxidants as well as their organoleptic characteristics make it necessary to use preservation processes that are compatible with these factors.
In this sense drying techniques are used mainly by lyophilization and by atomization that allow an adequate drying as well as an encapsulation that let the extracts stable storage over time. In addition to be able to these extracts for incorporation into food matrices, it is necessary to make a coating or encapsulation of them.
The processes of spray drying and lyophilization are suitable techniques for the preservation by microencapsulation of the antioxidant compounds of polyphenolic extracts. Thus, with the optimization of the parameters of these processes, it is possible to obtain stable extracts in terms of their useful life, quantifying for this: % moisture, antioxidant activity and total polyphenols.
Maltodextrin and gum arabic, both widely used in food, are used as encapsulating wall materials. In the lyophilization process, the following variables are studied: Emulsion process of the active material with the encapsulating material: high pressure microemulsion; freezing curve; and vacuum conditions on camera. In the process of spray drying the following variables are studied: Emulsion process of the active material with the encapsulating material: high pressure microemulsion; air intake temperature; and input flow of the product to be dried.
The objective of the study is to find the optimal encapsulation conditions to ensure the stability of the antioxidant capacity, as well as the rest of the properties of the extract during drying and its subsequent storage, in both encapsulation processes and to carry out a comparative study of the obtained results of the dried extract in each technique.

Keywords: extracts, antioxidants, microencapsulation, lyophilization, spray-drier.

#7794
Coupling of microwave radiations to convective drying for improving fruit quality

N. Bahloul, M. A. Balti, M. S. Guellouze, N. Kechaou

The present study aims to find the best drying method to minimize the duration of the operation while respecting the nutritional value of the product. Experiments of convective drying and microwave radiation were respectively carried out with a convective dryer (heat temperature: 65 °C and air velocity: 1.3 m/s) and a microwave oven (power level: 100 W and frequency: 2450 MHz). Six coupling tests between the convective drying and microwave radiation were conducted. The only variable condition is the time output of tomatoes from the convective dryer or the microwave oven corresponding to an intermediate mass ratio (IMR) 0.5, 0.4 and 0.3. The microwave drying removes the bound water faster than convective drying. This explains the observed time savings due to convection-microwave and microwave-convection combined drying. The combination of convection drying and microwave drying to an IMR 0.5 preserved better the red color and the antioxidants of the tomato. Thus, the convection–microwave combined drying (IMR 0.5) proved most suitable for preserving the quality of tomatoes.

Keywords: convective drying; microwave; coupled drying; color.

#7810
Comparison of individual effect of heat transfer mechanism in solar conduction dryer

Bhaskar Thorat

Solar conduction dryer (SCD) is a unique technology that uses conduction, convection and radiation mechanism of heat transfer making it one of the most efficient system. The present work unearths the quantitative comparison of individual effect of mode of heat transfer on drying rate. The SCD is one of the most effective piece of equipment and it has tremendous potential to capitalize in India and other erstwhile nations of tropical region where there is abundance of solar insolation. The most cost-effective dryer which runs on no electricity has already made inroads in the global market. In the present study, experiments were carried out to study dominance of mode of heat transfer mechanisms. Simulations was also carried out in order to compare with experimental results. The order of influence of mode of heat transfer mechanism can be said as conduction followed by radiation and then convection. Convection has the least impact on material drying. These results indicate that, by addition of conduction mode of heat transfer mechanism in earlier dryers (conventional) either by re-engineering the existing dryers or all together replacing them with high energy efficient solar conduction dryer.

#7872

Ohmic heating/vacuum impregnation treatments on osmodehydrated apples enriched in polyphenols from concentrated pomegranate juice

J. Moreno, P. Zúñiga, M. E. Guerra, K. Mella

The aim of this work was to study the combination of osmodehydration (OD), coupled with Ohmic Heating (OH) and Pulsed Vacuum (PV) and to introduce natural compounds from a cryoconcentrated pomegranate juice (47°Brix) at 30, 40 and 50 °C into apple matrix, during 180 min. PV was performed at 50 mbar for 5 min at the beginning of the process and OH generates an electric field of 6.6 V/cm. The results indicated that treatments reduced water content and increase polyphenol content of apples, evidencing that the osmotic treatment improve mass transfer, especially when they are applied together at higher temperatures.

Keywords: Ohmic heating; pulsed vacuum; cryoconcentration; enriched; pomegranate.

#7876
Valorization of the tomato to obtain a powder rich in antioxidant constituents

Djamel Mennouche, Abdelghani Boubekri, Bachir Bouchekima, Slimane Boughali, Rebiha Moumeni, Djihad Boutadjine

The tomato (Lycopersicon esculentum), widely consumed fresh fruit but also in processed form, is recognized for its nutritional qualities, rich in micro components, such as carotenoids (lycopene in particular), phenolic compounds and vitamin C.
The goal of this work is to valorize the tomato; in the form of paste, seeds, peel and mixture of seeds-peel; in order to obtain a powder rich in antioxidant constituents. Convective drying of the various tomato by-products (paste, seeds, peel and mixture) is an essential process in the valorization of the studies products. The results obtained, showed that our analysed samples are rich in phenolic compounds. The mixture seeds-peel has slightly higher total polyphenol content (190.65 mg EAG / ml), peel (157.36 mg EAG / ml), seeds (140.56 mg EAG / ml) and the paste (120 mg EAG / ml).
The evolution of the color of dried by-products (method L, a, b), shows that the mixture (seeds-peel) has a better result of parameter "a" (indicates the red color and signifies the presence of Lycopene).

Keywords: tomato, drying, antioxidant, polyphenols.

#7878
Effect of solar radiation on cooking/drying process of grapes using solar oven

Jannika Bailey, Marta Castro-Giráldez, Alfredo Esteves, Pedro J Fito

Solar ovens have become a very popular technology for cooking, specially, in underdeveloped countries where access to firewood is scarce, time consuming and expensive. The benefits of solar cooking are multiple, such as saving money, as this device requires no fuel, as well as having an important impact in the environment, decreasing carbon dioxide emissions and decreasing deforestation.
One challenge for food industry is to get to know the behaviour of food cooked with solar technology. The aim of this study was to model the drying process of white and red grape in solar oven using thermodynamics and spectrophotometry measurements, controlling the irradiation effect blocking the Ultraviolet radiation using a polarized vinyl film

Keywords: sun radiation; thermodynamics; solar oven; drying.

#8351
Microstructural characterization of apple tissue during drying using X-Ray microtomography

M. M. Rahman, M. M. Billah, M.I.H. Khan, A. Karim

This study aims to investigate the complex microstructural changes in plant-based food materials during drying by using X-ray micro-computed tomography (X-ray µCT) along with the image analysis. The apple samples were dried at 60 °C and tested using X-ray µCT at different stages of drying. The porosity, cell and pore size distribution were determined from the micro-CT data set. It was observed that significant changes in porosity, cell and pore size distribution take place at different drying times and moisture contents. X-ray µCT can serve as a very promising tool to elucidate the evolution of the food microstructure during the drying process.

Keywords: Food drying, characteristics, X-ray microtomography, nondestructive evaluation.

#8374
Rotary wheel atomizer study using computational fluid dynamics and full-scale testing

Tórstein Vincent Joensen, Maximilian Kuhnhenn, Frank Vinther, Mads Reck, Cameron Tropea

This study models the internal fluid flow from the center to the edge of a rotary atomizer wheel, the flow out of the atomizer, including the film, rivulet and ligament formation, as well as the subsequent atomization process associated with the atomizer outflow using computational fluid dynamics with a volume of fluid approach.

The model shows how fluid exits through the overflow and not through the bushing at high inlet fluxes and can reproduce experimental results of power consumption. Furthermore, the drop-size distribution at a given distance from the bushing exit is in good agreement with experimental results.

Keywords: Spray drying; Rotary Atomizer; CFD; Droplet size; Volume of Fluid.

DRYING PRODUCTS

Poster Presentations

#7256
Morphology studies of salt deposits from drying sessile droplets

Franziska Sophia Sondej, Mirko Peglow, Andreas Bück, Evangelos Tsotsas

The drying behavior of solid containing water droplets has attracted significant scientific interest in the last years. The solids, which are colloidal particles or soluble salts, form characteristic deposit structures according to the conditions during the drying process. The drying of single droplets has been investigated from various viewpoints to gain insight on factors that have a significant impact on the structure formation. This study presents new approaches to investigate the structure of deposit resulting from drying of solid containing micro droplets. It is shown that drying conditions influence strongly the final structure, the so called "footprint" as well as the internal porosity. This dependency may contribute to better understanding of particle-forming processes, such as fluidized bed coating. Sessile droplets containing sodium benzoate dissolved in water were dried on thin glass plates in a small drying chamber. The drying conditions (temperature, moisture content and flow rate of drying gas) and material parameters (solid content of solution) were systematically varied [1]. The final 3D shape of dried sessile droplets was measured using white-light interferometry and X-ray micro-computed tomography. By comparison of structural information and process conditions it is shown that the drying process may have a large influence on deposit structure. Additional thermogravimetric measurements reveal special characteristics of the used solid.

Keywords: drying of solid containing droplets, sessile droplets, micro-structure analysis, white-light-interferometry, X-ray micro-computed tomography.

#7277

Solar drying of strawberry coated with nopal mucilage: It's effect on phenolic compounds

M.J. León,, A. López-Ortiz, F.I. Pilatowsky, L.L.L. Méndez

The objective of this study was to evaluate the effect of indirect solar drying (ISD) and conventional (CD) (40, 50, 60 °C) on the concentration of phenolic compounds of strawberry slices, coated with opuntia mucilage (Opuntia ficus indica), and measured with the spectrophotometric method. The indirect solar dryer uses solar-thermal and photovoltaic technology with temperatures between 40 and 60 °C. The concentration of anthocyanins was higher in the ISD than in CD. The strawberry coated with the nopal mucilage has a preservation of phenolic compounds in CD and IDS.

Keywords: strawberry, solar drying, phenolic compounds

#7307

Optimization of the spray drying process for the obtaining of coconut powder (Cocos nucifera L.) fortified with functionally active compounds

J. C. Lucas-Aguirre, G. Giraldo, R. M. Cortes

The objective of this work is to contribute to the generation of a significant advance of the coconut agroindustry in Colombia, for which the process of spray drying was optimized to obtain coconut powder added with functionally active components (CP+PAC) (calcium and vitamins C, D3 and E), food that is framed in the context of functional foods. Initially, the behavior of the physicochemical properties of the coconut during storage at a temperature of 25ºC was evaluated. Then the base emulsion was designed, determining the influence of the composition of emulsions based on coconut milk, on its physicochemical stability, the answer surface methodology was used with a central composite design, considering the independent variables: water/coconut ratio; xantan gum; coconut fiber; terbutilhidroquinona. Subsequently, it was experimentally optimized according to the operating characteristics of the dryer and the product, using a response surface design based on five independent variables: Maltodextrin, air inlet temperature, air outlet temperature, atomizer disk speed and vacuum pressure in the drying chamber. Finally, the stability of the PC+PAC properties was evaluated, using a factorial design based on the independent variables: storage temperature, storage time and packaging.

Keywords: coconut, colloidal system, deposit formation, yield, vitamins.

#7322
Agglomeration of hydrolyzed collagen with blackberry pulp in a fluidized bed

Thayna Rua Viegas, Osvaldir Pereira Taranto

Hydrolyzed collagen (HC) is a fine powder applied in the pharmaceutical and food industries which has shown good results in the treatment of diseases related to bones, skin and joints. In this study, HC particles were agglomerated in order to increase particle size, optimizing its use as a food ingredient, its handling and storage. Agglomeration is a process that not only enlarge the size of fine particles, but also improves its properties, such as instatanization time and flowability. The aim of this work was the agglomeration of HC in a fluidized bed having blackberry pulp as liquid binder. A full factorial design 22 was used to study the effect of the temperature of the fluidizing air (60, 70, 80ºC) and the flow rate of the liquid binder (0.8, 1.2, 1.6 mL/min) on the process yield, mean particle size, water activity and total anthocyanins content. It was observed that anthocyanins content from the blackberry pulp had higher values with lower temperature. Water activity had lower values with higher temperatures, but in all conditions it was lower than 0.6. The enlargement of the granules was observed in all conditions studied, increasing up to 275%. Process yield varied from 67,9 to 80,0%. In all conditions, the instantanization time and flowability improved compared to hydrolyzed collagen before agglomeration.

Keywords: hydrolyzed collagen; agglomeration; granulation; fluidized bed; blackberry pulp

#7357

Effect of phospholipid composition on the structure and physicochemical stability of proliposomes incorporating curcumin and cholecalciferol

Matheus Andrade Chaves, Samantha Cristina Pinho

Proliposomes are dry phospholipid-based particles in which bioactives can be entrapped, and that can produce liposomal suspensions if adequately hydrated. In our study, curcumin and cholecalciferol were incorporated in proliposomes obtained by coating of micronized sucrose. Different mass ratios of Lipoid S40 and Phospholipon 90H were used to produce the proliposomes. The powders were structurally characterized and bioactives content were analyzed over 60 days of storage. Curcumin and cholecalciferol amounts in F100CV formulation were 100 and 98.7% of their initial amount, respectively. Strucutral characterization showed bioactives were successfully incorporated in concentrations compatible with recommended daily dosages.

Keywords: proliposomes, curcuminoid, vitamin D3, Raman spectroscopy, powder characterization.

#7374
Drying characteristics and drying quality of pineapple slices using a pulsed vacuum drying process

Jun Wang

In current work, the drying kinetics and quality of dried products (color and rehydration capacity) was investigated using a pulsed vacuum drying. The results showed that the shortest drying time was obtained at the vacuum pressure duration of 15 min, ambient pressure duration of 3 min and temperature of 75 oC. Products dried at temperature of 75 oC maintained the light-yellow color and high rehydration capacity. The moisture diffusion coefficient of pineapple (Deff) under various process were calculated by Fick's second law, ranging from 5.95×10-10 to 1.45×10-9 m2/s. Activation energy(Ea) of pineapple was 41.11 kJ/mol by Arrhenius equation.

#7398
Experimental characterization and modeling of the drying of Kampot pepper (*Piper nigrum L.*) in Cambodia

Elen Morm, Benoit Haut, Sokneang In, Frédéric Debaste

Thermal drying is an operation that involves removing water from a product, by supplying heat. This operation is generally used to increase the shelf life of food products and to reduce their transportation costs.
In Cambodia, most agricultural products and meats are sun-dried in order to increase their shelf life. Kampot pepper is a product of protected geographical origin. It is one of the most cultivated and most exported spices of Cambodia. Pepper (Piper nigrum L.) is mainly used for enhancing food flavor and taste. Beside this, this spice is also used in popular medicines since decades, due to its bioactive compounds, including flavonoid and phenolic compounds, vitamin C and piperine. The latter is an active alkaloid molecule known to provide diverse pharmacological activities. For instance, it has been shown that this molecule is anti-inflammatory, anti-diarrheal and antihypertensive1,2.
Traditionally, Kampot peppercorns are sun-dried for 4 to 5 days, depending on weather conditions. Although Kampot pepper has already been extensively studied, there has been little study of the influence of drying on the nutritional properties of the seeds and on their bioactive compounds. Therefore, the objective of this work is to conduct a detailed study to better understand the physical and chemical phenomena taking place within the seeds during their drying. For this, we have developed a laboratory experiment where peppercorns are continuously dried under controlled conditions. The measurement of their weight and their visualization with a camera during the drying give us information on their drying rate and on the change of their morphology during the drying. The experimental results are consolidated within a phenomenological model of the drying kinetics of the seeds. On the other hand, we also carry out partial drying (until different final product humidities), in order to analyze the evolution over time of the concentrations of certain bioactive compounds in the seeds during drying. These bioactive compound concentrations are determined by using HPTLC (High Performance Thin Layer Chromatography).

#7399
Monitoring of the evolution of several physicochemical parameters of Amazonian cocoa beans during their drying

Christelle Herman, Justine Fauvieau, Benoit Haut

During the drying of cocoa beans, physical and chemical transformations take place. These have a considerable influence on the quality of the chocolate that will be produced from these beans. Accordingly, the objective of this work is to study the influence of the drying temperature on the evolution over time, during drying, of several physicochemical parameters of cocoa beans. Prior to drying experiments, some physical characteristics of the beans were analysed (moisture content, dimensions and mass of their different parts, i.e. the core and the shell). The drying experiments were conducted on a laboratory convective dryer, using 20 Amazonian cocoa beans during each experience. The velocity, the temperature and the humidity of the drying air were continuously monitored and controlled during the experiments. The total mass of the beans was measured every 20 minutes, using an analytical balance. These measurements were used for the calculation of the moisture content (X) and the evaporation rate (J) of the cocoa beans, both defined on a dry basis. Two different drying temperatures were analyzed (35 and 50ºC). For each of the two selected temperatures, 5 experiments were realized. Each of these experiments was stopped at a different value of X (0.64, 0.49, 0.28, 0.12 and 0.07). At the end of the experiments, the beans were collected and several of their physicochemical parameters were measured: dry matter, pH, color and polyphenol content (Total Phenolic Content and Procyanidin Content). Due to the fact that drying experiments were realized until different final values of X, the results obtained for a parameter can be plotted as a function of X, for each drying temperature. This allows understanding the evolution of this parameter during the drying. Several conclusions can be drawn from the analysis of the results. For instance, the polyphenol content and the CieLAB color parameters of the beans are continuously and significantly increasing during the drying, but it appears that the temperature has a limited influence on these evolutions. The pH of the beans is almost constant when they are dried at 35°C, but it is monotonically increasing when the beans are dried at 50°C. Regarding the drying kinetics, it appears that the drying can be divided in two phases, with different dynamics. It can be demonstrated that, during the first phase, the water is mainly removed from the shell, while, during this second one, the water is removed from the core by diffusion.

#7404
Effect of different drying processes on mass transfer, color properties and chemical composition of physalis peruviana pulp

Luis A. Puente, Antonio Vega-Galvez, Alexis Pasten, Ivette Fuentes, Elsa Uribe

Physalis peruviana is a native berry from South American Andes. One of the distinguishing characteristics of this type of berries is its typical yellow-orange color that depends on the presence of carotenoid pigments, regarding to its chemical composition a high content of vitamin C is highlighted. The aim of this work was to use different drying treatments in order to obtain a stable powder from physalis peruviana to be used as functional ingredient. Drying methods used includes forced air (60 °C and 80 °C) as the standard drying most used for processing fruits and vegetables, moreover infrared assisted drying was used (60 °C and 80 °C assisted with 500 Watt of infrared energy) and finally and as a reference of the best quality drying method freeze-drying was performed. General chemical composition (proximate analysis) and color properties (L*, a*, b*, ΔE, h* and C*) where measured to evaluate the effect of the different used drying methods. Regarding to drying kinetics all the drying curves presented an exponential decay shape and drying times to reach a 10% of moisture in dried samples varied from 690 to 450 minutes, the lower times were obtained for 80 °C and 80 °C + infrared assisted, for the case of 60°C 690 minutes and 630 minutes in the case of infrared assisted. With regard to the proximal chemical composition, as expected, the method that best preserves the chemical composition of the dried fruit pulp was the freeze drying process, on the other hand the hot air and infrared drying methods presented similar results without observing significant differences between the treatments. Regarding the color properties, freeze drying showed a value of ΔE close to 0, for the rest of the treatments the total color difference varied between 8.34 for drying at 60 ° C and 13.98 for 60 ° C assisted by infrared. The highest values of L * were presented for lyophilized samples (70.43), in the case of hot air and assisted by infrared the values were around 60. The value of a * varied from 14.22 for drying by hot air at 80 ° C up to 18.7 for the case of freeze drying and drying at 60 ° C, regarding the value of parameter b * a greater variability was observed.

Keywords: functional ingredients, drying kinetics, infrared assistedfrom the shell, while, during this second one, the water is removed from the core by diffusion.

#7407

Drying of Iranian seedless barberry (*Berberis vulgaris L.*) in microwave assisted fluidized bed drier

Morteza Rashidzadeh, Gholamreza Askari, Zahra Emamdjomeh

Black seedless barberry was dried in microwave assisted fluidized bed drier. In order to evaluate and predict the effects of drying variables including air temperature (45, 60 and 75°C) and intensity of microwave power (0, 300 and 600W) on physicochemical characteristics of dried fruits, response surface methodology (RSM) was used. The effect of foregoing factors on drying time, water activity (aw), anthocyanin content (ACC), total phenol content (TPC), antioxidant activity (AA) and rehydration capacity (RC) were evaluated. According to obtained and calculated results, ACC, AA and TPC of dried samples were affected by process variables. Microwave heating could reduce drying rate and enhanced the AA of dried samples. Similar results were obtained in the case of TPC of dried samples.

#7413
Physical properties of commercial infant milk formula products

Eoin G Murphy, Nicolas E Regost, Yrjo H Roos, Mark A Fenelon

The physical properties of 12 commercially available infant milk formula (IMF) and follow-on (FO) powders were assessed. Polarised light micrographs of powders revealed that two types of powders existed: Type I - homogenous mixtures of milk powder particles and Type II – heterogeneous mixtures of milk powder particles and tomahawk-shaped a-lactose monohydrate crystals. Conventionally employed correlations between particle size, flowability and compressibility were found to be highly dependent on the presence of crystalline lactose in powders. Overall, results showed the importance of micro-structural evaluation during analysis of physical properties of dairy powders and, in particular, IMF/FO powders.

Keywords: max. Infant formula; microstructure; physical properties.

#7428

Drying kinetics and mechanical properties of the black spruce (Picea mariana (Mill) B.S.P.) wood using a vacuum and mechanical pressure process

Kamel Ben Dhib

The objective of this paper was to study the effect of temperature and vacuum on the drying kinetics and the mechanical strength of the black spruce wood (Picea mariana (Mill) B.S.P.).A total of 140 green wood boards of the black spruce were dried in four tests successively using a vacuum and mechanical pressure process. Results show that increasing temperature and vacuum decreases the drying time. A good homogeneity of wood moisture after drying is found, 95% of the dried boards showed moisture contents in the range between 6% and 8%. Mechanical properties of dried wood boards such as modulus of elasticity (MOE) and the modulus of rupture (MOR) in static bending of wood samples belonging to four grades (construction, utility, economy and standard) classified according to the National Lumber Grade authority of Canada were influenced by the vacuum and temperature used in drying. Weibull statistics theory was applied to find the probability of rupture of wood material as function of stress state for the four studied drying schedules. Temperature was the most important parameter which affects the mechanical properties during vacuum dryings.

Keywords:Drying kinetics, black spruce, wood, moisture content, Vacuum, temperature, mechanical properties,Weibull statistic theory.

#7448

Encapsulation efficiency and physical properties of pink pepper oleoresin (*schinus molle l.*) spray dried with prebiotics carriers

Soraia Vilela Borges, Jayne Abreu Figueiredo, Pedro Henrique Campelo, Regiane Victória Barros Fernandes Botrel, Diego Alvarenga Botrel

Schinus molle L. also known in Brazil as aroeira is widely distributed in the Brazilian territory most present in the regions of Atlantic Forest. From its fruit (pink pepper) and extracted an oleoresin that presents different therapeutic properties with antioxidant, antimicrobial and anti-inflammatory potential, due to the presence of polyphenols such as apigenin, ellagic acid, naringin and ursolic acid present in the plant extract. However the oleoresins are susceptibility to oxidative, thermal and luminous degradation, and an alternative of promoting the retardation these undesirable reactions is microencapsulation by spray drying using carrier agents. The objective of this study was to evaluate the use of prebiotic biopolymers as encapsulating materials in the physical and encapsulation efficiency of pink pepper oleoresin microencapsulated by spray drying. The biopolymers used were whey protein isolate (WPI), inulin (IN) and oligofructose (OL) ratios of WPI (1:1), WPI / IN (4:1) and WPI / OL (4:1). There was no significant difference between the samples for the analysis of moisture (1.37 - 2.03%), water activity (0.08 - 0.09), solubility (90.42 - 90.88%), bulk density (0.16 - 0.17 g.cm^3) and tapped density (0.28 - 0.29 g.cm^3). The microparticles produced with WPI/IN and WPI/OL presented lower wettability time (31 and 33s), respectively, compared to the treatment with WPI (68s). Encapsulation efficiency were 89% for the WPI and 84% for the WPI/IN and WPI/OL. These results indicate that the incorporation of the biopolymers also promotes high encapsulation efficiency of compounds and the addition of prebiotic biopolymers together with whey protein isolate is a good alternative to add functional value to the pink pepper oleoresin microparticles and contribute to consumer health.

#7449
Relaxation of ceramic tile stresses generated by fast drying: a kinetic model

J. L. Amorós, V. Cantavella, E. Blasco

Unfired tile mechanical properties are very important in the ceramic tile manufacturing process. Inadequate mechanical properties lead to rejects (both in unfired and fired tiles). Unfired tile mechanical strength changes significantly after the tiles exit the industrial dryer. This behaviour can be explained by assuming that the fast-drying process generates stresses in the tile, which subsequently relax. A kinetic model has been derived, based on Maxwell's viscoelastic elements, which explains the development of dried tile mechanical strength. This increases asymptotically when the dried tiles are stored in dry conditions. However, if tiles adsorb humidity (upon exiting the dryer), tile mechanical strength rises and then decreases. This is the result of two opposing phenomena: stress relaxation raises mechanical strength while the concurrent rise in moisture content lowers mechanical strength. The developed model successfully describes this joint mechanical behaviour.

Keywords: ceramic tiles, fast drying, stress relaxation, kinetic model.

#7452

Fixed-bed drying of grains: analysis of the structural properties of packed-beds of non-spherical particles

Heitor O Nogueira Altino, Maria do Carmo Ferreira

Structural properties of packed-beds of non-spherical biological materials were investigated. The particles tested were oats, lentil, barley and soy, with sphericity ranging from 0.4 to 0.8. Porous alumina particles with sphericity of 0.98 were also included. The particles dimensions and sphericity were measured under moisture content ranging from the equilibrium up to 24% (dry basis). Mean voidage, bulk density, permeability and tortuosity of the packed-beds were obtained in the whole moisture range. The data were used as input into a correlation to predict Sherwood numbers under constant air velocity and the results were compared to evaluate the influence of packing characteristics on convective mass transfer.

Keywords: Sphericity; Permeability, Tortuosity, Fixed-Bed Dryers.

#7459

Comparison between maltodextrin and inulin on the physical properties of the extract of green corn powder

Soraia Vilela Borges, Gerson Reginaldo Marques, Rhana A. R. Teodoro, Diego Alvarenga Botrel, Regiane Victória B. F. Botrel

Green corn powder extract is a good alternative to reduce its perishability and can be used in different food products. Spray drying is a promising and suitable method for thermosensitive substances such as food, due to fast contact time and low temperatures at which they are exposed. The objective of this work was to evaluate the physical properties of dehydrated green corn extract using maltodextrin (MD) and inulin (IN) as carrier agents. A univariate experimental design (control, MD and IN) with three replicates was used, evaluating moisture content, solubility, color parameters, particle size distribution and morphology. Moisture content was higher with inulin (1.8g / 100g dm). Solubility increased with the use of these hydrophilic carriers (97g / 100g dm). Regarding the color parameters, the MD promoted powder of greater luminosity (89.4). The use of MD and IN increased the chroma (18.9-17.8) and hue angle (85.9-87), respectively. Smaller particle size was obtained with the use of inulin (17.0μm). Spherical, smooth and very agglomerated particles were found for all products. Due to a few differences in these properties related to appearance and reconstitution it is recommended to use inulin, which is a prebiotic, to add nutritional value to this product.

#7460
Effects of ozone pretreatment on drying kinetics and quality of Granny Smith Apple dried in a fluidized bed dryer

Thatyane Vidal Fonteles, Ronnyely Braz Reis do Nascimento, Sueli Rodrigues, Fabiano Andre Narciso Fernandes

Fluidized bed drying is a method for controlled and mild drying of wet
This study aimed to evaluate the effects of ozone pretreatment on drying of green apple carried out in a fluidized bed dryer to determine drying kinetics and identify operating parameters for improved product quality. Results reveal that drying temperature in different levels affected water diffusivity and retention of bioactive compounds. The ozone pretreatment showed unexpected results since the pretreatment reduced the water difusivity and promoted an increase in the enzyme activity. The treatment time strongly afftected the final polyphenoloxidase and peroxidase activities. On the other hand, the ozone treatment resulted in lower color changes compared to non-ozone treated dried apples.

Keywords: diffusivity; polyphenoloxidase; enzymatic browning; ozone.

#7461
Effects of assistance of high frequency dielectric and infrared heating on vacuum freeze drying characteristics of food model

Atsushi Hashimoto, Ken-ichiro Suehara, Takaharu Kameoka, Kazuhiko Kawamura

By combining vacuum freeze drying combined with high-frequency dielectric and/or infrared heating, the drying time for frozen gels containing 1% agar with sucrose or sodium chloride was successfully shorten, and the drying time was influenced by the heating methods and by the additive component to the sample. Additionally, it was experimentally confirmed that the power consumption for freeze drying combined with electromagnetic wave heating could be reduced because of the shortened drying time. Consequently, this study could be a very important step for designing a vacuum freeze drying process optimally combining electromagnetic wave heating for each sample component.

Keywords: freeze drying, electromagnetic wave heating, food model, sucrose, sodium chloride.

#7462

Estimation of the apparent glass transition temperature of spray-dried emulsified powders and yeast powders by their flavor release behavior under temperature ramping conditions

A. Sultana, J. L. Zhu, H. Yoshii

Flavor release from powders depends on the glass transition temperature (Tg) and water absorption. This study reports a simple method to estimate the apparent Tg by aroma sensing upon flavor release from spray-dried powders. Four different wall materials (maltodextrin (MD), MD blends with fructose at 20 and 40wt%, and yeast cells) were used to encapsulate flavors by spray-drying. The apparent Tg valuesof MD and MD with 20 and 40wt% fructose were determined as 130, 110, and 75 °C, respectively, similar to those calculated by the Gordon–Taylor equation. The slow flavor release from dried-yeast powder afforded the highest Tg.

Keywords: yeast; flavor; encapsulation; spray drying; aroma sensor.

#7477

Hot air drying combined vacuum-filling nitrogen drying of apple slices: Drying characteristics and nutrients

Xiaoli Huang, T. Li, S.N. Li, Z.H. Wu, J. Xue

In this paper, hot air drying (HAD) was applied when moisture content of apple slices range from 50% to 86%, and then vacuum-filling nitrogen drying (VFND) was used till moisture content reaching 7%. Results showed that, the drying rate of apple slice during VFND period increased with temperature increment and decreased with increment of slice thickness; compared to freezing dried samples, samples dried in this research were owned lower Vc and higher flavonoid; when HAD (70℃,3.0m/s)+VFND(relative pressure 0.08MPa, 50℃) and thickness of 6.0mm, nutrients reached better levels: retentions of Vc, total phenolics and flavonoid were 1.63mg/100g, 4.07mg/100g and 2.10mg/100g, respectively.

Keywords: apple slices, hot air drying, vacuum-filling nitrogen drying, drying rate, nutrients.

#7478
Bioavailability of freeze-dried and spray-dried grapefruit juice vitamin C

María del Mar Camacho, Marta Igual, Juan José Martínez-Lahuerta, Nuria Martínez-Navarrete

An alternative as to offer higher stable and easy handling than fresh fruit is in powdered form, as long as the process used to obtain it ensures a high quality product. The objective of this study was to compare the bioavailability of the vitamin C of a juice prepared from powdered grapefruit obtained by freeze-drying and by spray-drying. A trial was conducted with 11 healthy volunteers. A relative increase of 1,4 – 25,8 % of blood serum vitamin C concentration was quantified after juices intake, with no significant differences ($p>0.05$) due to the process used to obtain the powder.

Keywords: vitamin C; bioavailability in humans; grapefruit powder; freeze-drying; spray-drying.

#7479
Economic feasibility of freeze-drying to obtain powdered fruit

María del Mar Camacho, Miguel Ángel Casanova, Loreto Fenollosa, Javier Ribal, Juan José Martínez-Lahuerta, Nuria Martínez-Navarrete

Fruit is a highly valuable food whose consumption should be encouraged. In addition, it would be desirable to design processes and products to channel the surplus and take advantage of the post-harvest losses that limit its fresh marketing. Freeze-drying is a known industrial process that permits the obtaining of high quality products, despite having always been labeled as very expensive. In this study, the economic feasibility of freeze-drying to obtain powdered fruit has been proven, as it yields a product more than twice as cheap as when obtained by spray-drying, recognized for its low cost.

Keywords: freeze-drying; spray-drying; economic profitability; production costs.

#7480
Influence of freeze-drying conditions on orange powder flowability

Mariana Usganda, Andrea Silva, Luis Egas, María del Mar Camacho, Nuria Martínez-Navarrete

Freeze-drying may be a good alternative to get less perishable fruit products. The objective of the present study was to evaluate the impact of freeze-drying conditions of an orange puree on some flow related and rehydration properties of the obtained powders. The results showed that the application of heat during freeze-drying does not affect the parameters studied. However, the partial dehydration of the initial sample results in a lesser porosity and wettability values.

Keywords: freeze-drying; porosity; wettability; angle of repose; particle size distribution.

#7481
Impact of shelf temperature on freeze-drying process and porosity development

L. A. Egas-Astudillo, A. Silva, M. Uscanga, N. Martínez-Navarrete, M. M. Camacho

The freeze-drying kinetics and the superficial porosity development of grapefruit puree. The impact of biopolymers addition (gum Arabic and bamboo fiber) and to apply (40 ºC) or not shelf temperature (room temperature) was considered. To increase the shelves temperature during freeze-drying allowed to an important drying time reduction and doesn't supposed a lower porosity related to the collapse development of the structure. Biopolymers do not affect the drying kinetics. From this results, biopolymers addition and to heat at least up to 40 ºC during grapefruit freeze-drying should be recommended.

Keywords: freeze-drying; shelf temperature; drying kinetics; image analysis; pore size distribution.

#7486

Determination of the moisture content of white and yellow corn from ohaji in imo state of nigeria using the dry-weight technique

Offurum Julius Chigozie

The water content determination of two maize species (Yellow corn- and White corn-) located at Ohaji in Imo State of Nigeria were considered in this study. This was motivated by the regular reported cases of the seed post-harvest spoilages, especially in the local communities. And the moisture content of a particular seed could vary according to the various location of crop, presumably due to the soil texture. The moisture content of a given crop seed can influence its storage value, as well as its choice of selection during manufacturing processes. It was, thus, necessary to determine the moisture content of the two maize species (white and yellow corn) from Ohaji in Imo State of Nigeria, in order to identify their dispositions, especially during storage. Modified High Constant Temperature Oven method, as prescribed by the International Seed Testing Association (which involves preliminary pre-drying and grinding), was employed, at a temperature of 102oC. This involved the use of dry-weight technique, which is expressed as a percentage of the dry weight of the seeds. The procedure for each sampling was replicated accordingly, and the mean value identified as the actual result. The moisture content for Sample A (white corn) was found to be 31.7%, while that of Sample B (yellow corn) was found to be 21.5%, which shows that the yellow corn would always have longer storage value than the white corn. As any change in the seed moisture content has a way of affecting its storage life, it is advisable not to store the white corn longer than it could be applied in the yellow corn for a better storage value.

Keywords: Determination, Moisture Content, White Corn, Yellow Corn, Dry-weight Basis.

#7487

Effect of saccharide additives on dehydration–drying kinetics and quality properties of dried kiwi fruit products

Shigeaki Ueno, Rei Iijima, Mari Harada, Hsiuming Liu, Reiko Shimada, Ken Fukami

The effects of saccharide additives on the dehydration and drying properties as well as the quality properties of dried kiwi fruit products were investigated. Sliced kiwi fruits were soaked and dehydrated in citric acid, glucose, sucrose and the pH-adjusted sugar solutions, individually. Osmotic dehydration and drying kinetic parameters were calculated using exponential models. Drying rate constants and water activities of dried kiwi fruits with osmotic dehydration were superior to those without osmotic dehydration. Soaking solutions with a lower pH led to a decrease in lightness. However, soaking sokution pH had no significant effect on the water activity or drying kinetics.

Keywords: drying; kinetics; kiwi fruit; osmotic dehydration.

#7488
Effects of freezing-thawing on drying kinetics and enzymatic reaction in soybean

Shigeaki Ueno, Natsuko Iryo, Shoji Sasao, Tetsuya Araki, Gab-soo Do

Drying kinetics and enzymatic reactions in frozen-thawed soybean cotyledons were investigated. Freezing induces injury on food materials due to the destruction of cell membranes and diminishes food quality. Many factors contribute to the destruction of cell membranes, one of which is mechanical stress due to volume changes caused by ice crystal formation. Objectives of this study were to investigate the effects of freezing on drying kinetics and gamma-aminobutyric acid (GABA) production reaction in soybean cotyledons. Water-soaked (including anti microbial agent) soybeans were frozen at –20, –80 or –180oC, and thawed samples were stored at 20oC for 3 d. To investigate the internal structural destruction of frozen-thawed soybeans, we estimated the drying rates of water vapor. From the time course of water content (g-water g-d.s.-1) during drying process of soybeans, drying rates (g-water m-2h-1) and diffusion coefficients of water were estimated at the selected water content. The drying rates of soybean cotyledons frozen at -180°C increased as compared to other freezing conditions. From the degree of cellular destruction by microscopic observation and dielectric measurements, more soybean cells were destroyed at lower freezing temperatures (higher freezing rates), and therefore, the diffusion coefficient of water increased according to the degree of cellular destruction. Particularly, the diffusion coefficient of water in frozen-thawed soybeans at -180°C was significantly higher as compared to other temperatures. The cellular structure of soybean cotyledons frozen at -180°C was heavily destroyed, and thus glutamate, substrate of GABA, dissolved in the cellular solvent would be widespread inside the soybean cells. GABA content in water-soaked and frozen-thawed soybeans increased rapidly during storage rather than untreated ones. Drying kinetics and GABA production kinetics in frozen-thawed soybeans indicated that GABA generation was promoted by the increase in apparent glutamic acid decarboxylase activity.

Keywords: Drying, Enzymatic reaction, Freezing, Kinetics, Soybean.

#7490
Drying of wastes of almond shells in conical spouted beds

Maria J San Jose, Sonia Alvarez, Raquel Lopez

The goal of this study was to prove the feasibility of a conical spouted bed dryer for the drying of wastes of almond tree fruit. The drying operating regimes ranges in sspouted beds contactors were determined. The drying tests were conducted in the spouted bed regime under determined experimental conditions. Beds consisting of almond shells were dried at drying air temperatures ranging from room temperature to 140 ºC. The drying behaviour was assessed based on the decrease in moisture content of almond shells with the time and the effect of drying air temperature on the drying process was analyzed.

Keywords: Almond shells wastes; conical spouted beds; biomass wastes; drying.

#7496
Effect of air drying temperature on phytochemical properties of brown seaweed Bifurcaria bifurcate

Santiago Vilas Arufe, Jorge Sineiro, Francisco Chenlo, Ramón Moreira

The purpose of this study was to determine the effects of convective air-drying at different temperatures (35, 50, 60 and 75°C) on the color of Bifurcaria bifurcata (BB) seaweed powders obtained after milling, the antioxidant activity and polyphenolic and carbohydrate content of the aqueous extracts obtained by ultrasound-assisted extraction. BB seaweed powders exhibited significant color differences between powders obtained from BB dried at 35ºC (yellowish-green) and 50–75 °C (brown). High air drying temperature (above 60ºC) significantly reduced the total polyphenolic, carbohydrate content and scavenging activity of aqueous extracts of BB.

Keywords: Phaeophyceae Antioxidant activity Carbohydrates Color Polyphenols.

#7514
Comparison on conductive drying technologies for drying of milk

Jun Qiu

Drying is one of the most energy consuming industrial unit operations. Spray drying is the traditional applied drying technology for milk products. This convective drying technology has lower energy efficiency compared to conductive drying methods, such as drum drying (Devahastin and Mujumdar 2006). It is reported that drum drying consumes on average 40% less energy, due to the lower energy loss via exhaust gas (Nindo and Tang 2007). Only few studies applied conductive drying to milk products (Daud 2006). We compared four selected conductive drying technologies, namely regular double drum drying (DD), vacuum drum drying (VDD), refractance window drying (RWD) and agitated thin film drying (ATFD) for drying of reconstitued milk solutions at varying drying conditions, i.e. drying temperatures and product types (skim milk and whole milk). After each drying process, samples were collected and milled for further analysis, i.e. colour, moisture content, water activity, free fat content (for whole milk), solubility and powder morphology. Comparison is made to spray dried powder as the benchmark. DD, VDD and RWD provided skim milk powders. Distinct differences in colour and appearance of dried films and particles between the different technologies were observed. For each technology also feed composition and drying conditions were varied, which could be related to varying moisture content of the final powder. Whole milk powders showed less well reconstitution behaviour than skim milk powders. The whole milk powders had relative high free fat, which probably released due to the milling after drying. Results obtained give insight in the different milk powder quality obtained by the conductive drying technologies.

#7516

Hot air and microwave-vacuum drying kinetics and quality of cranberries as influenced by pretreatment , hot air temperature and microwave power

Magdalena Zielinska, Danuta Zielinska, Marek Markowski

The aim of this study was to evaluate the effect of convectional and cryogenical freezing as well as hot air convective drying (HACD) and microwave vacuum drying (MWVD) on the drying kinetics and physicochemical properties of whole cranberries (Vaccinium Macrocarpon). The effect of air temperature (60, 70, 80, 90 °C) and microwave power (100, 150, 200, 300, 450, 500 W) on the total phenolic content (TPC), total flavonoid content (TFC), total monomeric anthocyanins (TMA), ferric reducing antioxidant power (FRAP), lightness (L*), redness (a*), yellowness (b*), total color difference (ΔE*), total saturation difference (ΔC*), total hue difference (ΔH*), hardness (H), gumminess (G), chewiness (Ch), cohesiveness (C), and springiness (S) was evaluated. HACD and MWVD of whole cranberries took from 310 ± 5to 11700 ± 5 and from 8.0 ± 1.0 to 91.0 ± 2.0 minutes, respectively. During HACD and MWVD of whole cranberries, the initial DR was from 1.76 x 10-3 to7.37 x 10-2 kg H2O/kg DM/min and from 0.09to 0.90 kg H2O/kg DM/min, respectively. HACD consisted of two distinctive falling rate periods, while MWVD consisted of constant and falling drying rate periods. The values of De of HACD cranberries were in the range from 0.04 x 10-10 to 2.37 x 10-10 m2/s, while that of dried by MWVD were in the range from 0.06 x 10-10 to 2.98 x 10-8 m2/s. MWVD produced dried snack foods of much higher nutritional value, more desired color and crispy texture than HACD. The content of bioactive compounds and their antioxidant activity were related to the presence of oxygen, drying time and microwave power. Berries subjected to MWVD at relatively low microwave power i.e. from 100 to 300 W were characterized by the highest redness and yellowness. MWVD was found to be good alternative to produce dried snack food products of hard and crispy texture, tolerant of manufacturing, packaging, storage and delivery stresses, while HACD produced brittle fruits difficult to store and transport with some limitations in their direct consumption. Convectional freezing before drying improved the appearance and consumer acceptance of MWVD berries. Cryogenical freezing combined with high temperature HACD adversely influenced the drying rate and moisture transport during HACD and resulted in unacceptable or suboptimal overall appearance of dried cranberries.

#7518
Effect of spray drying conditions on antioxidants activity, flavonoids and total phenolic compounds of stevia rebaudiana

Irene Chaparro-Hernández, Juan Rodríguez-Ramírez, Lilia L. Méndez-Lagunas, Luis Gerardo Barriada-Bernal

In this work the spray drying of the fresh stevia leaves aqueous extract without encapsulating agents was carried out. The effect of the inlet air temperature (160-200 ºC) and the feed flow rate (2-3 kg/h) on the total phenolic content, the total flavonoid content and the antioxidant capacity were evaluated using Folin-Ciocalteau, aluminum chloride and DPPH methods respectively. The inlet air temperature had a significant effect on all parameters evaluated that showed a decrease when increasing the inlet air temperature, the feed flow rate had a significant effect on total flavonoids content and the antioxidant capacity, by increasing the feed flow rate the inhibition of the DPPH radical decreased and the total flavonoid content increased. The treatment at 160 ºC and 3 kg/h retained highest total flavonoid content and the antioxidant capacity.

Keywords: Phenolic compounds, stevia, spray drying, antioxidant capacity.

#7519
Effects of drying conditions on the content of glycosides and antioxidants of packed bed of stevia leaves

Juan Rodríguez-Ramírez, Beatriz Noyola-Altamirano, Luis Gerardo Barriada-Bernal, Lilia L. Méndez-Lagunas

The commercial value of stevia dehydrated leaves is related to the content of glycocides and their appearance. The present work approaches the effect of packed bed drying conditions (temperature, flow rate and solid loading) on glycosides and antioxidants activity of stevia leaves of Morita II variety. Diffusion coefficient was calculated. The drying times ranged between 34 and 160 minutes, the temperature was the most significant factor followed by solid loading and flow rate. Drying increases the concentration of antioxidants, stevioside and reduces rebaudioside A.

Keywords: drying, packed bed, stevia rebaudiana, glycosides, antioxidants.

#7529

Experimental investigation of internal pressure during drying of highly shrinking materials using celeriac root as an example

Robert Adamski

The aim of this work is to investigate transport mechanism of moisture and evolution of internal pressure during convective drying in air of celeriac root which is an example of highly shrinking solid.
Samples of cylindrical form of 20 mm in dia., 60 mm long were cut with a tubular dice from a celeriac root in axial direction. They were dried in a wind tunnel at 40°C, 50°C, 60°C and air velocity of 1 m/s. The tunnel is a closed loop consisting of two arms 2000x250x250 mm each, thermally insulated, equipped with air circulating fan, heater, humidifier and flow equalizer. It has two double-glazed doors on opposite walls for sample placing and observation.
The installed measuring equipment includes air temperature and RH measurement. Sample measurements are performed on two identical samples, one is placed on a rotating tray continuously weighted by electronic balance for mean MC measurement, the other is stationary with embedded thermocouples and pressure sensor needles. Both samples are insulated at both ends with acrylic glass-styrofoam disks to insulate against heat/mass transfer to make the case close to 1D. A considerable shrinkage was monitored with a digital camera hooked up to the data acquisition system.
On the basis of the measured mean MC, solid temperature, internal pressure and sample dimensions, using a mass transfer model with uniform shrinkage, the model parameters were identified in an inverse problem formulation and solution. Consequently, differences in pressure evolution of highly shrinking and non-shrinking solids were described and commented.

#7530
Effect of ultrasound on drying kinetics of El Henna leaves (*Lawsonia inermis*)

Said Bennaceur, Lyes Bennamoun, Antonio Mulet, Belkacem Draoui, Juan A. Cárcel

In this work the influence of some process variable on drying rate of henna leaves was studied. For this reason, henna leaves were dried (1 m/s) with and without ultrasound application at three temperatures, 40, 50 and 60 °C. As can be expected, the higher the temperature the faster the drying process. Ultrasound application increase drying rate at every temperature tested. Drying kinetics were modeled by using different experimental models. Weibull model provided the best fit for henna leaves drying kinetics.

Keywords:Ultrasonic; Weibull model; henna leave;, temperature.

#7554
Spray drying of lipid nanosystems (SLN and NLC) loaded with Syzygium aromaticum essential oil

Debora Morais Rosa, Wanderley Pereira Oliveira

A quality by design approach was used to investigate the influence of formulation composition and spray drying conditions on physicochemical properties of redispersable lipid based nanosystems loaded with Syzygium aromaticum essential oil. Four critical independent variables were studied: presence or absence of the liquid lipid oleic acid (0% - 1%), of the cationic surfactant CTAB (0% and 1%), inlet drying temperature (60 ºC -80 ºC), and ratio of the drying aids (ADJ) regarded to total formulation constituents weight (1:1 and 2:1). Resuls showed the production of spray dried redispersable lipid systems loaded with essential is feasible under very restrict conditions.

Keywords: Encapsulation; lipid systems; essential oil; spray drying; redispersable.

#7561
Decontamination of dried red pepper powders pretreated by cold plasma

Deng Li Zhen, Zhang Qian, Ji Xian Wei, Zhang Xiao Lin, Gao Zhen Jiang, Xiao Hong Wei

Red pepper powders have a high microbial load, and can been spoiled with human pathogens, which cause foodborne diseases. This study was aimed to evaluate decontamination effects of cold plasma on microorganisms (total viable count, yeasts, molds and Salmonella enterica) and quality (color, red pigments, antioxidant capacity) of dried red pepper powders. Naturally contaminated powders, and with Aspergillus flavus and Salmonella enterica inoculated ones were treated using an atmospheric plasma with power of 750 W. The results showed that, cold plasma treatment can significantly reduce the microbial flora of the dried powders. Total viable count, yeasts, molds, A. flavus and S. enterica were reduced by 4.5, 2.7, 2.3, 2.5 and 4.8 log, respectively, after 30 min plasma treatment. Weibull model well fitted the survival curves of the microbe with goodness of fit (R2> 0.95). What's more, the treatment didn't significantly influence the powders color, red pigments and antioxidant capacity. The cold plasma have demonstrated the potential to inactivate the microorganisms and maintain the quality of dried red pepper powders.

#7568
Ultrasound assisted osmotic dehydration of persimmon

Hamza Bozkir, Ahsen Rayman Ergün, Gülhan Metin, Emine Serdar, Taner Baysal

Drying is one of the oldest methods of food preservation and the most common technique. The drying provides longer shelf-life and smaller space for storage. The aim of this study was to determine the effects of ultrasound application on the osmotic drying of persimmon. Osmotic dehydration removes water from the fruits and vegetables which are introduced into the concentrated solution. Osmotic drying reduces the energy input and provides the desired product quality obtained. Ultrasound is used as a pretreatment which enhances the activity of osmotic dehydration method. Ultrasound assisted osmotic and osmotic drying treatments were applied to persimmon samples at 30°C by using sucrose solution. The sample of the cubed persimmons was then placed directly into the ultrasonic bath containing sucrose solution 45 °Brix (sucrose solution to fruit ratio was 4:1). The ultrasound pretreatment was performed during 10, 20, and 30 min at 30 °C (480 W and 35 kHz).
When the °Brix of fruit- sucrose solution was in equilibrium, persimmon samples were taken from 45 °Brix solution transferred to 70 °Brix solution. All applications groups were put into shaking incubator at 100 rpm except osmotic dehydration (control group). The resulting samples at 60 °C and 1.5 m/s air velocity dried in the tray dryer. Ultrasound assisted osmotic drying applications increased the water loss, sugar gain, weight loss but the processing time was reduced compared to the control group. The ultrasound assisted osmotic drying application (30 min) increased the effective diffusivity at 60 °C and 1.5 m/s air velocity compared to the control group. The ultrasound assisted osmotic drying applications preserved better the quality characteristics of samples such as the total phenolic content, L*, a*, b* and the acidity in comparison with the control group.

Keywords: Persimmon, osmotic dehydration, ultrasound, quality.

#7573

Influence of drying conditions on chemical characteristics of the essential oils from lemongrass (*Cymbopogon citratus (DC) Stapf.*) and orange (*Citrus sp.*) peels

Gabriela Cunha Bonilha, Carmen Boyaciyan, Gustavo Nakamura Alves Vieira

Essential oils are substances which are obtained from plants submitted to hydrodistillation or steam distillation processes. Their chemical and biological properties are widely explored in many industrial sectors, such as food and pharmaceutical products. Considering that they are obtained from plants, drying processes might aid on reducing water activity, hence increasing their availability by reducing eventual seasonality. On the other hand, the increased temperature in drying processes might affect the essential oil compostition and hydrodistillation yield. In this context, the objective of this work was the analysis of the influence of drying process variables (temperature and drying time) on the hydrodistillation yield (in terms of mass of oil per mass of dried material submitted to the process) and essential oil composition. Lemongrass (Cymbopogon citratus (DC) Stapf.) and orange (Citrus sp.) peels were chosen for this work, due to the fact that the essential oils from these plants are widely used in food products. Response surface methodology was used for the analyses of the inlet variables on hydrodistillation time. Essential oils were analyzed in a gas chromatograph coupled to a mass spectrometer (GC-MS), in order to evaluate their composition.

#7576
Influence of drying mode on physical and thermal properties of fish protein hydrolysates

Inna Petrova

Fish protein hydrolysate produced from cod leftovers was dried in a spray dryer equipped by nozzle atomizer. The temperatures of drying were 100, 130 and 150 °C. The change in water content and water activity affected by drying process were analyzed for the liquid and dried hydrolysates. Final dried hydrolysate was evaluated by different scanning calorimetry in order to analyze thermal properties in respect to three drying temperatures. Glass transition temperature and amount of unfreezable water were measured and compared. A conclusion about the influence of drying mode on the quality of the final hydrolysate was made.

#7600
Effect of rehydration on texture properties of Mexican plum (*Spondias purpurea L.*) dehydrated by tray drying and freeze drying

Paulina Guillen-Velazquez, Cinthia Muñoz-López, Denis Cantu-Lozano, Guadalupe Luna-Solano

Mexican plum (*Spondias purpurea L.*) is a fruit with high nutritional content. Freeze and tray drying increases its shelf life, however non-reversible changes may ocurr. Properties as rehydration capacity and texture are considered as a measure of the injury to the material caused by drying. In this sense, the objective of this research was to evaluate the texture profile of dehydrated plum during rehydration and compare it with properties of raw plum. Freeze drying provided a product with less tissue damage reflected in the high rehydration capacity and texture characteristics very close to original unlike those dehydrated by hot air.

Keywords: Mexican plum; rehydration; texture profile analysis.

#7609
Evaluation of the physicochemical properties of dehydrated artisanal cheese during storage

Carlos Jair Calis-Pérez, Alfredo Domínguez-Niño, Galo Rafael Urrea-García, Guadalupe Luna-Solano

Artisanal fresh cheese is a type of cheese from Hispanic origin and one of the most consumed; however, its shelf life is short due to of its pH is close to neutrality, high aw and low salt content. The fluidized bed drying was employed as an efficient alternative to fresh cheese; however, in order to achieve the desired shelf life in a product, it is necessary to study different packaging and storage conditions that will depend on the specific characteristics of the product. A design of factorial experiments 23 was adopted, the storage study was carried out for 90 days, studying two qualitative variables: type of packaging and type of atmosphere in the packaging, and one quantitative variable: drying temperature.

Keywords: Dehydrated cheese; storage; water activity; type of packing.

#7612

The infrared radiation and vacuum assisted drying kinetics of flue-cured tobacco leaf and its drying quality analysis

Wenkui Zhu, Gaofei Guo, Chaoxian Liu, Liangyuan Cheng, Le Wang

Dehydration is widely involved in tobacco processing such as tobacco leaf curing, tobacco trip redrying and cut tobacco drying, which plays a key role due to its effect on the physical and chemical quality of tobacco. The current drying methods in tobacco processing mainly use heat conduction, heat convection or their combination to dehydrate tobacco materials. However, radiation heat transfer as one of basic heat transferways has not been investigated in the tobacco drying. In the present work, infrared radiation dryer was designed to explore the tobacco infrared radiation drying characteristics. The effect of radiation heat transfer conditions and vacuum on the drying kinetics and temperature of tobacco leaves was investigated. Diffusion coefficient of middle tobacco leaves C2F is between 0.848×10-10 ~ 1.597×10-10 m2/s. At the same time, the pore structure andpetroleum ether tobacco extracts in dried tobacco were also analyzed in order to explore the different effects of infrared radiation drying and traditional drying technology on tobacco quality.

Keywords: Flue-cured tobacco; Infrared radiation; Vacuum; Dryingkinetics; Tobacco quality.

#7613
Quality design of spray dried mannitol microparticles: Capturing the vital importance of process parameters on particle properties

Niyanhan Jiang, Shanshan Wang, Ruohui Lin, Zeneng Cheng, Wenjie Liu

Mannitol is a widely used pharmaceutical excipient due to advantages like inertness, low hygroscopicity and good compatibility. The properties of mannitol products may be engineered to meet the diverse needs for formulation development of different dosage forms. In this study, the spray drying engineering process was investigated for quality design of mannitol microparticles. Uniform mannitol microparticles were spray dried from a pilot scale microfluidic-jet spray drying rig excluding the complexity incurred from the inherent polydispersity of spray dried products. Different process parameters including drying temperature, feed solid content, solvent, and droplet size were employed for the preparation of mannitol microparticles. Particle size, morphology, internal structure and polymorphism of the obtained microparticles were shown to dependent on the process parameters indicating the different underlying particle formation mechanisms. And the correlation between the process parameters and particle properties may lead to a quality by design strategy for the spray drying engineering of mannitol microparticles with specific particle functionalities.

#7634

Study of the kinetic drying in double stage and the equilibrium conditions of fillets of salted and smoked bonito

David Vivanco Pezantes

The kinetics of hot air drying of bonito fillets were studied, which were previously salted and smoked with liquid smoke in order to obtain fundamental parameters for process engineering and equipment design. Samples of fish fillets were previously subjected to an osmotic dehydration with an initial vacuum pulse at 5ºC with 15% concentration of the brine and 150mbar, the processing time was 60 minutes, reaching a concentration of under these conditions, 2,90% NaCl in the fish fillet. For the application of spray liquid smoke, a concentration of 40% at 20ºC was used, with an application time of 30 seconds. The pre-drying step was determined for a time of 40 minutes at a temperature of 30°C using air velocity in this period of 0,5m/s. The individual coefficients of heat and mass transfer obtained in the pre-drying with a constant drying speed behavior were of and of .
The drying of the samples was carried out in two stages, the drying of fish took place in the falling rate period in every one; effective diffusion values, taking into consideration the sample parallelepiped with one of its faces isolated by the presence of the skin, during the drying process for the temperatures of the first stages of 40, 50 and 60ºC were of the order of 1,25x10-10, 1,45x10-10, and 1,85x10-10 m2/s; For the second stages of 60, 70 and 80ºC were of the order of 0,96x10-10, 1,25x10-10, and 1,75x10-10 m2/s, for both stages the drying air velocity of 1,50m/s was used, the values obtained are concordant with those reported in the literature. The two-stage Page model equation turned out to be the one that best adjusted to the experimental data of moisture variation with drying time.For the study of equilibrium conditions, two models were used for the adjustment of the desorption isotherms, the mathematical model that best fits the experimental results is the GAB model, also interesting because of the results obtained from the Oswin model -modified.

Keywords: Drying. Kinetics. Fish. Desorption. Isotherms.

#7637

Moisture sorption isotherms and isosteric heat sorption of habanero pepper (Capsicum chínense) dehydrated powder

Mario Luna-Flores, Mariana Gisela Peña-Juarez, Angélica Mara Bello-Ramirez, Javier Telis-Romero, Guadalupe Luna-Solano

Moisture sorption isotherms of the habanero pepper powder were determined using the Dynamic Vapor Sorption (DVS) method at 20, 25, 35, 45 and 55 °C in a range of water activity from 0.10 to 0.90 at which the processes of drying, packing and storage of habanero pepper are developed. The sorption capacity decreased with increasing temperature at a given water activity and the sorption isotherms showed a sigmoid form (Type II). The hysteresis phenomenon was observed in the sorption isotherms at all temperatures studied and it was more pronounced at temperatures high. The experimental sorption curves were fitting to the GAB, BET and Oswin models. It was concluded that the models that best describe the adsorption and desorption data for habanero pepper dehydrated powder were the GAB and Oswin models. The isosteric heat of water sorption was calculated with the moisture content data in equilibrium. The desorption isotherms present a higher isosteric heat in relation to the adsorption isotherms. In both, the isosteric heat decreased as the moisture content increased.

Keywords: Habanero pepper dehydrated powder; Convective drying; Moisture sorption isotherms; Mathematic models.

#7642

Observation of microstructure change during freeze-drying by in-situ X-ray Computed Tomography

Kyuya Nakagawa, Shinri Tamiya, Shu Sakamoto, Gabsoo Do, Shinji Kono, Takaaki Ochiai

X-ray computed tomography technique was used to observe microstructure formation during freeze-drying. A specially designed vacuum freeze-drying stage was equipped at the X-ray CT stage, and the frozen and dried microstructures of dextrin solutions were successfully observed. It was confirmed that the many parts of the pore microstructures formed as a replica of the original ice microstructures, whereas some parts formed as a consequence of the dehydration dependent on the relaxation level of the glassy phases, suggesting that the post-freezing annealing is advantageous for avoiding quality loss that relates to the structural deformation of glassy matters.

Keywords: freeze-drying; X-ray CT; ice microstructure; glassy state.

#7649

A green coffee based product and its comparasion to commercial products regarding the antioxidant capacity

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Green Coffee Products (GCP) consumption have been increased recently and is justified due its benefits to human health, as the antioxidant activity and thermogenic properties and ant mutagenic and ant carcinogenic capacity and also present alleged weight loss control. The aim this work was to elaborate a GCP with Coffea canephora by spray drying and compare its antioxidant capacity to commercial GCP samples by ORAC methodology. The results presented a range of 33.02 – 2,408.05 µmol Trolox/g for commercial products and 1,861.91 µmol Trolox/g for the product obtained in this work.

Keywords: Antioxidant Activity;Green Coffee;Spray Drying;ORAC.

#7650
Nutritional potential of dehydrated residues from rice milk production

L. Ramos Silva, A. C. A. B. Casari, J. I. Velasco, F. M. Fakhouri

The aim of this work was to verify the influence of drying on physical and chemical characteristics of residues from rice milk production. Residues were from the production of white, red and black rice. They were dehydrated in an oven with air circulation at 60ºC for 8h. Characterization of them were carried out by physical and chemical analyses. Residues have presented statistical difference for all parameters measured. Its characterization is necessary to justify its use in other process or application on new products.The residues from rice milk production have high content of nutrients and phenolic compounds, even after dehydration.

Keywords: Nutrients; Oryza sativa; waste.

#7651
Microencapsulation of vanilla extract via spray drying and spray chilling

Figen Ertekin

Vanilla, which has not only a great influence on consumer preferences and economic value, but also sensitive and volatile component, has an important place in the food industry. It is stated that vanilla is widely used in beverages, foods, perfumes and pharmaceutical industries as fragrance, aroma supplier, sweetener, medicine and food additive. Vanilla, one of the aromas having a pure, soft and spicy flavour, is imitated by producers using synthetic vanillin having a similar flavour. When natural vanilla is used in these products, soft and rich aroma can be noticed on the contrary of vanillin. Vanilla is known as natural aroma and vanillin is known as the aroma additive obtained by chemical means and is defined as substances, which are quite different from each other. While only 2% of commercial vanillin is obtained from vanilla, the remaining 98% is produced by chemical routes in the laboratory conditions.

Techniques such as spray drying (SD), spray chilling (SC), extrusion, freeze-drying, coacervation and molecular inclusion are used in the encapsulation of aroma components. Furthermore, the encapsulation of aroma components, which are usually liquid at room temperature, can provide some advantages such as protection from environmental factors and increased shelf life when the product is in a powder form.

In this study, vanilla extract was encapsulated via SD (in whey protein isolate as coating material) and SC (in palm stearin as coating material) methods with the aim of converting to the powder form and preserving its aroma. The first part of the study was the determination of the most suitable homogenization parameters considering high emulsion stability and proper micro particle images. The second part of the study depends on determining both of spray processing conditions. Finally, vanilla extract (containing 1, 3, 5 % vanilla in emulsions (dry basis)) was encapsulated at the constant process parameters through SD and SC methods. Also, physical properties (flowability, particle morphology, particle diameter) and microencapsulation efficiency % of encapsulated vanilla extract powders were analysed. The results showed that encapsulated vanilla obtained from SD technique had higher microencapsulation efficiency (71%) comparing to SC technique (49%). On the other hand, SC implied significant changes in flowability, particle morphology and particle diameter.

Keywords: Vanilla, Microencapsulated powder, microencapsulation efficiency, flowability, particle properties.

#7654

Effect of storage conditions on the bioactive compounds degradation of microencapsulated moringa oleifera spray dried ethanolic extracts

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Moringa oleifera (Moringa) leaves contain bioactive compounds (BC) like phenols, carotenoids and ascorbic acid, which are of special interest for both food and pharmaceutical industries due to their antioxidant properties. BC are recovered from vegetable materialsby solid-liquid extraction, followed by a drying process. Due to the liquid nature of the extract and content of thermolabile compounds, spray-drying the most proper method. In order to preserve the integrity of dehydrated BC´s, controlled conditions must be used during storage. Therefore, the objective of this work was to evaluate the effect of storage conditions on the BC degradation kinetics in microencapsulated moringa oleifera spray dried ethanolic extracts. Moringa leaves ethanolic extract was spray drying in a closed loop with nitrogen as drying gas in order to avoid the previous evaporation stage of the organic solvent. Spray-dried extracts were stored at 22 ºC (room temperature) into low density polyethylene bags. The effect of light exposure, dark and UV radiation on BC content during storage was evaluated. BC content determination was carried out every 5 or 15 days (in according to the degradation rate) for 6 months. The evolution of total phenols (Folin-Ciocalteu assay), total carotenoids (spectrophotometric method), anti-radical activity (DPPH and ABTS assays), water activity (Aqualab Decagon Devices hygrometer), moisture content (AOAC 32.1.03), color (Hunter Lab colorimeter) and chlorophyll (a) were determined. Statistical analysis of results showed a significant effect ($p < 0.05$) of visible light and UV radiation conditions on both BC contents and antiradical activity. Samples stored in the dark showed a bigger retention of total phenols, total carotenoids and antiradical activity, followed by samples that were exposed to a visible light (310 lux/day). For treatments performed under UV radiation at 60 days resulted in carotenoids and chlorophyll (a) degradation up to 50%. Moisture content and water activity increased during storage. BC degradation showed a first order kinetic.

Keywords: Moringa oleifera dried extracts; storage; bioactive compounds degradation.

#7655
Healthy apple snack developed using microwaves

Dinar Fartdinov, Josep Comaposada, Israel Muñoz, Nieco De Wit, Pere Gou, Maria Dolors Guàrdia

The MW heating at early or at final stage of drying process to obtain a crispy apple snack was studied. The effect of MW power and time of application was also evaluated on colour, texture, physico-chemical and sensory properties. Apple snack obtained with the MW heating (7.5 min at 3.000 W) at early stage after an osmotic pre-treatment resulted in apple slices more porous and with better sensory attributes than if it is applied at later stage of drying.

Keywords: apple; snack; drying; microwaves.

#7656
Solar convective drying kinetics and sorption isotherms of Citrus aurantium flowers

Hicham El Ferouali, Ahmed Zoukit, Said Doubabi, Naji Abdenouri

Citrus aurantium flowers are high value aromatic and medicinal plants. The storage conditions and quality of dried Citrus aurantium flowers depends on their hygroscopic stability. The equilibrium moisture content was determined at temperatures (from 30 to 60 °C), and the sorption phenomenon is well described by Peleg model. The optimal water activity for the storage of the product was estimated at awop=0.373. Afterwards, the net isosteric heat was evaluated in the range of 88 kJ.mol−1 for small values of the moisture content (Xeq=0.14kg water/kg d.b), and it decreased along with the increase of Xeq. The experimental drying curves showed only a falling rate period. Finally, Midilli-Kucuk model was found to be the more suitable to describe the drying kinetic of Citrus aurantium flowers.

Keywords: Drying kinetics; Solar energy; Modeling; Citrus aurantium; Sorption isotherms; Conservation process.

#7657

Effect of the combination of osmotic, convective dehydration and frying on the physical and chemical properties of Taro chips (Colocasia esculenta)

Montserrat Chávez-González, Guadalupe del Carmen Rodríguez-Jimenes, Miguel Angel Garcia-Alvarado, Victor Jose Robles-Olvera, Marco Antonio Salgado-Cervantes

Food frying is commonly performed at 120 -180 ° C, which may produce oxidation and hydrolysis reactions that have affect in the final characteristics of the fried product and that generate toxic compounds (as example acrylamide) for the human being. The high moisture content in products to fry, promotes oil absorption and increased reactions. Therefore, the use of dehydration pre-treatments decreases the humidity and consequently the frying time. Dehydration pretreatments may be osmotic dehydration (OD) and convective drying (CD). OD have the advantage to improve the organoleptic characteristics of the dry product due to texture preservation. By the other hand Taro (Colocasia esculenta) is a starchy tubercle with potential for snack production with high risk of acrylamide generation and high oil absorption.

Therefore, the objective of this project was the evaluation of osmotic and convective dehydration effect on oil absorption, and physico-chemical properties in fried taro slices (Colocasia esculenta).

Taro was cut into 3 mm thickness slices and 8.5 cm of diameter. The slices were pre-treated with OD and CS. The OD was performed at 4 and 7 % (w/w) of NaCl, 1:6 slices/solution (g/mL) and 30 ° C. CD was carried out at 40, 60 ° C, 1.5, 1 m/s or air velocity in a tray dryer. The least pre-treatment was a combination of OD and CD at the same variables levels. Pre-treated samples were fried at 140, 160 ° C and, 1/40 (g/mL) pre-treated slices/palm oil ratio. Oil content, color (L, H and C) and texture were evaluated in fried slices, by Soxhlet extraction, HunterLab colorimeter and texturometer.

The analysis of covariance shows that the oil absorption, color (L, H and C) and texture differed statistically as function of the moisture content just prior of frying independently of OD or CD. At 8-14% of moisture content just prior of frying the oil content in fried slices was 14.0% in average. At 30-35% of same moisture the average oil content was 19.1%; and finally at 65-72% of moisture the oil content was 24.3%.

Results indicates that oil content in fried tare slices is reduced with any of the pre-treatments. However the CD or CD/OD pre-treatments produced crispy but weak slices; and OD pre-treatment produced crispy and stronger slices.

Keywords: convective and osmotic drying, taro frying, oil content, colocasia esculenta.

#7664
Microencapsulation of fucoxanthin by using spray drying method

Figen Ertekin

Carotenoids are orange-brown colorants, which can be found in fruits, vegetables, some fungi and algae. Fucoxanthin, which can be derived by brown algae, has many health functions as strengthening the immune system and reducing the risk of certain chronic diseases. The basic problem of using natural active compound fucoxanthin in industrial applications is its low stability and solubility. In this study, fucoxanthin extracted from Phaeodactylum tricornutum was encapsulated by spray drying method to increase its stability and solubility. The first part of the study was the determination of the most suitable wall material combination considering the highest encapsulation efficiency at constant spray drying conditions. Fucoxanthin concentration of encapsulated powder was analyzed with HPLC-DAD equipped with YMC C30 carotenoid column (25cm, 4.6 ID, 5µm) (mobile phase: methanol:acetonitrile (70:30), flow rate: 1ml/min) in order to calculate encapsulation efficiency. Maltodextrin (MD) and whey protein isolate (WPI) combination were selected from MD, WPI, Gum Arabic and Na-caseinate. The second part of the study focused on optimization of wall material composition and inlet air temperature of spray dryer. The optimization study was performed according to the combined D-Optimal design experimental patterns to determine the mixing ratios of the combination of coating materials and the process parameters specific to the encapsulation method. The encapsulation efficiency was selected as the response in the optimization study performed by spray drying method. Optimum spray dryer conditions were determined by using the Design-Expert, the mixing ratio of the coating material is 39.2% MD, 60.8% WPI and the air inlet temperature is 150°C. The encapsulation efficiency was found 70.64% at the optimum point. Additionally, microencapsulation yield (21.84%), total phenolic content (79.96 mg gallic acid/g), Hunter L*, a* and b* color values (86.57, -5.36, 17.28 respectively), moisture content (4.03% dry basis), water activity (0.210), solubility (79.64%), were also examined for microencapsulated fucoxanthin sample at the optimum point and also D-Optimal design experimental patterns all of points.

Keywords: microencapsulation, fucoxanthin, Phaeodactylum tricornutum, spray drying, optimization.

#7675

Physical characterization of spray dried whole dromedary milk powder: A multi-factorial investigation in relation to its storage proprieties

Ahmed Zouari, Pierre Schuck, Frédéric Gaucheron, Claire Gauzelin-Gaiani, Guillaume Delaplace, Hamadi Attia, Mohamed Ali Ayadi

Compared to whole cow milk, whole dromedary milk exhibits several physicochemical differences such as caseins micelles and fat globules size. Thus, in this study, both surface composition and microstructure of whole dromedary milk powder (WDMP) were investigated. The behavior of fat globules inside powder particles was also studied in order to better understand WDWP the storage parameters. Under the same drying conditions and with the same total fat content, cow and dromedary milks were spray dried at an inlet and outlet drying temperature of 175°C and 75°C, targeting a water activity of 0.25. The composition and the hydrophobicity of WDMP were analyzed by the X-Ray Photoelectron Spectroscopy at a surface of 600 µm with layer depth of 6 to 10 nm. Results highlighted the presence of approximately 1 % of lactose at the surface of WDMP instead of 0 % for cow milk powder (CMP). In addition, although it contains higher surface fat level than cow milk, WDMP exhibited the same surface hydrophobicity. WDMP glass transition temperature (Tg) was analyzed following a referenced rheological method. Measurements at a water activity of 0.13, 0.23 and 0.33 highlighted that WDMP presented lower and significant Tg values than cow milk, however it remained in the same temperature range. On the other hand, WDMP behavior against water adsorption was estimated following the dynamic vapor sorption method at 25°C. The obtained isotherms highlighted the lower critical lactose crystallization humidity for WDMP as compared to CMP (60 % and 70 %, respectively). However, SEM micrographs showed that lactose crystals started to be formed at 53% of humidity. Fitted to the Guggenheim-Anderson-de Boer model, the constant K and C showed that WDMP was more hygroscopic than cow milk with higher water binding energy.
Analyses of dromedary milk fat globules (DMFG) by laser diffraction granulometry highlighted their smaller mean diameters. Inside the powder, micrographs, obtained by Confocal Laser Scattering Microcopy, showed a different fat globules distribution inside the WDMP as compared to CMP. DMFG seemed to be encapsulated in the protein and lactose matrix with less coalesced patches. Moreover, higher crystallization and fusion temperatures were recorded for DMFG inside powder. In conclusion, lactose crystallization in the WDMP seemed to be more sensitive to humidity adsorption than storage temperature changes. However, taking into account the DMFG behavior inside the powder, DMFG fusion temperature should be considered as well as the Tg while setting the storage temperature.

Keywords: microencapsulation, fucoxanthin, Phaeodactylum tricornutum, spray drying, optimization.

#7689

Organic apples (cv. Elstar) quality evaluation during hot-air drying using Vis/NIR hyperspectral imaging

Luna Shrestha, Roberto Moscetti, Stuart Crichton, Oliver Hensel, Barbara Sturm

Organic dried apples are common snacks fulfilling functional as well as nutritional aspects. However, appearance of dried slices does not always satisfy consumer requirements, thus, improvements are needed. In this study, partial least squares (PLS) regression models were successfully developed to monitor changes in colour and moisture content in apple slices during the drying process over the Vis/NIR spectral range. The regression vector analysis results suggested that features at 580, 750 and 970 nm are better for predicting moisture content, while 580 and 680 nm allow to measure the (a*/b*) colour ratio.

Keywords: Drying; Dried apple slices; Moisture content; Colour; PLSR modelling.

#7691
Physicochemical parameters and consumer acceptance in espresso and american coffee pods

Lina Ximena Parrado, Andrés Felipe Bahamon, Nelson Gutierrez

This study presents the consumer acceptance of coffee beverages made from espresso coffee pods (CCE) and american coffee pods (CCA), six quality attributes were evaluated by a sensory panel conformed to judges of different experience level. A physicochemical characterization was made for the coffee powder in CCA and CCE. The beverage preparation via different machines was made for to observe the influence on the consumers acceptance. The coffee powder in CCA showed high aw and high moisture content, this factors should affect the consumer perception; in general, a low acceptance level of coffee beverages made from CCE and CCA was observed, maybe because of the strong habit of consuming filtered coffees.

Keywords: Coffee; Espresso; American; sensory; physiochemical.

#7707
Physicochemical characterization of mesquite flours

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Ethnic foods are healthy products interesting for the new societies. Mesquite flour offers another option for making gluten-free recipes as part of a diet for people with celiac disease. The physicochemical properties of mesquite flours (Prosopis laevigata) were characterized. The mesquite pods were dried at 60°C, 15% RH and 2 m/s airflow; then a grinding and sieving process were applied. The nutritional composition and the sorption isotherms were obtained at 30, 35, 40 and 45°C for water activities of 0.07-0.9. The particle-size distribution, morphology and thermal stability of the flours were determined by different methods.

Keywords: Mesquite Flours; drying; isotherms; chemical properties; morphology.

#7716
Thermal stability of amorphous sugar matrix, dried from methanol, as an amorphous solid dispersion carrier

K. Imamura, K. Takeda, K. Yamamoto, H. Imanaka, N. Ishida

Developing a technique to disperse hydrophobic ingredients homogeneously in a water-soluble solid matrix (solid dispersion) is one of the topics that have been extensively investigated in the pharmaceutical and food industries. Recently, we have devised a novel solid dispersion technique (surfactant-free solid dispersion), in which a preliminarily amorphized sugar was dissolved in an organic media containing hydrophobic component, without using any surface active substances, and then vacuum dried into the amorphous solid mixture [Food Chem., 197 (2016) 1136; Mol. Pharm., 14 (2017) 791]. In this study, the physicochemical properties, especially thermal stability of the surfactant-free amorphous solid dispersion, were investigated.

keywords: solid dispersion; amorphous sugar; surfactant-free; vacuum drying; glass transition temperature.

#7719

Effect of tray dryer's independent variables (drying temperature and air velocity) on the quality of olive pomace and system's energy efficiency

Ulaş Baysan, Mehmet Koç, A. Güngör, Figen Kaymak-Ertekin

In this study, the effects of drying temperature (70, 80, 90°C) and air velocity (0.5, 1.8 m/s) of hot air drying (tray drying) on quality of dried 2-phase olive pomace and system's energy efficiency were investigated. The drying experiments were carried out in a tray dryer. The effects of drying conditions were evaluated with analyzing drying time, the primary and secondary oxidation and calculating specific moisture extraction rate (SMER), moisture extraction rate (MER) and specific energy consumption (SEC). The results showed that increase in drying temperature and decrease in air velocity led to decrease in quality of dried olive pomace.

Keywords: Waste valorization, 2-phase olive pomace, Tray dryer, Energy efficiency, oxidation stability.

#7739
Identification of key factors determining the surface oil concentration of encapsulated lipid particles produced by spray drying

Annika Linke, Tobias Balke, Reinhard Kohlus

Potential factors leading to surface oil were investigated by analyzing the impact of emulsion properties, atomization and drying conditions separately. An increased oil load, droplet size and in particular the size of droplet aggregates led to significant more surface oil. Increasing the viscosity, inlet temperature and relative humidity resulted in larger particles with a higher encapsulation efficiency. The results indicate that the probability of oil droplets being in contact with the particle surface determines the amount of surface oil. Oil diffusion towards the surface was excluded due to the short residence times and high viscosities.

Keywords: microencapsulation; encapsulation efficiency; emulsion properties; atomization; drying conditions.

#7743

Drying-induced changes of phytochemicals in response to carriers added during transformation of blackcurrant juice into powders

Anna Michalska

The conversion process of a liquid fruit juice into a dry form of powder is a complicated task. It is mainly due to the presence of constituents with a low glass transition temperature (Tg) (i.e. low molecular sugars and organic acids) and also due to their relatively high hygroscopicity, low melting point and a high water solubility. Several approaches, including the addition of high-molecular weight carrier agents that increase the Tg during the drying of blackcurrant (Ribus nigrum L.), were undertaken in order to change the sticky characteristics of the fruit material. The commonly used additives, i.e. maltodextrins, Arabic gum, starches, etc, were previously added in order to improve the physical properties and stability of the powders obtained. However, there is limited information about the influence of selected carriers added on the qualitative changes of phytochemicals present in blackcurrant juice during the drying processes. Taking above into consideration, the study aimed to evaluate the changes of polyphenolic compounds present in blackcurrant juice in relation to the addition of maltodextrins (low and high DE), Arabic gum, inulin and starches during freeze-, vacuum and spray drying processes. The major group of polyphenolic compounds in blackcurrant powders consisted of 6 anthocyanins (approx. 70% of total polyphenols) including delphinidin-3-O-glucoside, delphinidin-3-O-rutinoside, cyanidin-3-O-glucoside, cyanidin-3-O-rutinoside, petunidin-3-O-rutinoside, and peonidin-3-O-rutinoside. Their content significantly differed in relation to the type of a carrier added and a drying method applied. Application of freeze- and spray drying resulted in a similar quantity of anthocyanins in powders (average 360 mg/100 g dm), whereas vacuum drying at 80 °C caused a significant degradation of these constituents. What is more, the lowest content of anthocyanins in those powders was noted when inulin was used. The second group of polyphenolic compounds (approx. 24% of all polyphenols) present in blackcurrant juice powders consisted of 6 flavonols (myricetin-3-O-rutinoside, myricetin-3-O-galactoside, quercetin-3-O-rutinoside, quercetin-3-O-glucoside, quercetin-3-O-malonylglucoside and kaempferol-3-O-rutinoside). In contrary to anthocyanins, the lowest content of these constituents was noted after freeze-drying process, regardless of the type of carrier added. The highest content of flavonols was indicated after spray drying, especially when Arabic gum was added. Among phenolic acids, neochlorogenic, chlorogenic and p-coumaric acids were identified and their content constituted approx. 5% of all polyphenols. Among drying methods applied, the strongest antioxidant capacity measured by TEAC ABTS and FRAP methods was noted when vacuum drying at 80 °C was used. The strongest antioxidant properties were noted when inulin was added into blackcurrant juice, suggesting the formation of the compounds with strong antioxidant properties.
Keywords: Ribes nigrum, maltodextrin, inulin, drying, polyphenols, antioxidant capacity.

#7745

Influence of drying method in yield and composition of essential oils of three Mediterranean herbs

Juan A. Llorens-Molina, Sandra Vacas-Gonzalez, Guillem Cebrián Ortega, Jose V. Garcia-Perez

Drying is a preliminary stage in essential oils (EOs) extraction both for analytical and industrial purposes. On the one hand, drying can affect the EOs composition and yield, thus influencing on the compliance with the market regulations. On the other hand, for research purposes related to taxonomic issues or environmental influences affecting EOs profiles, there may be important differences between EOs extracted from fresh and dried materials. The influence of drying method in yield and composition of EOs extracted from leaves of three typical Mediterranean herbs Salvia officinalis L., Rosmarinus officinalis L. and Ocimum basilicum L. has been studied in this work.

Herbs were dried by three different methods: air drying at room temperature (20.0±1.5 ºC), convective drying at 40ºC and lyophilization. The EOs were extracted by simultaneous distillation extraction (SDE) and analysed by GC/MS for identification and GC/FID for quantification. Finally, yield and composition of EOs in dried herbs was compared to those found in fresh ones.

The major compounds in EOs were verbenone (16.8-19.1 %) and camphor (15.8 – 17.0 %) for Rosmarinus officinalis L and a-thujone (25.8-26.9 %) and camphor (17.4-20.2 %) for Salvia officinalis L. Regarding these species, no significant ($p>0.05$) differences were observed among drying treatments, either in yield or composition. However, in the case of Ocimum basiliculm L, a significant ($p<0.05$) decrease was observed in its major compound (methyl eugenol, 35.2-55.2 %) for convective drying at 40 °C. The other major component (eugenol, 1.1-9.4 %) also showed a significant ($p<0.05$) decrease both in convective drying at 40ºC and air drying at room temperature. No differences were found when fresh and lyophilized samples were compared.

#7748
Convective drying of pork liver in a wide temperature range

Eduardo A. Sanchez-Torres, Jose Benedito, Juan A. Llorens-Molina, Marina Contreras, Jose M. Lorenzo, Jose V. Garcia-Perez

Liver could be considered a relevant by-product of pork industry, its consumption has been decreasing with current consumption trends and nowadays has a low commercial value. Thus, pork liver is frequently used for animal feeding. However, liver represents a potential source of technological proteins to be used in food industry. Drying is a necessary pre-treatment in order to stabilize the liver previous its further processing. Drying temperature is a key parameter which influences not only on the energy cost and processing time but also may affect protein functionality. Thereby, the main aim of this paper is to determine the effect of the temperature on drying kinetics of pork liver in a wide experimental range. For this purpose, drying of pork liver was carried out from -10 to 70ºC in a lab-scale convective drier, while air velocity was kept constant at 2 m/s. Drying kinetics were modeled considering diffusion models and the effective moisture diffusivity was identified at the different temperatures. Experimental results showed as drying rate increased as the temperature was risen. The influence of temperature on effective moisture diffusivity was quantified using an Arrhenius-type relationship, being a different activation energy calculated for temperatures below and above liver freezing point.

#7759
Kinetics of algae drying

Bhaskar Thorat

Determination of the kinetics of algae drying using Vacuum Tray Dryer, Infrared Dryer, and an Innovative Patented Solar Conduction Dryer. The drying is carried out under varied conditions of temperature, pressure & sunlight intensity. Algae being a biological material, it is temperature sensitive and degenerates at temperature above 65-70°C. Algae is dried in Vacuum Tray Dryer at 60°C under varied pressure conditions ranging from 25 millibar to 75 millibar, where the drying rate kept reducing as the pressure applied reduced. The vacuum tray dryer makes use of specially designed double condenser system. The Solar Conduction Dryer makes use of pure conduction to dry the algal slurry. It retains the nutrient contents of the algae and also prevent decolouration. We expect the polar and non-polar lipids to be retained during the SCD drying, in post drying treatment. The final use of the dried algae is as feed for fishes, extraction of oil and other vital products, therefore the drying conditions are controlled to prevent the loss of these essential materials. The drying data was used to develop Reaction Engineering Approach (REA) model whereby, the conduction heat transfer takes place ubiquitously used convective heat transfer.

Keywords: Drying Kinetics, Solar Conduction Dryer, Reaction Engineering Approach, Algal Drying.

#7760
Technological and nutritional aspects of gluten-free pasta based on chickpea flour and tiger nut flour

M. E. Martín-Esparza, G. B. Bressi, A. Raga, A. Albors

Gluten-free (GF) dry egg pappardelle was prepared with tigernut flour (50%), chickpea flour (50%) and pregelatinized TNF (0, 5, 10%), and compared to plain pasta (100% durum wheat semolina). The GF pasta may have a significant higher content of insoluble fibre, minerals and fat rich in oleic acid and a similar protein content. It was not found any clear relationship between the flour functional properties and its proximate composition. The use of PG did not imply an improvement on the firmness but did provide some continuity to the pasta structure.

Keywords: Gluten-free pasta, tigernut flour, chickpea flour, texture, cooking properties.

#7774

Study of the effect of various heat treatments on some physico-chemical, nutritional and functional properties of acerola

Angel Argüelles, Ana Heredia, Ana Andres

Although Acerola is considered, among all fruit, as one of the major sources of vitamin C and other phytochemicals such as polyphenols and carotenoids, its availability and use is limited because of its ease of deterioration and conservation treatments applied to it.
This analysis has been developed to study the effect of various heat treatments, freeze drying and hot air drying at different temperatures (60-80 °C) on some physico-chemical, nutritional and functional properties of acerola with the aim to evaluate its possible use as "healthy" ingredient in the production of functional foods.
Whole frozen fruit was used for the study. The moisture content, water activity, Brix, electrical conductivity, pH and colour, content of vitamin C, carotenoids, flavonoids, phenols and antioxidant capacity were analyzed once treatments were completed.
According to the results, it can be concluded that freeze drying is the treatment that best preserves the nutritional properties (content of vitamin C, carotenoids, flavonoids and phenols) and the functional properties (antioxidant capacity) of the final product. As to the optical properties, no significant differences were observed in the brightness, chroma and hue of the products obtained according to the different treatments applied.
The freeze-dried acerola has a high antioxidant capacity that makes it an option to be used as a functional ingredient in the preparation of various foods.

#7784
Flow ability of the coking coal in a superheated steam gravity bed dryer

Zhonghua Wu

Coal moisture control (CMC) technology is an emerging one in the current coking process, which can improve the production rate of coking oven and product quality, reduce waste water pollution. Traditional CMC dryer comprised of tube-bundle and fluidized bed ones, where the flue gas was widely used as the drying medium. In this project, a new CMC dryer-superheated steam gravity bed dryer (SSGB Dryer) was developed where superheated steam is applied to directly dry the 12% coking coal into 6.5%. The flow ability of coking coal inside the SSGB dryer is an important issue and this paper is aiming to develop an optimized inner structure design, which comprise of series of tapered perforated plates and to make coking coal flow successfully. The flow ability parameter of coking coal was measured. The effect of cone angle, perforated hole size, air flow velocity, etc on flow ability of coking coal was investigated. Experimental results show that the cone-shaped porous folding plate whose angle is above 35 degrees can distribute the material uniformly and the cause a smooth flowing of coking coal. When the air flow velocity in the dryer is bigger than 0.5m / s, the coking coal particles was observed to begin to fluidized. The final water content of the coking coal can be controlled at 6% ~ 6.5%.

#7785
Experimental investigation of drying of malt bagasse

B. D. Zorzi, K. Machry, P. Krolow, C. M. Moura, E. G. Oliveira, G. S. Rosa

The aim of this work was to investigate the convective drying process of malt bagasse and to evaluate the influence of this process on the application of this residue as adsorbent in methylene blue removel by adsorption process. The experimental system for drying was a fixed bed dryer with parallel airflow, with operating conditions: air temperature in the range of 40 to 90 oC and air veocity of 2 m/s. The adsorption experiments were perfomed with solution of methylene blue at 70 ppmconcentration. The drying kinetics showed a constant drying rate period followed by a falling drying rate. The results obtained for the dye removal efficiency were 56% for in natura sample and in the range of 81.69% to 93.99% for dried samples.

Keywords: dryin; malt bagasse; adsorption.

#7786
Influence of the acoustically assisted low temperature drying of lemon peel on the pectin extraction yield

Mónica María Umaña Zamora, Beatriz Rayo, Henry Váquiro, José Bon, Oscar Rodríguez

The by-products generated in the industrial production of juices are potential sources of bioactive compounds. Among them, essential oils, phenolic compounds and polysaccharides (cellulose, hemicellulose and pectin) excel for their high market value. The aim of this work is to evaluate the feasibility of power ultrasound application during the low temperature drying of lemon peel slabs, analyzing the influence of the acoustic power (20.5 W/m3) and air-drying velocity (1.0, 1.5, 2.0 m/s) and its effect on the pectin yield of the extraction. As expected, increasing the air-drying velocity led to a faster drying process regardless ultrasound application. The acoustic assistance intensified the drying kinetics of the lemon peel slabs. This effect was more noticeable at the lowest air-drying velocity tested (1.0 m/s) than at the highest one (2.0 m/s). Regarding the pectin extraction, a significantly higher yield was observed in samples acoustically dried compared to the yield attained in those dried without acoustic application. The air-drying velocity did not affect significantly the pectin yield in both groups of samples with and without acoustic application. Therefore, the acoustic energy affected the internal structure of the sample which eased not only the water removal during the drying process but also improved the pectin extraction from a so-called by-product as lemon peel.

#7789
Study on drying-induced cracking of rice kernel using acoustic emission method

Zhonghua Wu

Fissuring often occurs in the mechanical hot air drying process, which lowers the head rice yield and rice's economic value. In the drying process, micro-cracks in the rice kernel would developed into meso-ones, and furthermore into macro-ones. These cracking was accompanied by the acoustic emission and in this paper, the acoustic emission method was applied to study the drying-induced cracking process. The acoustic energy pulse signal released by cracking inside the rice kernel during the drying process was being monitored by an acoustic emitter. The acoustic emission signals of rice kernel at different drying stages were extracted and the spectral characteristics were analyzed. The combination of glass transition theory and acoustic emission technology was used to study the change of rice crack. Experimental results show that the acoustic emission signal can effectively reflect the crack characteristic of the rice drying process. This work verified that the acoustic emission technique could be a new method for the detection of the drying-induced cracking of rice kernel with possible other grains.

#7800
Intensification of low-temperature drying of mushrooms by means of power ultrasound

Francisca Vallespir, Cristina Reche, Laura Crescenzo, Francesco Marra, Carmen Rossello

The effect of the drying temperature (5, 10 and 15 °C) and the application of ultrasound (20.5 kW/m3) on the drying kinetics (at 1 m/s of air velocity) and the functional properties such as swelling (SW), water retention capacity (WRC) and fat adsorption capacity (FAC) of button mushrooms have been studied. The effective diffusion coefficient was estimated from the Fick's law combined with the microscopic mass balance. The governing equation for a slab geometry was solved by using a separation of variables method. The acoustic assistance (20.5 kW/m3) promoted an increment of the effective diffusion coefficient from 2.2 to 3.0 x 10-11 m2/s at 5 °C, from 2.3 to 4.3 x 10-11 m2/s at 10 °C, and from 2.6 to 6.1 x 10-11 m2/s at 15 °C, leading a reduction of the drying time of 33, 51 and 57%, respectively, after a weight loss of 85% from an initial moisture content of 11.8 ± 0.8 g water/g d.m. A lyophilized sample (at -50 °C and 0.6 bar) used as control exhibited SW, WRC and FAC figures of 28.5 ± 0.9 mL/g d.m., 8.7 ± 0.8 g/g d.m. and 10.5 ± 1.2 g/g d.m., respectively. Compared to the control sample, samples dried at 5, 10 and 15 °C without acoustic application exhibited significantly lower ($p<0.05$) figures for the functional properties and ranged between 21 and 56% below the control sample. Regarding SW and FAC properties, no effect of the drying temperature was observed, however the WRC figures decreased as the drying temperature increased. Regarding the acoustic application, samples dried at 5, 10 and 15 °C exhibited FAC figures 4, 13 and 17% lower than the control one, but in all cases higher than those of the dried samples without acoustic application (53 – 56 % lower than control). Regarding the SW and WRC properties, no significant differences were observed between samples dried at 5 and 10 °C without and with acoustic application. However, sample dried at 15 °C exhibited a significantly higher SW figure (20.9 mL/g d.m.) among all dried samples, while WRC figures were not affected by the drying temperature being average figure of 6.2 g/g d.m. The low temperature drying assisted by ultrasound not only allowed the intensification of the drying process, but also, mushroom dried at 15 °C with acoustic assistance preserved better its functional properties than the one dried without ultrasound application.

#7803
Vitamin C content of freeze dried pequi (Caryocar brasiliense Camb.) pulp

C. T. Soares, F. G. Nogueira, A. A. Santana, R. A. Oliveira

Vitamin C is one of the constituents of pequi pulp. It is a natural antioxidant, capable of sequestering free radicals. The present study aimed to freeze dry a pequi pulp encapsulated with maltodextrin and whey protein and analyze vitamin C content. Vitamin C loss was lower in the experimental run that did not use encapsulating agent. Whereas, the run that used 15% of whey protein concentrate as encapsulant agent in relation to pequi solids presented the highest value (220.74 mg vitamin C / g pequi solids). Freeze drying of pequi pulp is a technique for vitamin C conservation independently of the variation in maltodextrin and whey protein proportion.

Keywords: drying; encapsulating agent; ascorbic acid.

#7808
Effect of spray drying on volatile compounds of acerola pulp

P. M. Nogueira, M. T. Leite Neta, H. C. S. Araújo, M. S. Jesus, S. Shanmugam, N. Narain

The objective of this work was to optimize the drying conditions in order to obtain acerola powder and to focus on the product aroma quality. Acerola fruits were selected, washed and sanitized before extracting the pulp. An emulsion was obtained by adding maltodextrin in the pulp. The dehydrated powders were obtained in spray dryer by drying at inlet temperatures of 128 and 152 ºC. Twenty five volatile compounds were identified in fresh acerola pulp and in the dehydrated powder. These results prove that use of maltodextrin in spray drying of acerola pulp helps in retention of key aroma compounds in acerola powder.

Keywords: Acerola, Spray drying, dehydration, volatiles, aroma, GC-MS.

#7811
Aroma retention during drying of caja-umbu fruit pulp

Anderson Santos Fontes, Maria Terezinha Santos Leite-Neta, Patricia Nogueira Matos, Hannah Caroline Santos Araújo, Monica Silva Jesus, G. Rajkumar, Narendra Narain

This study was aimed to obtain and characterize the dried powder of cajá-umbu (Spondias spp) fruit pulp obtained by spray-drying and lyophilization. Spray-drying of the pulp was done at different temperatures. Analysis of bioactive compounds and volatile compounds was performed. The total phenolic compounds content was high in the dried powder obtained at the temperature of 140 °C. The volatiles analysis of dried powders revealed that the powder dried at 140°C contained a larger number of compounds. The cajá-umbu powder showed that it is a better alternative for storage and conservation since it retained the majority of volatile compounds.

Keywords: Cajá-umbu, volatile compounds, gas chromatography, mass spectrometry.

#7815
Blackberry pulp microencapsulation with arrowroot starch and gum arabic mixture by spray drying and freeze drying

Gislaine Ferreira Nogueira, Farayde Matta Fakhouri, Rafael Augustus de Oliveira

The objective of this research work was to obtain blackberry pulp powder (BL, without encapsulating agent) and microencapsulated blackberry pulp (ML, with encapsulating agent :mixture of starch arrowroot and gum arabic (1:1)) obtained by freeze drying and spray drying and evaluate their physico-chemical properties. The yield of blackberry freeze drying process was higher than the value found for spray drying process. The presence of encapsulating agent and drying method used for producing the powders influenced the average particle size, diameter, hygroscopicity, solubility, wettability and anthocyanin content of the powders.

Keywords: process yield; average size; hygroscopicity; solubility; anthocyanin; antioxidant property.

#7817
Study of drying and cooking stages to obtain fast cooking senia rice

Maria Dolores Ortola

Several studies have established the soaking, precooking and drying of rice as common pretreatments to obtain a wide range of fast cooking products. Drying as a unit operation is one of the critical steps obtaining this type of product. The drying method and conditions play an important role in achieving the desired quality. In this study, the drying by hot air of pre-cooked Senia rice at different temperatures (40º, 60º, 80ºC) has been evaluated as part of the process to obtain fast-cooking rice. The loss moisture of the product during drying was modeled by three models widely used in agricultural products, the Fick diffusional model, and the Page and Midili models. In the first two, a deviation of the experimental data was observed compared to those predicted for long drying times, while the Midili model seems to fit throughout the period of time considered. With those three models, a dependence of the air temperature with the drying speed was observed, increasing it with higher temperature.

In addition, the influence of the drying temperature on the final cooking phase was evaluated, studying the water absorption capacity and the necessary cooking time by analyzing its mechanical properties. In general, white rice has a greater water absorption capacity than integral rice, reaching its cooking point at 5 minutes compared to more than 9 minutes of the integral. At the end of the cooking, no significant differences were observed in the mechanical parameters evaluated by the effect of the drying temperature, so it would be recommended to dry at 40ºC to reduce energy expenditure. For both types of rice, reductions in cooking time were achieved between 60 and 75% respecting to traditional Senia type rice.

#7830
Drying conditions and analysis of physicochemical characteristics of Capsicum pubescens

Consuelo Sánchez-García, Óscar Ándres Del Ángel-Coronel, Ingrid Paniagua-Martínez, Guadalupe Luna-Solano, Alejandra Ramírez-Martínez

Capsicum pubescens, a chili specie present in south Mexico (Veracruz state) registers upon 30% loss due to the constraints of the market. Therefore, the objective of this project was to determine the physical and chemical parameters of Capsicum pubescens as well as to evaluate the kinetics of drying of this species. Color tests revealed that the samples were the color was less affected by drying conditions ($p>0.05$) correspond to those dried at 60ºC (0.5 cm thickness), and 50ºC (0.5 and 1 cm thickness) which coincides with the preference of surveyed population. Thus, Capsicum pubescens may be dried under these conditions.

Keywords: Capsicum pusbescens; drying; sensorial analysis; food loss.

#7832
Quantitative changes of polyphenolics and antioxidant capacity in plum by-product powders caused by different drying techniques

Joanna Majerska

The study aimed at evaluation of physical (i.e. dry matter, water activity, true and bulk density, porosity, colour) and chemical properties (i.e. polyphenolic compounds and antioxidant properties) of plum (Prunus domestica L.; cv. Valor) pomace obtained after juice preparation (initial moisture content 3.72 kg · kg-1). The pomace was subjected to: (1) freeze drying (FD), (2) convective drying (CD) at 50, 60, 70, 80 and 90 °C, (3) microwave-vacuum drying (MVD) at power mode set up to 120, 240, 360, 480 W and (4) combined drying (CD-MVD). The drying kinetics were described using a modified Page model. Among the drying methods applied, the shortest duration of the process was noted in case of MVD at 480 W that was 32 mins, whereas the longest time was indicated after FD (1440 mins).

The lowest moisture content and water activity was in powders obtained by, respectively, MVD at 480 W and FD, whereas the highest values of these parameters were indicated after CD at 50 °C. Among all powders obtained, the values of true and bulk density as well as porosity were at the comparable level. Similar observation was made when the colour coordinates L*, a* and b* were concerned. In plum pomace powders, the polyphenols content ranged from 181 up to 422 mg · 100 g-1 dm (dry matter). The major group of polyphenolic compounds were phenolic acids (approx. 54 %), followed by flavonoids (approx. 23 %), proanthocyanidins (approx. 20 %) and anthocyanins (approx. 3 %). The drying methods applied significantly influenced the total polyphenols content being the highest after combined drying (CD at 70 °C and MVD 120 W). In case of CD, the application of 70 °C also resulted in the highest content of polyphenols when compared to the rest of the temperatures applied. The antioxidant capacity measured by TEAC ABTS and FRAP method was within the ranges, respectively, from 2.7 to 4.6 mmol Trolox · 100 g-1 dm and from 2.73 to 4.51 mmol Trolox · 100 g-1 dm. In case of CD, it was observed that higher the temperature during the process, higher the antioxidant capacity of the samples. The highest values of antioxidant capacity were noted when MVD was used. When combined drying was applied, the antioxidant properties were at the comparable level but lower in comparison to CD and MVD. Thus, it was probably connected with the applied power of magnetrons used for finish microwave vacuum drying.

#7834
Functional properties of dried tarragon affected by drying method

Banu Koç, Nazan Çağlar, Gamze Atar

Tarragon is a small shrubby perennial herb in the Asteraceae family. It is cultivated for the use of its aromatic leaves in seasoning, salads, sauces, vinegars, mustard and spices. In this study, tarragon was dried in two different drying equipment (infrared (ID) and microwave dryers (MD)) to compare the drying and final product properties (moisture content, water activity and colour change). Three different output power levels of 125, 250 and 500 W were used for MD, whereas the ID treatment involved three drying temperature levels that were 60, 70 and 80°C. A comparison of the drying kinetics, MD was more effective in shortening drying time when compared with ID.

Keywords: Tarragon, microwave drying, infrared drying, color change.

#7843
Effect of the solar dehydration on the antioxidant capacity and the content of flavonoids of the blackberry pulp (rubus spp)

Azucena Silva-Norman, Anabel López-Ortiz, Isaac Pilatowsky-Figueroa, Octavio García-Valladares

Technical performance of two solar drying technologies was evaluated: Solar Greenhouse Drying (SGD) with auxiliary heating system, and Direct Solar Drying (DSD) in order to evaluate its effect on antioxidant activity (AA) and total flavonoids of blackberry (rubus spp) waste destined. The SDG and DSD results were compared with those of the dehydrated samples in an electric stove (ES). The fresh and dried fruits were evaluated; the blackberry seedless pulp was used. The AA and flavonoids showed degradation of 70% and 20% compared to the fresh sample. For both compounds, SGD is the one that offers the greatest conservation.

Keywords: solar drying; antioxidant capacity; flavonoids; blackberry pulp (rubus spp); solar energy.

#7844
Long-term maintenance of dried acellular matrices

Alessandro Zambon, Giovanni Giobbe, Massimo Vetralla, Filippo Michelino, Luca Ubani, Maria Pantano, Nicola Pugno, Paolo De Coppi, Nicola Elvassore, Sara Spilimbergo

Dried and sterile acellular esophageal matrix was obtained within a new drying process based on the use of supercritical carbon dioxide (SC-CO2). Experiments were performed coupling a conventional detergent enzymatic treatment with two different drying methods: (i) SC-CO2 drying alone; (ii) dehydration in ethanol and a subsequent SC-CO2 drying. Long term preservation was achieved for several months after drying, demonstrating the maintenance of extracellular matrix (ECM) structure, mechanical properties and biocompatibility within cell repopulation studies in vitro. Overall, the results highlighted the potential of this novel technology to obtain a dry and sterile acellular matrix that can be easily stored for oesophageal regeneration in patients with emergency need.

Keywords: decellularized tissue; supercritical drying; carbon dioxide; tissue engineering; long term storage.

#7845
Physical properties of novel cranberry powders composed of by-products and fruits

Anna Michalska

Cranberry (Vaccinium ssp. L.), a dwarf shrub that produces edible red fruits, contains significant amounts of phenolic compounds including procyanidins, phenolic acids, anthocyanins, flavonols and flavan-3-ols with strong antioxidant properties. Due to the presence of these compounds cranberry could prevent from i.e. urinary tract infections and might have antifungal, antimicrobial, and detoxifying properties. Unfortunately, the bitter and astringent taste of fresh cranberry fruit halt its consumption in a fresh form. Taking above into consideration, technological transformations of cranberries e.g. into a powder might cover the undesirable taste and in such form cranberry fruit-based products could be added into different foodstuffs. Additionally, during the cranberry juice production a vast amount of valuable cranberry by-products (pomace) are produced being often unexploited. Thus, the study aimed at a design of novel cranberry powders including raw fruit and osmotically dehydrated (OD) cranberry in chokeberry concentrated juice with addition of a selected portion of pomace. The further aim was to evaluate the physical properties of powders obtained. The combined drying including convective pre-drying at 60 °C and microwave-finish drying at power mode of 240 W was chosen in order to prepare cranberry powders. The drying kinetics were described using basic drying models taking into account the values of coefficient of determination and root mean square error. The water activity of powders obtained ranged from 0.103 up to 0.221 and was higher when the cranberry after OD was used. Among samples obtained, the values of true density were at the comparable level, whereas the bulk density was slightly higher when OD cranberry was applied. The addition of pomace as well as the OD of cranberry fruit altered the colour of products obtained measured by coordinates L*, a* and b*.

#7853
Experimental and numerical study of the drying of aromatic herbs

Hedi Romdhana, Ahlem Soltani, Soufien Azzouz, Afif Elcafsi

Since the development of synthetic flavors, there is a certain recognition for natural ones. Many of these compounds are present in plants but in very small quantities. It is therefore necessary to concentrate them and then reformulate them for their future use (e.g. in the form of powder).
Although the low value of raw materials, their processing is expensive, especially the drying step which is essential for the preservation of the product including more than 60% moisture content for most of the aromatic herbs. The drying step could be expensive in terms of energy consumption but also could induce alteration on aromatic herbs considered as heat-sensitive if the drying temperature and the drying time are not optimized.
In this work, we are interested in the bay leaf. We first propose an experimental study of convective drying in a thin layer. The drying experiments are conducted under different conditions of temperatures, air velocities and relative humidity. Several drying kinetics are therefore explored, including also the hygroscopic equilibrium between the drying air and the bay leaf. In a second step, a mathematical model is developed. The model predicts internal transfers of heat and mass within the leaf as well as external transfers between the leaf and the drying air. Thanks to experimental data (i.e. drying kinetics) as well as the theoretical model, an inverse problem is formulated in order to estimate thermophysical properties such as the mass diffusivity.

#7856
Studies on drying of spurilina using convective process assited by capillary drainage

Hassini Lamine

The aim of this work was to study the drying of fresh spirulina using a convective process assisted by capillary drainage. Two sets of drying experiments were carried out. The first set of experiments was performed with the spirulina biomass spread in a thin layer (dimensions: 80x80x3 mm3). The second set of experiments was performed with the spirulina biomass spread in the form of cylindrical extrusions (diameter 3mm and length 12cm), with two different spacing (1 cm and 2 cm). For the both sets of drying experiments, the spirulina biomass was dried without any draining support (non-assisted drying) and placed on different draining support, namely: cotton fabric, microfiber cloth, 30 micron fabric and 80 micron fabric. According to the obtained results, for the biomass dried in thin-layer, the capillary drainage with the different draining fabrics reduces considerably the drying time, especially with the cotton fabric and the fabric 80 microns. Indeed, these two last industrial fabrics give almost the same result; the drying rate was 4 times greater than that of the trial without draining support. For the drying of cylindrical extruded biomass on the 80 micron fabric, the maximum drying rate was doubled for the small spacing and multiplied by a factor of 2.5 for the large spacing, compared to a trial without draining support. For all drying tests, the kinetic coefficient (called also the global mass transfer coefficient), specific to the falling rate period was calculated based on first-order kinetics.

#7859

Spray dried proliposomes of Rosmarinus officinalis polyphenols: a quality by design approach

Victor Oloruntoba Bankole, Claudia Regina F. Souza, Wanderley Pereira Oliveira

Harnessing the benefits of rosemary polyphenols is limited by variability in their physicochemical properties. These limitations may be overcome by encapsulation in systems possessing hydro-lipophilic centers thereby accommodating molecules of different polarities. Proliposomes offer a viable option in this regards, being particles which form liposomal suspension in water. Lyophilized extracts of rosemary was encapsulated in hydrogenatedsoyphosphatidylcholine/cholesterol by solvent replacement method. Spray dried proliposomes were obtained with lactose as carrier. Using Central Composite Design, the effects of lipid, extract and carrier concentrations on response variables including bioactive content and retention, moisture content characteristics, recuperation and redispersibility were evaluated by statistical analysis.

Keywords: Polyphenols; antioxidant; proliposomes; spray drying.

#7860
The drying and rehydration process of chayote (Sechium edule)

Alejandra Álvarez-Morales, Guadalupe Luna-Solano, Alejandra Ramírez-Martínez

Chayote (Sechium edule) is a fruit that is said to be a nutritional and have healing properties. 90% of its weight is made up of water which makes this fruit highly perishable. Convective drying is an excellent option to reduce the loss of this product as well as prolong its shelf life. Thus, the main objective of this work was to assess the physicochemical characteristics of different chayote samples (slices, cubes and strips) during its drying and rehydration process. Results suggest that cubes represent an alternative for commercial use as an additive in foodstuffs due to their size.

Keywords: chayote; convective drying; rehydration process; physiochemical properties.

#7861
Drying parameters influence on 'Ameclyae' Opuntia ficus prickly pear oil quality

L. Hassini, H. Desmorieux

The aim of this work is to study the effects of drying conditions on the quality of extracted pricly pear seed oil, specifically α-tocopherol content. Drying experiments were carried on following a full 23 factorial design using a vertical drying tunnel. The temperature range was 45 to 70°C, relative humidity range was 15 - 30% and air velocity was 1 and 2 m/s. The Midilli-Kucuk model was found with satisfaction describing the seed air drying curves with a correlation coefficient of 0.999 and a standard error of 0.01. For each drying condition, the extraction of fixed oil seeds was performed at cold using mechanical pressing method. The oil quality was evaluated on the basis of the a-tocopherol content. The a-tocopherol was identified and quantified by high-performance liquid chromatography (HPLC-UV). According to the experimental results, it was found that convective drying of thin layer of seeds at soft air conditions, drying temperature of 45°C, relative humidity of 15% and air velocity of 1m/s give the optimal quality of extracted oil in terms of a-tocopherol content.

Keywords: prickly pear seeds; convective drying; semi-empirical modeling; a-tocopherol seed oil; optimization.

#7871
Generation of high drug loading amorphous solid dispersions by Spray Drying

Bhianca Lins de Azevedo Costa, Martial Sauceau, Romain Sescousse, Maria Ines Re

Amorphous solid dispersions (ASDs) refers to drug - carrier systems, where the drug is dispersed in the carrier at a molecular level. In this work, ASDs were formulated by spray drying. The aim was to achieve high drug loads of an amorphous hydrophobic drug (Efavirenz - EFV) in the carrier Soluplus®. Solid state characterizations (mDSC, XRPD, DVS, Raman, SEM, stability and solubility studies) were done. EFV amorphisation in ASDs (20 to 85% EFV loads) resulted in improved drug solubility compared to unprocessed EFV crystals and tendency of properties evolution over time for ASDs with EFV loads higher than 70 wt%.

Keywords: amorphous solid dispersion, spray drying, high drug loading, soluplus, efavirenz.

#7879
Effect of particle size of blueberry pomace powder on its properties

Laura Calabuig-Jiménez, Cristina Barrera, Lucia Seguí, Noelia Betoret

Producing dried powders from blueberry pomace allows to reduce its environmental impact and gives value to this waste material. This work aims to evaluate the effect of particle size (fine or coarse) of blueberry pomace dried at 70 ºC on its fibre content and main physicochemical properties, including antiradical capacity, total phenols and anthocyanins content, hydration and emulsifying properties. The effect of storage on antioxidant properties was also evaluated. Results showed a significant effect of particle size on fibre content and consequently, on water retention, holding and emulsifying capacity of the powder. Neither phenols nor anthocyanins were affected by particle size or storage time.

Keywords: blueberry pomace, powders, fibre, antioxidant properties.

#7880
Changes in antioxidant and probiotic properties of a freeze-dried apple snack during storage

Cristina Burca, Lucía Seguí, Noelia Betoret, Cristina Barrera

This research developed an apple snack with potential probiotic effect (> 107 CFU/g) by combining vacuum impregnation with Lactobacillus salivarius spp. salivarius (CECT 4063) and freeze-drying. Throughout storage (30 days), both the lactobacillus viability and the total flavonoids content decreased. Trehalose adition (10% by weight) to the impregnation liquid and/or its homogenization at 100 MPa accelerated the loss of cell viability but delayed flavonoids degradation and promoted an increase in the amount of phenols and total antioxidants.

Keywords: L. salivarius spp. salivarius; homogenization; trehalose; freeze-drying; antioxidants.

#7881
Preliminary study of superheated steam spray drying: A case study with maltodextrin

Maelada Fuengfoo, Sakamon Devahastin, Chalida Niumnuy, Somchart Soponronnarit

A spray dryer was modified and tested with superheated steam as the drying medium. The effect of the inlet temperature on the recovery and morphology of the dried powder was then investigated. The results were compared with those obtained from hot-air spray drying. The results showed that the use of superheated steam and an increase in the inlet temperature led to an increase in the product recovery. The morphological results correlated with those of the product recovery in that superheated steam powder exhibited more inflated skin, leading to less adhesion of the sprayed droplets to the dryer wall.

Keywords: morphology; product recovery; spray drying; superheated steam drying.

#7883
Pre-fry drying: effect on physicochemical characteristics and formation of acrylamide on corn tortilla chips

M. Uscanga-Ramos, A. Ramirez-Martinez, R. I. Castillo-Zamudio, M. A. García-Alvarado, V. Robles-Olvera, Marco Antonio Salgado-Cervantes

The demand for fried products in the world has increased in recent years; however, the need for healthy products has prompted the food industry to develop low-fat fried foods without losing its original sensorial attributes and its characteristic texture. Thus, this study aimed to evaluate the effect of pre-fry drying on the absorption oil, physical and chemical characteristics and formation of acrylamide in corn tortilla chips fried in ten cycles. Additionally, frying tests were compared with tortilla chips that were not pre-dried and two commercial brands. The tortillas were randomly purchased from located mills in Veracruz, Mexico. Before drying, tortillas with 0.75 mm thickness were cut in a triangular shape (6.0 x 6.0 x 4.8 cm). Pre-drying treatment was performed in a tray dryer (Apex 28-BE) at 40, 50 and 60 ºC using two air velocities (1.0 m/s2 and 1.5 m/s2). Frying experiments were carried out by an electrically heated 1600 W, 6-l stainless steel vessel, using palm olein and avocado oil as frying oils at 160 and 180°C, during 60 and 90 s. The ratio oil: product was 40:1 mL/g according to Pérez-Tinoco et al. (2008). One mathematical model was used to analyze the effect of the number of cycles frying and type of oil on eight physiochemical characteristics (water activity, moisture content, fat content, °Hue parameter, Chroma parameter, luminosity, fracturability, and modulus of deformation during frying. The moisture content of chips was 0.60 kg water/kg s.s. after 35 min of drying, at 60 ºC and 1.5 m / s and it was achieved in less time than the rest of the treatments. Furthermore, the pre-dried chips showed a significant ($p<0.05$) decrease on the final oil content compared to tortillas chips without pre-drying (49-58%). Neither the repeated frying cycles nor to the oil type showed a significant ($p<0.05$) effect on the response variables studied. Furthermore, no significant ($p<0.05$) difference were observed between the fracturability values of samples of tortilla chips from repeated frying cycles (for both oils) and commercial brand chips. Finally, no sample presented acrylamide levels above the limit of quantification (LOQ<20 μg/kg). These results suggest that pre-fry drying, using palm olein or avocado oil, is an excellent technique to obtain low-fat, healthy corn chips.

Keywords: pre-fry drying, palm olein, avocado oil, acrylamide.

#7890
Influence of drying temperature and ultrasound application in some quality properties of apple skin

Matheus P. Martins, Edgar J. Cortés, Susana Simal, Antonio Mulet, Nieves Pérez-Muelas, Juan A. Cárcel

The great amount of waste produced by the food industry can be an interesting source of bioactive compounds. To this end, convective drying is one of the most extended method to stabilize the industrial by-products. However, drying conditions can affect not only drying kinetics but also the bioactivy of some compounds. Apple skin constitutes one of the main by-product generated in apple juice or cider production. It contains important amounts of functional compounds such as polyphenols or vitamin C whose extraction can be interesting. The main aim of this work was to determine the influence of drying conditions, temperature and application of ultrasound, in some quality parameters of dried apple skin. For this purpose, apple skin samples were dried at different temperatures (-10, 30, 50 and 70 ºC) and with (20.5 kW/m3) or without application of ultrasound. Color, total phenolic content, antioxidant activity and vitamin C was measured in fresh and dried samples. The increase of drying temperature and the ultrasound sligthly reduced the antioxidant properties of samples while no influence in sample color was observed.

Keywords: by-product; antioxidant; polyphenol; vitamin C; color.

#7960

Radio frequency-vacuum drying of kiwifruits: kinetics, uniformity and product quality

Shaojin Wang, Xu Zhou

A radio frequency (RF) vacuum technology is proposed for drying kiwifruit slices using a 27.12 MHz, 3 kW RF-vacuum drying system. The results demonstrated that electrode gap, vacuum pressure and sample thickness had major effects on the RF-vacuum drying. The RF-vacuum drying was associated with internal heating and rapid drying, resulting in 65% reduction of hot air (60ºC) drying time. Moreover, kiwifruits dehydrated by RF-vacuum drying were associated with better color stability, higher vitamin C retention and higher rehydration capacity ($P<0.05$). Overall, the RF-vacuum drying process may provide a more effective and practical method for high-quality dehydration of kiwifruits.

Keywords: radio frequency-vacuum drying; hot air; moisture content distribution; moisture effective diffusivity; quality.

#7965

Characteristics of oven-dried Jerusalem artichoke powder and its applications in phosphate-free emulsified chicken meatballs

Burcu Öztürk, Meltem Serdaroğlu

In this study, we aimed to investigate chemical and technological characteristics of oven-dried Jerusalem artichoke powder (JAP) to be further incorporated into emulsified chicken meatballs (with/without sodium carbonate) as sodium tripolyphosphate (STPP) replacers. The dietary fiber content of JAP was quite high to improve the health profile of the meat system. JAP samples showed equivalent technological quality to industrial inulin in terms of water-holding, oil-binding, emulsification and gelling abilities. Phosphate-free meatballs formulated with JAP and sodium carbonate had better health impacts compared with phosphate containing meatballs while cooking characteristics were similar. The results showed that oven-dried JAP presented a good health profile and high technological quality to be evaluated as inorganic phosphate replacers in formulation of emulsified poultry products.

Keywords: Jerusalem artichoke, oven-drying, emulsified chicken meatball, sodium tripolyphosphate, phosphate-free.

#7966
Quality changes of sucuks produced with turkey meat and olive oil during fermentation and ripening

Aslı Zungur-Bastıoğlu, Meltem Serdaroğlu, Burcu Öztürk, Berker Nacak

In this study, it was aimed to determine the effects of partial replacement of beef fat with olive oil on quality changes of fermented turkey sausages (sucuk) during processing. Three formulations were prepared by using the lipid phase as 100% beef fat (control), 85% beef fat+15% olive oil and 70% beef fat+30% olive oil. Total moisture, pH, acidity, water activity (aw) and peroxide values were analyzed in sausage dough, at the end of the fermentation and at the end of ripening. The production steps significantly affected moisture decrease in samples, pH and aw values were decreased and acidity was increased in all samples during production. Peroxide value of the samples increased during processing steps and the samples with olive oil had higher peroxide values compared to control. The results showed that during processing steps of fermented turkey sausages, considerable changes could occur depending on lipid type.

Keywords: sucuk, fermented sausage, dry fermentation, fat replacement, olive oil, turkey meat.

#8267
Effect of annealing on freeze drying of amorphous pharmaceutical formulations with high solid content

Getachew Assegehegn, Edmundo Brito-de la Fuente, José María Franco, Críspulo Gallegos

Freeze drying process is a common drying process used by pharmaceutical and biopharmaceutical industries to achieve long term stability of liquid formulations, which otherwise are unstable in their liquid form. Freeze-drying consists of three steps: freezing, primary drying and secondary drying. The freezing step determines the ice crystal size, number and morphology and, hence, affects the subsequent primary and secondary drying rates. The objective of this study was to evaluate the effect of annealing on the primary drying rate of a model amorphous formulation with high solid content during freeze drying of shelf-frozen samples in vials. A model multi-API complex pharmaceutical formulation, with a high solid content, was prepared for the purpose of this study. The model system was freeze dried in 10-mL vials with 5 mL fill-volume. Two freezing protocols (with annealing and without annealing) were performed. Annealing was carried out at a temperature of -20°C for 3 hours. During the freeze drying processes, the process parameters during primary drying were kept identical, in order to eliminate their effect on primary drying rate. Different researchers (Searles et al., 2001; Liu et al., 2005) had previously reported that annealing increases primary drying rate, due to the fact that the increase in ice crystal size during the annealing step reduces the mass transfer resistance during the subsequent sublimation process. In opposition to these findings, the results obtained in this study demonstrate that annealing does not have any effect on primary drying rate of the model system used. It can be then concluded that the effect of annealing on primary drying rate can be formulation-dependent and, for amorphous formulations with high solid content, annealing has been found to have no effect on primary drying rate.

#8268
Determination of rehydration properties of sun dried fruits

A. Ö. Karabacak, C. E. Tamera, Ö. U. Çopura

Drying is one of the most important preserving methods used in the food industry. This process is mostly used to minimize chemical, microbiological and enzymatic reactions which limit shelf life of fresh fruits and vegetables. The rehydration capacity is the most important quality properties for dried foods. Rehydration is a process in which dried product is treated with a liquid phase to regain its fresh properties. During rehydration, the increase in the product mass occurs due to the absorption of water into the food tissue. Several factors affect rehydration properties such as, drying methods, conditions and pretreatments, product composition and immersion media temperature. In this research, sun dried blueberry (Vaccinium corymbosum L.), ginger (Zingiber officinale Roscoe) and strawberry tree (Arbutus unedo L.) fruits with the moisture contents of 22.19 %, 14.04 % and 21.60 % respectively, were rehydrated in a distilled water with different temperatures (20°C, 30°C and 40°C). Rehydration experiments demonstrated that rehydration ratio of fruits increased with the rise of immersion water temperature. Moreover, at the beginning of the rehydration process, moisture recovery of the products was quickly carried out whereas, when moisture content of product approached equilibrium moisture content, rehydration rate was decreased. The highest moisture recovery was obtained from strawberry tree samples at 40°C and its moisture content increased from 0.27 to 1.30 g water/g dry matter.

Key words: rehydration, sun drying, blueberry, strawberry tree, ginger.

#8269

Effects of convective hot air drying on colour and drying characteristics of pumpkin slices

Azime Özkan Karabacak, C. E. Tamer, Ö. U. Çopura

Pumpkin (Cucurbita moschata Duch.) slices with the moisture content of 9.19 g water/g dry base were dried by convective hot air drying at 60, 70 and 80°C temperatures until the moisture content fell down to 0.13 g water/g dry base. Drying experiments were completed between 190 and 395 min depending on drying temperatures. For the selection of the most suitable thin layer drying model, six mathematical models (Page, Modified Page, Logarithmic, Lewis, Henderson and Pabis, Two Term Exponential) have been applied to the drying treatments. The higher correlation coefficient (R2), and reduced RMSE, Chi square (χ2), were used to identify the excellence of fit model in the drying of pumpkin slices. In the light of the statistical tests, Page and Modified Page were considered to be the best models with the highest value of R2 (0.9965) and the lowest value of RMSE (0.003498) and χ2 (0.000272) compared to the other models. All color parameters (L*, a*, b*, C*ab, ΔE* and h°) changed depending on the drying temperatures. The effective moisture diffusivity (Deff) values of dried pumpkin slices increased with the rise of drying temperatures and ranged between 2.79 ×10-10 to 6.01×10-10 m2/s.

Key words: pumpkin, drying, mathematical modelling, colour, effective moisture diffusivity.

#8280

A perspective on economic importance and nutritional value of the main dried fruits produced in turkey

Senem Suna, Canan Ece Tamer, Ömer Utku Çopur

Turkey plays an important role worldwide in the production of many different kinds of fruits and vegetables related with geographical location and favorable climate conditions. In this point, fruits can be consumed as in fresh and dried forms. Dried fruits are of great importance in agricultural sector with a fairly high market demand worldwide. According to the world statistics of 2016, Turkey came in the first place in the production of dried apricots, dried figs and raisins with the ratios of 62% (110.000 tons), 47.1% (60.000 tons) and 22.1% (300.000 tons) respectively. Additionally, dried apricots contain provitamin A and vitamin E and minerals like phosphorus and potassium. Dried figs also include fiber, complex carbohydrates and minerals like copper and manganese. Raisins are a good source of vitamin B, iron and potassium. In this study, economical potential and nutritional value of these top three dried fruits will be discussed in details.

Key words: Raisin, dried fig, dried apricot, nutrition, minera.

#8352
Comparison of drying characteristics and thermal properties of precooked white kidney-beans and mung beans

Gamze Okur, Ismail Bölük, Melisa Günaydın, Sebnem Tavman, Seher Kumcuoglu

Legumes are great sources of fat, protein and carbohydrates also contain large amount of fiber. Basically, a legume is a flowering plant that has edible fruits or seeds. These foods are a staple of vegetarian diets but also non-vegetarians have benefit from eating legumes. The aim of this study is to obteined a ready to eat product to be used as snacks or in in salads or in dried soup mixes. The processed applied to the legumes are soaking, precooking then drying, to extend the shelf life. For this purpose two different species of legumes; white kidney-bean and mung bean were used as testing material. Before white kidney-beans are soaked for 8 hours while for mung beans two different soaking time 4-8 hours were applied. For white kidney-beans the time for boiling were 5-15-30 minutes and then each boiled samples were dried at 70-80-90°C. For the mung beans the time of the boiling were 5-10 minutes and then the samples were dried at temperatures of 50-60-70°C. Their sensory tests were applied to the samples to compare color and taste. The samples were subjected to differential scanning analyses to determine glass transition temperature to determine the degree of scalding and drying gelatinization. According to the rehydration tests the water uptake rates increased as the boiling period of the beans increased, and also the time required for drying with increased boiling time were also increased. As the drying temperature increased, the time required for drying was decreasedand the darkness of the color were increased. And glass transition temperature of these samples was checked

Key words: Drying, Kidney bean, mung bean.

#8368
Phenolic content, antioxidant and antibacterial properties of three Tunisian plants dried using hot air

Radhia Abdelkebir, Cristina Alcantara, Maria Carmen Collado, Mohamed Neffati, Jose F. Fernandez-Salguero, Francisco J. Barba, Jose V. Garcia-Perez

Since ancient times people have explored the nature of plants in search of new drugs or active principles with health beneficial properties. Tunisia has a high diversity of plants, as a result of the variation in climate and edaphic conditions around the country, thus exhibiting a wide range of high-added value compounds. Most of the beneficial properties of plants are attributed to their high content in antioxidant bioactive compounds (eg. polyphenols), which also can have antimicrobial properties. This work aims to address the impact of hot air drying on bioactive compounds of three characteristic edible plants of the Tunisian arid areas (Erodium glaucophyllum, Ziziphus lotus and Cymbopogon schoenanthus), which has been traditionally used for therapeutic and culinary uses.
Samples were dehydrated at 25 ºC by using a convective drier and ground into a powder. Extractions were carried out using conventional extraction an ethanolic solution (50%, v/v) as solvent for 10 min. Total Phenolic and carotenoids content, antioxidant capacity (Trolox Equivalent Antioxidant Capacity TEAC), and antibacterial activity (against 6 bacteria) were measured.
The Analysis of Variance showed a significant ($p<0.05$) influence of plant matrix on the extraction of the high-added value compounds and antimicrobial activities, obtaining the highest phenolic content for Erodium roots (29.2 mg GAE/g DM) followed by Ziziphus roots (20.4 mg GAE/g DM) and Cymbopogon aerial part (13.1 mg GAE/g DM). Similar results were found for total flavonoids, obtaining the highest amount in the extracts obtained from Erodium roots (16.1 mg CE/g DM) followed by Ziziphus roots (9.7 mg CE/g DM) and Cymbopogon aerial part (4.7 mg CE/g DM). The highest antimicrobial potentials against Salmonella enterica (in growth rate and maximal optical density) and Listeria innocua (in growth rate) were observed for the Erodium bark/roots extract. Ziziphus extract showed the highest growth rate for the pro-inflamatory strain Staphylococcus aureus. Concerning the probiotic strains, Cymbopogon aerial part extract stimulated the growth of Lactobacillus casei. Further studies addressing the influence of different drying methods on bioactive compounds are required in order to optimize the industrial extraction stages.

#8371

Impacts of air drying and DIC pretreatments on textural properties of frozen/thawed apple fruits

L. Ben Haj Said, Sihem Bellaga, K. Allaf

This research work is about dehydrofreezing assisted by DIC treatment as an innovative conservation process of apple fruits. Samples previously dehydrated and DIC treated were frozen at -30 °C and at two different practical freezing rates. The effects of sample water content (W) and practical freezing rate (PFR) on freezing characteristics and apple texture were examined. Thaw exudate water (TEW) of 200% and 100% db samples was approximately 3 g/100 g water. Whereas, it was lower than 0.5 g/100 g water for samples with 30% db W during thawing at 4 °C. Moreover, the impact of PFR on TEW was significant and very important only for high W samples. For samples whose water content was lower than 100% db, firmness was as higher as the W was lower, without any significant impact of PFR.

Keywords: Dehydrofreezing; Instant controlled pressure drop; Water content; Practical freezing rate; Texture.

#8372
Partial drying of apple fruits to improve freeze/thaw quality during long term frozen storage

L. Ben Haj Said, S. Bellaga, K. Allaf

Apple samples were submitted to partially drying prior to freezing. Then, quality assessments were achieved in order to evaluate the quality of these various frozen samples during frozen-storage. Significant positive effects of water content were observed on thaw exudate water and total color difference of dehydrofrozen/thawed apples. Total polyphenol content and total flavonoid content losses were important for samples without any dehydration pretreatment. They noticeably decreased when water content decreased during the whole period of storage. Thus, a partial removal of water prior to freezing is a relevant way to maintain the stability of fruit quality during long-term frozen-storage.

Keywords: Apple fruits; dehydrofreezing; frozen storage; color; polyphenol.

#8373

Combined effects of sodium carbonate pretreatment and hybrid drying methods on the nutritional and antioxidant properties of dried Goji berries

Huihui Song, Jinfeng Bi, Qinqin Chen, Mo Zhou, Xinye Wu, Jianxin Song

Combined effects of sodium carbonate (SC) pretreatment and hybrid drying methods (freeze drying-instant controlled pressure drop drying (FD-ICPDD), hot air drying (HAD-ICPDD) on nutritional and antioxidant properties of Goji berries were investigated. Compared with distilled water pretreatment, SC pretreatment could obtain products with better quality. Goji dried by FD-ICPDD showed better overall quality than that dried by HAD or FD alone. FD-ICPDD products exhibited higher contents of total Lycium barbarum polysaccharide (140 g/kg), total carotenoids (2.4 g/kg) as well as the strongest ABTS.+ radical scavenging activity (57.6 μmol TE/g). FD-ICPDD could be an alternative drying method for processing valuable agro-products.

Keywords: sodium carbonate, instant controlled pressure drop drying, nutritional properties, antioxidant activity

#8535
Modeling of prebiotic-supplemented powdered infant formulas quality parameters using machine learning

Carlos Sabater, Antonia Montilla, Adrián Ovejero, Agustín Olano, Nieves Corzo

The food industry has made several attempts to develop infant formula (IFs) that fulfill the nutritional needs of the new born including supplementation with prebiotic oligosaccharides. Some processes in IF manufacture, involving heat, can give rise to a loss of nutritive value. Maillard reaction (MR) takes place during IFs processing and storage causing deterioration of proteins. Furosine is an indicator of early stages of MR while hydroxymethylfurfural (HMF) is used to evaluate intermediate and advanced stages. On the other hand, data modelling allows finding valuable relationships between the chemical changes suffered by the samples. Two classification methods based on statistical learning theory, support vector machines (SVM) and random forests (RF) have been applied on spectroscopic data of milk powder for brand identification and component analysis. Therefore the aim of this work has been to use SVM and RF classification methods to study the relationships between 24 commercial prebiotic-supplemented and not IFs considering a set of quality parameters: pH, aw, protein content, carbohydrate composition (reducing sugars and prebiotic content) and MR indicators (furosine and HMF). For this, samples were grouped in different categories according to i) protein source (whey, whey hydrolysates, milk, soy, amino acids), ii) carbohydrate source (lactose, maltodextrins, lactose and maltodextrins) and iii) by age, (starting, follow up) types.
Furosine, HMF and prebiotic content ranged from 94 - 1226 mg 100 g-1 protein, 62 -510 μg 100 g-1 and 0.08 – 5 g 100 g-1 product, respectively. Then, samples were classified using SVM and RF. SVM finds patterns in empirical data with regard to sample categories. In RF, multiple decision trees are constructed, outputting the different classes and each node is split using a subset of variables. These models were trained with 70% of the data, 10-fold crossvalidated and then tested with 30% of new data. According to the results obtained, high classification rates of new IFs were reported with these models, being according to protein and carbohydrate source and by age types, 90.0, 90.0 and 90.0% and 80.0, 90.0 and 85.0%, for SVM and RF prediction parameters, respectively. Furosine and reducing sugars were the most influent factors in SVM, while prebiotic content was also influent in RF prediction.
These models allowed to classify commercial IFs and could be applied on identification of IFs from unknown origin.

DRYING PROCESS

Oral Presentations

#7251
Experimental analysis of particle breakage and powder morphology in foam spray drying

Artur Lewandowski, Maciej Jaskulski, Ireneusz Zbiciński

The paper presents results of experiments of gas admixing foam spray drying of maltodextrin in co-current spray tower. Significant effect of feed foaming on particle sphericity, angle of repose, apparent and bulk density, Hausner ratio and porosity was found. Number of broken particles achieved 60 % for high foaming gas rate (GLR) and inlet air temperature due to particle overheating and bubble expansion. Analysis of the experiments results allowed to determine optimal range of operating conditions to reduce number of damaged particles, to around 15 % for the highest GLR and to minimize product degradation.

Keywords: foamed materials, gas admixing, powder properties, powder quality.

#7289

Spray drying of high viscous food concentrates: Investigations on the applicability of an Air-Core-Liquid-Ring (ACLR) nozzle for liquid atomization

Marc Oliver Wittner, Heike Petra Karbstein, Volker Gaukel

Spray drying is widely used for powder production from liquid concentrates. Often low input temperatures are desired, as many materials, like proteins, are sensitive to heat. However, this demand leads to increased concentrate viscosities. Commonly used pressure swirl atomizers are limited concerning maximum processible viscosity. In this study, a so called Air-Core-Liquid-Ring Atomizer is used for pilot scale spray drying of whey protein concentrate (WPC80) at 40 °C and hence a viscosity of 0.09 Pa s. The produced powder was compared to an industrially produced reference. As a result, no significant differences in particle size distribution and particle morphology were observed.

Keywords: spray drying, atomization, ACLR, high viscous feeds, whey protein concentrate.

#7300
Heat recovery from biomass drying in energy systems

J. Havlik, T. Dlouhý

This paper deals with energy savings by the heat recovery of waste vapour from moist biomass drying in energy systems. Drying is an energy-intensive process. Energy consumption can be reduced by using indirect drying by recuperating the heat of waste vapour generated in the process; however the vapour is polluted by air and small mechanical particles. Experiments with green wood chips were realized on an indirect dryer with a condensing heat exchanger to experimentally verify the grade and conditions of heat recovery from waste vapour. On the basis of the experimental results, the potential of the heat recovery from waste vapour was evaluated.

Keywords: Indirect drying; Biomass; Waste vapour; Heat recovery.

#7313
Capillary disconnect during drying in model porous media at different wettability

Ayorinde K. Rufai, John P. Crawshaw

We carried out drying studies on a 2.5D micromodel based on a thin section of a carbonate rock to investigate the impact of wettability on the capillary disconnect, the moment when liquid films de-pin from the external evaporating surface. While this is coincident with the transition to low evaporation rate (diffusion limited) for deionized-water, our experiments show, the corner wetting films persisted after the transition to low evaporation rate for both water-wet and mixed-wet micromodels for brine, as solid salt continued to build up at the external evaporating surface. Fully oil wet micromodels showed a drying rate transition coincident with de-pinning.

Keywords: Capillary; Liquid films; Micromodel; Wettability; Crystallization.

#7329
Ultrasound assisted low temperature drying of food materials

H. T. Sabarez, S. Keuhbauch, K. Knoerzer

An ultrasonic design based on the indirect transmission of ultrasonic energy from the ultrasound emitter through to the material to be dried was investigated to assist in low temperature drying of food materials. The application of the improved design tested in this work was found to enhance the low temperature drying by shortening the overall drying time of up to 45% (i.e., lower energy consumption and may enable better retention of product quality). This offers a promising approach towards a better applicability of ultrasound in industrial operation, since no direct contact between the sample and the ultrasonic emitter is needed.

Keywords: ultrasound; drying; low temperature; drying intensification.

#7368
Microwave assisted fluidized bed drying of celery

Amanat Kaur, Yvan Gariépy, Valérie Orsat, Vijaya Raghavan

The drying kinetics of celery in a microwave assisted fluidized bed dryer was studied at different drying air temperatures (45°C, 55°C and 65°C) and at different initial microwave power densities (0W/g, 1W/g and 2W/g). Dried product quality, product mass, air temperature, air relative humidity, and electric power consumption were used to monitor the performance of the drying process. The results showed that the Midilli-Kucuk model was best in predicting the moisture ratio as a function of drying time. At any given temperature, the utilization of the microwave energy reduced by more than 50% the drying time.

Keywords: drying; celery; MWFBD.

#7372

The consumption of exergy for lignite drying with different technologies: a comparative theoretical study

Ming Liu, Shan Wang, Rongtang Liu, Xiaoqu Han, Junjie Yan

Pre-drying is an effective method to upgrade lignite and broaden its utilization areas. Various drying technologies could be applied to pre-dry lignite. The drying temperature in these drying technologies are different, which means that energy at different grades is used in these dryers. To analyze the irreversibilities of drying process, the exergetic analysis models are developed in this study. The exergy feeding and consumption rates are defined as the indicators. Various lignite drying technologies are calculated and quantitatively compared. Results show that exergy consumption rate for steam fluid-bed dryer is the smallest, which is 432.6 kJ (kg H2O)-1.

Keywords: lignite; drying technologies; exergy analysis; thermodynamics.

#7380
CT-scanning of the drying process of Eucalyptus nitens

José Couceiro, Lars Hansson, Ahec Ambrož, Dick Sandberg

The drying of Eucalyptus nitens is a troublesome process as the species is extremely prone to drying defects. This paper reports ongoing research to improve the understanding of surface checking and cell collapse in Chilean grown Eucalyptus nitens during drying. Computed tomography (CT) scanning was used as a powerful tool for studying the internal changes in the wood-material during the drying process. Different levels of temperatures have been tested with the same equilibrium moisture content (EMC) conditions and low air velocity. The results confirm that a low drying temperature and a low air velocity, which results in a slow rate of drying, reduce internal cell collapse and surface checking .

Keywords: Cell collapse; computed tomography; surface checks; wood drying; internal checks.

#7396
Experiments, modeling and optimization of fluidized bed PVC drying

Benoit Haut, Frédéric Debaste

Poly-vinyl-chloride (PVC) is an omnipresent material in nowadays life. With a worldwide production of 33 109 kg in 2007, PVC is one on the most synthesized polymers. Most of the PVC production processes include a operation of drying of the granular material, generally realized in a fluidized bed. The huge worldwide PVC production combined to the fact that drying is highly energy consuming leads to a need for optimization of the process conditions, in order to minimize energy consumption without degrading production rate and product quality. However, no simple model to simulate the drying of PVC grains is available today.

In this work, the fluidized bed drying of PVC grains is optimized using a simplified model. This model is validated by comparison with data obtained on an experimental laboratory batch fluidized bed dryer. The model is based on a simplified expression of the transport phenomena in the dryer and in the grains. In the dryer, the gas phase is assumed to behave like a continuous stirred tank reactor (i.e. it is assumed that the air moisture content and temperature are homogeneous at a given time in the whole drying chamber). The drying of the grains is divided in two successive periods: a constant rate period (CRP) characterized by a constant mass transfer rate from the grain to the surrounding air and a falling rate period (FRP), during which the evaporation is assumed to take place from a linearly decreasing fraction of the surface of the grain. Heat losses to the surrounding are also taken into account. This model has only one adjustable parameter: the critical moisture content defining the transition between the CRP and the FRP. This parameter value is obtained on a typical experiment and then validated on another set of data (cross-validation).

The identification of the conditions to minimize the drying time in a batch fluidized bed dryer does not require the use of a model: inlet temperature and air flow rate have to be maximized and inlet air humidity has to be minimized, both within acceptable ranges. However, the model is useful to predict what set of conditions minimize the energy consumption. Choosing a cost function, taking into account energy costs of inlet air drying, inlet air warming and flow generation, and combining it to the model allows determining which conditions leads to the minimal energy consumption. Different cost functions have been selected and the resulting optimal operating conditions of the laboratory fluidized bed are determined.

#7402

Effects of different drying methods on the physicochemical properties of powders obtained from high-oleic palm oil nanoemulsions

M. Hernández-Carrión, M. Moyano-Molano, L. Ricaurte, F.L. Moreno, M. X. Quintanilla-Carvajal

Nanoencapsulation is an efficient process to incorporate high nutritional oils, such as high oleic palm oil (HOPO). Several drying technologies can be applied for obtaining HOPO powders. The aim of this work was to study the effect of two different drying methods (spray-drying, SP and freeze-drying, FD) on some physical properties and microstructure of powders obtained from HOPO nanoemulsions. Results showed that FD powders presented lower aw and bulk density, and higher dissolution rate than SD powders. Results suggest that SD could be a more economical alternative to FD in order to obtain HOPO powders with low moisture and aw.

Keywords: freeze-drying; high oleic palm oil; nanoemulsion; spray drying.

#7426
Multifluid macroscopic approach to drying in papermaking

Francisco J. Durán-Olivencia, Milad Farzad, Burt S. Tilley, Jamal S. Yagoobi

Drying process represents one of the main energy-consuming stages for a broad variety of manufacturers. However, despite its significant impact on energy efficiency, most implementations at manufacturing level do not operate within the optimal conditions.
This work investigates the interplay among different parameters involved into the paper-drying process. To do so, we analyze both experimental and numerical results. The theoretical approach couples a non-isothermal flow, along with the heat transfer and transport of different fluids participating. Our results, experimental and numerical, show a good agreement according to the characteristic drying time scale. The results thus enable to estimate the impact of different mechanisms into drying process.

Keywords: paper-drying process; free water; bound water; papermaking.

#7469

Freeze dried quince (Cydonia oblonga) puree with the addition of different amounts of maltodextrin: physical and powder properties

Özle Ünlüeroğlugil, Hira Yüksel, Gülşah Çalışkan Koç, Safiye Nur Dirim

This study aims to determine the drying behavior of quince puree and as an adverse effect powdered sugar added quince puree with the addition of maltodextrin. The addition of powdered sugar increases the drying time and the total amount of energy and the same time slightly decreases the moisture content and water activity values. The color values and the properties on these values changed both with the addition of maltodextrin and powdered sugar. The density values, flow properties and reconstitution properties are significantly affected by the amount of maltodextrin in plain or powdered sugar added samples.

Keywords: quince, freeze-drying, maltodextrin, powder properties.

#7489
Accelerated drying of whole unpeeled cherry tomatoes after skin abrasive treatment

Theo Guenter Kieckbusch

This research considered an innovative method to accelerate the production of dehydrated unpeeled whole cherry tomatoes to be established as a gourmet product. In order to decrease the impermeability of the tomato skin without visible damage to the fruit integrity, Sweet Grape cherry tomatoes were submitted to an abrasive treatment of the epicarp, necessary and sufficient to exfoliate part of the external superficial skin layer, the main resistance to moisture mass transfer. The test were conducted in a horizontal rotating drum, with the internal wall covered by grit size 180 sandpaper, during 30 minutes. The performance of the abrasive treatment was evaluated monitoring the dehydration of treated and untreated cherry tomatoes placed in a perforated tray inside a vertical cylindrical dryer with air at 55ºC, 70ºC and 85ºC flowing through the fruits. Considerable reduction in drying time was found for the abrasive treated tomatoes in relation to the untreated ones, mainly at lower drying air temperatures. Differences in the drying behavior were observed from the very beginning of the dehydration process so that the initial water loss flux was use as a parameter to quantify the extension of the effect of the abrasive treatment. Considerable degradation of Ascorbic Acid was found in tomatoes submitted to the abrasive process and the final contents of Vitamin C in the dehydrated tomatoes , peeled and unpeeled, was very low.

#7501
Drying the corn in a farm heat pump dryer with fluidized bed

Stanislav Pavlovich Rudobashta, Galina Albertovna Zueva, V.M. Dmitriev, E.A. Muravleva

The possibility of using a heat pump as a part of on-farm drying plant is considered taking drying of corn grain as an example. The methodology for kinetic calculations of a drying plant with a batch fluidized bed for granular materials is developed. These calculations are based on the use of an analytical solution for the problem of mass conductivity and taking into account the time-related changes in drying agent parameters over the layer height. To determine the concentration dependence of the mass-conductivity coefficient, a zonal method has been used.

Keywords: heat pump; dryer; kinetic calculation.

#7502

Optimization of processing parameters during foam mat drying of hybrid (EVA F1) tomato pulp

Adejoke Awodein, Olajide Sobukola, Abdul-rasaq Adebowale, Lateef Sanni, Oluseye Onabanjo, Augustine Okoruwa

Response Surface Methodology based on Box-Behnken design was used to optimize the processing parameters during foam mat drying of tomato pulp (EVA-F1). Effect of three independent variables (concentration of foaming agents-3, 4 and 5% Glycerol monostearate; drying temperature-50, 60 and 70oC; and drying time-6, 7 and 8 hrs) were investigated on some quality attributes of dried sample. Foam mat dried samples were analysed for moisture, beta-carotene, vitamin C (as Ascorbic acid), flavonoids, lycopene, Total Titratable acidity and pH. Optimized foam mat dried samples were then compared with samples dried under sun, cabinet and oven driers. The effect of drying temperature and time was more significant. However, the effect of concentration of GMS was more significant on beta-carotene of the samples. The optimum processing condition for best quality foam mat dried tomato powder was drying temperature of 60.72 °C, drying time of 6 hours and GMS concentration of 4.67%. Generally, foam dried tomato powder retained more nutrients than sun, cabinet and oven dried tomato slices.

#7511

Ultrasonic atomizing-assisted spray drying: Effect on the quality of skimmed milk powders

Yuchuan Wang, Ying Cui, Bo Wang, Min Zhang

Skimmed milk powders (SMP) were produced by ultrasonic atomizing-assisted spray drying (UASD). It was found that UASD can produce high quality SMP (with < 5% moisture content and < 2% insolubility) at lower inlet temperatures (~130℃). The particle size of the UASD-SMP was 10 times smaller (decreased from ~20 μm to 4 μm) than the tranditionally spray-dried SMP and the color appeal of UASD-SMP was also better (L* value increased by > 6 %). Overall, this research shown that UASD can be used to produce small particle size and high quality SMP.

Keywords: Skimmed milk powder; ultrasonic atomization; spray dryer; particle size distribution; color.

#7515
Agitated thin-film drying of spinach juice

J. Qiu, R. M. Boom, M.A.I. Schutyser

Agitated thin film dryers (ATFD) has been considered as an effective technology for drying viscous liquid foods, pastes or pureed foods. In this study, a lab-scale ATFD was developed and applied for drying of juices from spinach leaves at varying temperature (60 – 90 ˚C), feed rate (0.3 – 0.5 kg/h) and blade rotation speed (300 – 600 RPM) combinations. Juice suspensions were successfully dried into powder with a moisture content ranging from 0.049 to 0.114 kg/kg total. Increasing the wall temperature and feed rate were found to improve the specific evaporation rate and evaporation rate of the ATFD, respectively. The blade rotation speed had limited effect on the water removal rate, while it played a crucial role in powder formation.

Keywords: Food solution; Spinach juice; Thin film drying; Scraped surface; Vacuum conductive drying.

#7551
Influence of the low temperature drying process on optical alternations of organic apple slices

M. Bantle, C. A. Kopp, I. C. Claussen, I. Tolstorebrov

Drying conditions for convective driers are often based on empirical approaches in which the final product quality is evaluated post processing. Modern sensor technology and data processing enable second-by-second quality analyses but conventional systems do not utilize this possibility. An industrial convective drying chamber was modified with a camera system to investigate the product during the drying process. The obtained data was analyzed on color alternation (CIE-L*a*b* color space and Browning Index), shrinkage and deformation. Both, shrinkage and deformation show minor dependence on drying conditons. The investigation shows the time depending optical parameter at different drying conditions. This might offer new "smart" drying programs with focus on improved product quality.

Keywords: color alternation; shrinkage; deformation; convective drying; smart drying.

#7569
Drying of orange slices using vacuum microwave dryer

Hamza Bozkir, Yeliz Tekgül, Taner Baysal

Drying is one of the oldest methods of food preservation. Conventional drying, which contains hot air, is the most common techniques uses in the food industry. However, there is much loss of thermal energy and lengthy drying time in convective drying. Furthermore, conventional drying also gives rise to change in physical, chemical and nutritional properties of food such as undesired food flavor, color decomposition, tough texture, severe browning, low rehydration rate and vitamin degradation. In recent years, novel drying techniques have gained importance the disadvantages of conventional drying. Novel techniques such as vacuum microwave dryer increases drying rates and keep the product quality. In this study, the aim was to evaluate the influences of vacuum microwave technique on some quality characteristics of the orange slices (color, vitamin C, total phenolic content, bulk density, and limonene content). Vacuum microwave dryer (50, 60 and 70 °C, 334 W) was used to model the drying curves.
Consequently, it was determined that the drying times of the vacuum microwave dryer at 50, 60, 70 °C were 126, 87 and 51 min, respectively. It was determined that the increase in temperatures of 50, 60, and 70 °C vacuum microwave dryer caused a decrease in values of L* whereas an increase a* and b* values. It was found that the increase in temperatures of 50, 60, and 70 °C vacuum microwave dryer caused a decrease total phenolic content. It was found that the increase in temperatures of 50, 60, and 70 °C vacuum microwave dryer caused an increase total carotenoid content.

Keywords: orange slices, vacuum microwave, drying, and quality.

#7581
Synthesis of titanium dioxide precursor by the hydrolysis of titanium oxychloride solution

P. Le Bideau, M. Richard-Plouet, P. Glouannec, A. Magueresse, D. Iya-Sou, L. Brohan

This communication focuses on the development of an approach to improve the synthesis of [Ti8O12(H2O)24]Cl8.HCl.7H2O crystals which is one of the precursor for titanium dioxide TiO2 particles. This study provides a significant improvement in crystallization kinetics with a production rate increased by a factor nineteen by intensifying heat and mass transfers compared to the process in a close vessel. This enhancement was made possible by the development of a new reactor to control the heat and mass transfers involved. In parallel with the experimental set-up, a numerical model representative of the transfer phenomena was initiated. The first numerical results are encouraging and present a good agreement with the measurements.

Keywords: Heat and mass transfer; Co-desorption, Modelling, Experiment.

#7625
Stabilization of Lactobacillus sp. with enhanced thermal resistance by spray-drying

Daniel Rivera, Mariana Valverde, Ana Valera, Ana Torrejón, Joaquín Espí, Encarna Gómez, Begoña Ruiz

Combining biotechnology and encapsulation by spray-drying is possible to obtain microorganisms-based products in powder format without losing viability. A methodology based on the improvement of the thermal stress resistance of selected strains of Lactobacillus sp. and subsequent culture stabilization by spray-drying by optimizing the process parameters and using thermal protectant materials has been developed. The results obtained showed that the final product kept the viability of the initial culture in addition to be a solid, powdery and ease-to-handle product.

Keywords: thermal resistance; spray-drying; probiotics; viability; fermentation; encapsulation.

#7638
Microwave-freeze-drying of fruit foams for the production of healthy snacks

Mine Ozcelik, Sabine Ambros, Ulrich Kulozik

Due to increasing health awareness, healthy snack products have recently become more attractive for many consumers. Foams made out of fruit purees can subsequently be dried and consumed as snacks. Such dried foams can disintegrate very quickly upon contact with the saliva in the mouth, leading to a spontaneous flavor release. This "Aroma-Flash" is perceived as a positive sensory experience. Foams produced by microwave-assisted freeze drying have a more porous and cellular structure, which makes them favorable compared to the foams obtained by conventional drying of fruit puree. It is well known that freeze-drying is one of the leading methods to obtain high quality products. However, it requires long drying times, which result in high energy consumption and thus, proportionaly high production costs. To make such fruit snacks affordable for the consumer, a gentle but simultaneously fast drying process has to be applied. Since a volumetric heating of a product can be achieved via electromagnetic radiation, the addition of microwave (MW) energy to a freeze-drying process can lead to a rapid and also an energy-efficient drying without deteriorating the product.

The aim of this study was to investigate the effect of MW-assisted freeze drying on the drying behavior of raspberry foams. Potato protein as plant origin protein is applied as a foaming agent and the polysaccharides maltodextrin and pectin are used as stabilizers.

Raspberry foams were dried by MW-freeze-drying under various MW power input levels at a constant chamber pressure. During the MW-assisted drying, the product temperature was controlled via pulsed MW application. Freeze-drying experiments was performed as a reference.

The drying behavior was evaluated based on the drying kinetics, temperature distribution, absorbed microwave energy, and energy efficiency for the tested conditions.

The results showed that MW-assisted freeze drying yields shorter drying times, lower energy consumption, and highly satisfactory foam characteristics. In this regard, microwave-assisted freeze drying could be a promising alternative to conventional freeze drying as it offers a more efficient process with comparable product quality.

#7686
CFD study of air flow patterns and droplet trajectories in a lab scale vortex chamber spray dryer

Umair Jamil Ur Rahman, Ilias Baiazitov, Artur Pozarlik, Gerrit Brem

In order to develop an alternative spray drying technology, a high drying rate in a smaller volume must be achieved. In this paper, results of CFD study are presented, carried out to investigate the possibility of spray drying in a novel design vortex chamber. The model is validated against experimental data, that makes a good agreement with an average error of 7% with only air and 24% with water spray. Results of temperature fields and droplet impact positions are discussed. The computations demonstrate that vortex chamber spray dryer can be an attractive solution for drying technology.

Keywords: CFD; spray drying; vortex chamber; atomization.

#7762
Challenges in thermal & non thermal processing of algae

Bhaumik Bheda, Deepthi Menon, Ramesh Bhujade, Bhaskar Thorat

Algae can be widely used as feed for fishes, extraction of oil, energy resources, fertilizer, pigments and many other purposes. However, the processing of algae for the final use poses a lot of challenges. The filtration of algae for removal of excess water poses a challenge because algae being slimy clogs up the filter paper and prevents filtration. The drying of algae is also another challenge because the solid content is only 10-15% therefore, a lot of energy is used and therefore the process is not energy efficient. Also algae being a biological product, it degenerates at temperatures above 65°C, hence the drying temperatures have to be controlled to obtain the desired nutrient and LPC (Lipid, Protein & Carbohydrate) content so that it can be used as the final product. This paper emphasis on the challenges faced and the possible solutions to overcome these challenges so that the application requirements are met.

Keywords: Processing, Algae, Filtration, Drying.

#7791
Effects of drying temperatures on color and curcuminoid contents in turmeric

Nilobon Komonsing, Pramote Khuwijitjaru, Marcus Nagle, Busarakorn Mahayothee, Joachim Müller

Turmeric (Curcuma longa L.) is a herbal plant widely grown in Asian countries. Its rhizome is a good source of curcuminoids which play an important role as orange-yellow color pigment, antioxidant and anti-inflammatory agent. Curcumin, demethoxycurcumin and bisdemethoxycurcumin are the major curcuminoids found in turmeric. Tumeric is generally processed into dried slices and powder for extending shelf-life. In this study, the influence of drying temperatures on color and curcuminoid contents was investigated. Fresh turmeric rhizomes at the maturity of 9 months were sliced to a thickness of 4 mm, and then cut into a rectangular shape of 4 × 40 × 8 mm before drying. Drying experiments were conducted using a high precision hot air tray dryer (±1 °C) with an under- and overflow mode. The drying conditions were varied at 5 temperatures (40, 50, 60, 70 and 80 °C). Air velocity and specific humidity of drying air were fixed at 0.5 m/s and 25 g water/ kg dry air, respectively. The fresh samples were dried until the moisture content of dried products was lower than 12%. Fresh and dried samples were taken for color measurement (L*, a*, b*, C* and h°), total curcuminoid contents, curcumin, demethoxycurcumin and bisdemethoxycurcumin analyses. For color measurement of dried samples, dried turmerics were ground into powder prior to analysis. The drying times used for drying at 40, 50, 60, 70 and 80 °C were 37, 26, 9.7, 6.8 and 3.6 h, respectively. It was found that with a very different in drying times, drying temperature did not obviously influence the color values of dried products. However, b*, C* and h° values of turmeric powder obtained from 70 °C were significantly different from those of 40 and 50 °C ($p < 0.05$). The three color values of powders from 70 °C were the lowest which indicating the better color of dried product. In addition, drying temperature did not show significant effects on total curcuminoid contents, curcumin, demethoxycurcumin and bisdemethoxycurcumin of the dried turmerics ($p > 0.05$). Thus, turmeric slices using a tray dryer could be done at higher temperature for accelerating the drying process without an adverse impact on the color and bioactive compounds of dried products.

#7795

Features of an industrial nut roasting process to enhance quality, safety and efficiency

Pablo García-Pascual, Francisco Pastor-Martí, Charles Boddy, Jose Vicente Roig-Borrell

Roasting is a process that comprehends a drying stage as well some physico-chemical changes in the product parameters. Currently, the design of an industrial roasting process for food and agricultural materials, such as nuts, must comply with different issues, which, taken as a whole, defines the limits of the roasting system. Those requirements include at least the following ones: energy efficiency, energy sources, clean ability, low fire risk, product quality homogeneity, pasteurization alternatives and modularity, among others. These criteria will be reviewed and matched with current industrial equipment and/or developments to be addressed in the future. Examples for the main requirements, taken from the roasting of some common nuts (almonds, hazelnuts, peanuts…) will be provided in order to enlighten the aforementioned issues.

#7813
Augmenting natural convection and conduction based solar dryer

A. Chavan, A. Sikarwar, V. Tidke, B. Thorat

Solar conduction dryer (SCD) is a unique technology that uses conduction, convection and radiation mechanism of heat transfer making it one of the most efficient drying system. The SCD is one of the most effective piece of equipment's designed indigenously and it has tremendous potential to capitalize in erstwhile nations of tropical and torrid region where there is abundance of solar insolation. SCD, the most cost-effective dryer which runs on no electricity has already made inroads in the global market. In the present study, CFD studies were carried out for a given geometry and the corresponding boundary conditions.

Keywords: Solar Energy; Solar Conduction Dryer; CFD modeling.

#7829
Intermittent drying effect on total polyphenol and acetic acid in cocoa beans

Jader Rodriguez Cortina

Drying process is of crucial importance for the final quality of the cocoa beans. The drying conditions affect not only the drying time but also the polyphenol (TP) oxidizing reactions and outward migration of acetic acid (AA) from the beans. The loss of TP and AA contributes to a reduction of astringency and bitterness, and acidity respectively, in the cocoa beans. In the literature, a drying temperature of 60 °C, appears to be the best for drying cocoa beans according to degradation of polyphenols, but acetic acid levels increases with increase drying temperature, thus, leading to a build-up of acidity in the beans. Intermittent drying at different temperature could be beneficial to degradation of polyphenols and migration of acetic acid. From these considerations, the goal of this work was to establish a drying strategy with which to manage heating and rest periods which will effective drying time to be shortened and to reduce of total polyphenols (TP) and acid acetic concentration in dried cocoa beans. The intermittent drying consisted in two heating periods (Ts) separated by a rest period (Tr) defining a cycle. The heating periods were carried out at 60, 50 y 40 °C and rest period at environmental conditions (21 °C), at an air velocity (V) 1 ms-1. Compared with constant drying conditions, intermittent drying time.

#7858

Post-harvest treatment of algerian broad beans using two different solar drying methods

S. Chouicha, A. Boubekri, M.H. Berbeuh, D. Mennouche, I. Frihi, A. Rzezgua

This work was carried up in the objective to valorize the broad beans, largely harvested in Algeria, by solar drying means. In the present research paper, an experimental study was conducted on solar drying of broad beans by two different methods. Experimental trials were performed on a direct and an indirect laboratory scale solar dryers at Ouargla university in the southern of Algeria. Selected samples were dried at 50°C, 55°C, 60°C and 65°C. In both two applied cases, drying curves were obtained and compared. Among twelve consulted drying models the Page model was correlated with satisfaction to describe the solar drying of broad beans using a non linear regression analysis method. Operating and thermal performances of the two used drying systems were checked by the energy effeceincy and economic calculation. Obtained results showed that the direct solar drying ensures good preservation of the final product with a drying time of 5 hours.

Keywords: solar drying ; convective drying ; broad bean ; quality.

DRYING PROCESS

Poster Presentations

#7268
Drying the corn in a farm heat pump dryer with fluidized bed

S. P. Rudobashta, G. A. Zueva, V. M. Dmitriev, E. A. Muravleva

The possibility of using a heat pump as a part of on-farm drying plant is considered taking drying of corn grain as an example. The methodology for kinetic calculations of a drying plant with a batch fluidized bed for granular materials is developed. These calculations are based on the use of an analytical solution for the problem of mass conductivity and taking into account the time-related changes in drying agent parameters over the layer height. To determine the concentration dependence of the mass-conductivity coefficient, a zonal method has been used.

Keywords: heat pump; dryer; kinetic calculation

#7269

Heat and mass transfer modelling of continuous Wurster-spray-granulation with external product classification

Daniel Mueller, Andreas Bueck, Evangelos Tsotsas

Wurster granulation with external product classification can be used for stable continuous coating or layering processes. It has been ascertained from recent population balance simulations that the ratio of the spray rate to the nuclei feed rate can be used to control the thickness of the sprayed product layer. However, thermal conditions are not considered by population balances regarding the particle size as distributed property. For this reason, heat and mass transfer is investigated in the present contribution by modelling of several subprocesses. The results can be used to discuss the cause of fluidized bed destabilization due to over-wetting.

Keywords: continuous operation; Wurster fluidized bed; spray granulation; spray limits; heat and mass transfer

#7271
Concept of heat recovery in drying with chemical heat pump

Michal Tylman, Maciej Jaskulski, Pawel Wawrzyniak, M. Czapnik

Drying is one of the most energy intensive unit operations. It easily accounts for up to 15% of all industrial energy consumption. In the most drying processes heat is required to evaporate moisture which is later removed with a flow of air. The hot, humid air leaving the dryer is often considered as a waste stream, and a large fraction of energy is lost. The aim of the theoretical and experimental concept study presented here was to evaluate a method of reclaiming energy from low temperature waste streams and converting it to useful in industry saturated steam of temperature from 120 to 150 °C. Chemical heat pump concept based on the dilution and concentration of phosphoric acid was used to test the method in the laboratory. Heat of dilution and energy needed for water evaporation from the acid solution were experimentally measured. The cycle of successive processes of dilution and concentration has been experimentally confirmed. Theoretical model of the chemical heat pump was tested and coefficient of performance measured. Energy balance of the drying system and efficiency increase of the dryer supported with chemical heat pump were calculated.

Keywords: Efficiency of drying; energy recovery; chemical heat pump

#7273
Reduction of graphene oxide by the high temperature disperse drying

Bartosz Opara, Maciej Jaskulski, Marcin Piątkowski, Paweł Wawrzyniak, Ireneusz Zbiciński

Graphene, alotropic carbon form, is interest material for his excellent physico-chemical properties like high tensile strength or heat and electric conductivity. There are four methods of graphene production: by micro-mechanical exfoliation of pyrolytic graphite, epitaxial growth, chemical vapor deposition and the reduction of graphene oxide. In comparison to the first three methods graphene oxide can be easily produced by the chemical methods from graphite which is inexpensive raw material.
One of the chemical methods of graphene production is the Hummers method. In this process, graphite flakes are oxidized with $KMnO_4$ and as a reaction product is obtained graphene oxide which, after centrifugation create suspension in water. Final product in form of the fine graphene powder is produced by the spray drying or lyophilization.
In this work method of graphene production by the combination of the spray drying and pyrolysis at elevated temperatures of graphene oxide suspension is presented. Graphene oxide is nebulized inside the pyrolysis furnace where is dried and heated up to 800°C in environment of neutral nitrogen. During the pyrolysis process oxygen groups were removed from the graphene structure. The resulting graphene is cooled and separated from the air. A series of experiments allows us to determine the optimum conditions for the drying process.

#7280
Agglomeration of spray dried milk powder with the addition of carob, cinnamon, and ginder powders

Safiye Nur Dirim, Hira Yüksel, Gülşah Çalışkan Koç

Milk is consumed in large amounts worldwide because it contains most of the necessary nutrients. The conversion of milk into the powder form increases the shelf life and extends the storage period even at ambient temperatures without loss of quality. Milk powders are more convenient for storage, transportation, handling, packaging, processing, and for product formulations than milk itself. Agglomeration process has been widely used in recent years to improve functional properties of food powders. The use of agglomerates in production processes increases the efficiency and production intensity, improve working conditions, and reduces raw material loss. During the agglomeration process, particles bond together and improve their handling and reconstitution properties like dispersibility, solubility etc. The aims of this study are to determine the effect of the agglomeration process on the physical (moisture content, water activity, and color) and powder properties (screen analysis, solubility times, bulk and tapped densities, flowability, cohesiveness, hygroscopicity, and dispersibility) of milk powders with the addition of different ingredients aimed to give improved flavor and to calculate the efficiency (%) and the total energy consumption of the agglomeration operation. For this purpose, carob, cinnamon, and ginger powders were added to milk at 2% concentration, mixed for 30 minutes and filtered by crude filter paper and then the mixture was spray dried (160/80 °C inlet and outlet air temperatures, 392 kPa atomization pressure, 1.54 m3/min air flow rate). Then, the agglomeration process was performed in a modified fluidized bed agglomerator (1.8 m/s air flow rate and 80°C temperature for 15 minutes). During this process, water (1:0.1 w:w) was added to milk powders as a binder. Consequently, the efficiency of agglomeration process was calculated as the ratio of the amount of obtained agglomerates to the milk powder and the calculated values ranged between 50.27-69.41%. The higher moisture content (3.45-4.60%, wet basis) and water activity (0.194-0.217) values were obtained for the agglomerates compared to powders (moisture content=1.15-3.12%, aw=0.194-0.277). The a*, b*, and Browning Index values of milk powders increased with the agglomeration process whereas L* value decreased. The average volume-mean diameter of agglomerates was calculated based on a screen analysis and ranged between 0.23 and 2.20mm. Agglomeration process improved the flow properties (Carr Index and Hausner Ratio decreased) of milk powders, increased the bulk and tapped density values. Solubility times are very long for milk powders (194-350s) whereas the solubility times of the agglomerates ranged between 10-50s.

Keywords: Agglomeration, agglomerate, milk powder, powder properties, efficiency.

#7294

Drying characteristics and quality of lemon slices dried undergone Coulomb force assisted heat pump drying

S. K. Chin, Y. H. Lee, B. K. Chung

AIn this research, a Coulomb force assisted heat pump (CF-HP) dryer was invented for the purpose of improving the drying characteristics and product quality of biomaterials. As compared to heat pump drying alone, the assistance of Coulomb force in heat pump dryer enhanced the drying rates and effective moisture diffusivity of lemon slices up to 26%, which eventually shortened the total drying time to 40%. This saved the total energy consumption of HP drying by 31.5%. High retention of vitamin C and TPC were also found in CF-HP dried slices due to mild drying temperature and fast drying rate.

Keywords: coulomb force; heat pump drying; drying rate; vitamin c; total phenolic content (tpc)

#7297

Impact of thin layer drying on bioactive compounds of jaboticaba (Plinia cauliflora) peel

Karine Machry, Marcílio Machado Morais, Gabriela Silveira da Rosa

Jaboticaba (Plinia cauliflora) is a Brazilian fruit with a high content of anthocyanins compounds. Peel corresponds to 30 % of the fruit weight and it is considerated a residue since just the pulp is used. The aim of this work was to analyze the convective drying process of the jaboticaba peels. Moisture content of dried peels showed a range of 7.17 to 13.26 (% w.b.). The results also reported that jaboticaba peels have high anthocyanins content (fresh: 1162.99 ± 41.35 mg/100g d.b) and it was possible to maintain these compounds even after the drying process (1052 to 1270 mg/100g d.b).

Keywords: jaboticaba; peel; drying; residue; anthocyanins

#7310

Experimental investigation on pore size distribution and drying kinetics during lyophilization of sugar solutions

P. Foerst, M. Lechner, N. Vorhauer, H. Schuchmann, E. Tsotsas

The pore structure is a decisive factor for the process efficiency and product quality of freeze dried products. In this work the two-dimensional ice crystal structure was investigated for maltodextrin solutions with different concentrations by a freeze drying microscope. The resulting drying kinetics was investigated for different pore structures. Additionally the three-dimensional pore structure of the freeze dried samples was measured by µ-computed tomography and the pore size distribution was quantified by image analysis techniques. The two- and three-dimensional pore size distributions were compared and linked to the drying kinetics.

Keywords: pore size distribution; freeze drying; maltodextrin solution; freeze drying microscope

#7333

Microwave assisted convective drying of kale (Brassica oleracea L. var. sabellica L.) at stationary and non-stationary conditions

Dominik Mierzwa, Justyna Szadziński

This paper concerns hybrid drying of kale. Eight different schedules of drying were tested experimentally to find out the influence of microwave enhancement on the kinetics (drying rate and time), energy consumption of convective drying and quality of products. Different power of microwaves and modes of microwave application were tested. Quality of products was assesed through water activity and colour measurements, as well as retention of ascorbic acid. The results obtained in the studies allowed to state that intermittent application of high-power microwave pulses may lead to a meaningful reduction of drying time and high quality of the dry products.

Keywords: hybrid drying; intermittent drying; kale; ascorbic acid; colour

#7334
Drying effect on the content of Warionia saharae leaves Essential Oils

Fedol Amel

The objective of this study was to evaluate the effects of drying on essential oil content and composition of Warionia sahareae leaves. Aerial parts of Warionia plants were dried under the climatic conditions of temperature between 13 and 39° C, and the humidity ranges from 13 to 16.98% during the period of drying, and the wind speed between 8.2 and 9 km / h. The moisture content of the material plant decreases during drying. It goes from 20.19 to 57.62 % in the shade drying at the end of the thirteenth day. The humidity becomes substantially constant at the end of the drying period. Drying increases the concentration of essential oils. When the leaves are drying in the shade, the maximum level is obtained on the ninth day (0.84%).Beyond this period, the content drops steadily before stabilizing. Increasing the concentration of essential oils, expressed in dry weight during the first days of drying can be explained by the important physiological activity (enzymatic reaction). The biosynthesis of essential oils continues and accelerates after the harvest of plant material in reply to water stress. Its decrease after seven and nine days of drying is due to the reduction or cessation of enzyme activity causing cell death due to strong dehydration. Volatile oil content and composition of plants were determined by Clevenger apparatus and GC-MS method respectively. The qualitative analysis of essential oils identified 28 constituents in 3 days of drying and 42 compounds after nine days of drying. The dominant compounds were 2-naphtaleneméthanol (50.38% and 47.17), the nirolidol (15, 54% and 8.82), linalool (3.79 and 10.53) , +(-) delta selinéne (3.23 and 2,59 %) and geranial (1.87 and 1. 44).

#7339
Effect of Freezing-Thawing on Drying Kinetics and Enzymatic Reaction in Soybean

Shigeaki Ueno, Natsuko Iryo, Shoji Sasao, Tetsuya Araki, Gab-soo Do

We investigated effects of freezing on drying kinetics and enzymatic reaction in soybean cotyledons. Frozen-thawed soybean membrane structures were partially destroyed, and which resulted in increasing drying rates and water diffusion. Combinations of freezing and storage led to increase in γ-aminobutyric acid (GABA) and decrease in pH. Higher GABA accumulation after freezing of soybeanmay be caused by improvement in mass transfer and enzymatic conditions.

#7340
Influence of drying conditions on continuous spray fluidized bed layering granulation with internal and external separation

Martin Schmidt, Andreas Bück, Evangelos Tsotsas

Spray fluidized bed layering granulation is used to transfer solid-containing liquids to the solid state. Therefore a solution, suspension or melt is sprayed onto a fluidized bed of particles, dries/solidifies, and induces particle growth. This technology is mainly applied to produce particulate products in chemical, pharmaceutical and food industries.
To achieve high product throughput, spray fluidized bed layering granulation can be conducted continuously. To achieve a continuous process, nuclei feed and product discharge have to be realized. In this work, of new granulation nuclei were supplied internally by the fraction of spray droplets, which dried prior to particle contact (overspray). A classifying product discharge was realized in two ways, using internal separation by a classifying tube and external separation by two sieves, separating the discharged particles into oversize, undersize, and product fraction. The oversize fraction was milled and fed back to the fluidized bed alongside with the undersize fraction as additional nuclei.
This work experimentally compares the process stability of continuous spray fluidized bed layering granulation with internal and external separation for respectively similar drying conditions. Experiments with intense drying conditions were unstable or resulted in oscillating particle size distributions for internal separation (Fig. 1, left). For equal drying conditions, but external separation, the unstable and oscillatory experiments were transferred to a stable steady-state (Fig. 1, right). Experiments with moderate drying conditions and internal separation, which were already stable in this configuration, resulted in oscillatory particle size distributions for equal drying conditions and external separation. The differences in process stability were attributed to different amounts of nuclei formed by drying (internal and external separation) and milling (only external separation).

Keywords: fluidized bed, layering granulation, continuous process, process stability, oscillation

#7343

Effect of closed cycle modified atmosphere drying on characteristic of kiwi fruit during storage

Ihsan Burak Cam, Handan Basunal Gulmez, Emrah Eroglu, Ayhan Topuz

Drying is one of the oldest known methods of preserving food and applied industrially since the 18th century. There are lots of study on drying in terms of the quality of product and energy efficiency. It is known that in the existing drying methods applied in the hot air containing oxygen, the products are subjected to oxidation and the nutritional value, color and aroma are lost to a great extent.

In this study, the influence of closed-cycle modified atmosphere (CC-MAD) drying on chemical properties of kiwi (Actinidia deliciosa, A. Chev) was investigated. Kiwi was peeled and cut into a circle of 5mm in thickness using laser slicing knife. Sliced kiwi fruits were subjected to two different drying treatments as CC-MAD at 60˚C with 3 m/s air velocity in 5% oxygen medium and 10% oxygen medium. The products were stored in polyethylene packages with modified (95% N_2) and normal atmosphere (air) at room temperature and in semi-darkness for 4 months. The color values of the products were determined based on image processing technique. The ascorbic acid content of fresh and dried kiwi fruits was determined by UPLC-DAD-MS/MS electronic spraying ionization (ESI).

Research results showed that the lowest ascorbic acid loss was determined in 5% oxygen medium dried. Modified atmosphere package was found to be more successful in terms of browning, and ascorbic acid activity of kiwi fruit during storage.

#7344

Improvement of pea protein isolate powder properties by agglomeration in a fluidized bed: comparison between binder solutions

R. F. Nascimento, K Andreola, J. G. Rosa, O. P. Taranto

This study aimed to compare the agglomeration process of pea protein isolate (PPI) using water and aqueous gum Arabic solution as binder liquids. Drying air temperature and binder flow rate were set at 75 °C and 3.1 mL/min, respectively. Moisture content, mean particle size, wetting time and flowability were analyzed. Using water as binder liquid, the responses were (4.0 ± 0.4)%, 316.13 ± 16.73 μm, 10 s and free flow, respectively. Aqueous gum Arabic solution provided (2.9 ± 0.5)%, 462.67 ± 51.23 μm, 3 s and free flow as responses. Gum Arabic solution showed to be a more promising binder.

Keywords: agglomeration; pulsed fluidized bed; pea protein isolate; wetting time; flowability

#7345

Influence of drying conditions on the acacia gum particle growth in fluidized bed agglomeration: in-line monitoring of particle size

J. G Rosa, R. F. Nascimento, K. Andreola, O. P. Taranto

Acacia gum is an important food emulsifier that presents poor instant properties which can be improved by fluidized bed agglomeration. This study investigated the influence of drying conditions on particle growth kinetics using an in-line particle size monitoring by spatial filter velocimetry. The drying conditions varied according to the binder flow rate and the fluidizing air temperature. The particle growth kinectis showed drying conditions dependence. At mild drying conditions the growth rate and the process yield were higher. The in-line particle size monitoring was useful to observe the influence of the drying conditions on the growth kinetics.

Keywords: fluidized bed agglomeration; acacia gum; particle growth kinectis; in-line monitoring

#7346

Fluid bed agglomeration and drying of rice protein concentrate powder using grape pulp as binder: in-line monitoring of particle size

Osvaldir Pereira Taranto, Kaciane Andreolla

The interest in rice protein concentrate (RPC) has increased in food industries due to its unique nutritional value and nutraceutical properties. However, RPC powder presents fine particles (D50 = 54.2 µm) with moderate flowability and low wettability in liquids, limiting its use as a food ingredient or dietary supplement. The agglomeration process is widely used in the food, pharmaceutical as well as in the chemical industries to improve the quality attributes of powders such as flowability, wettability, appearance, and dust formation, by increasing the particle size and changing physical properties of the particles. Therefore, the agglomeration process represents an efficient way to enhance the quality attributes of the RPC powder. Fluid beds are commonly used for wet agglomeration process, which consists of spraying a liquid binder onto the moving particles. The hot fluidization air provides the liquid binder evaporation and the particles drying. Grape pulp can be a potential binder for the agglomeration of RPC since it is rich in anthocyanins that are associated with human health benefits, contributing to the nutraceutical properties of the final powder. In-line particle size monitoring during the agglomeration process is important since it is one of the key characteristics of an agglomerated product. This work aims to investigate the feasibility of fluid bed for agglomeration and drying of RPC powder using grape pulp as binder to produce a highly nutritional powder with improved quality attributes. The influence of binder flow rate (1.5-2.5 mL.min-1) and fluidizing air temperature (65-85 °C) upon the process yield, median particle size, and anthocyanins content was examined using an experimental design. Moreover, the effect of operating conditions on the performance of agglomeration was evaluated through in-line monitoring of particle size using a spatial filter velocimetry probe. Statistical analyses pointed out the optimal process condition (77 °C and 1.98 mL.min-1) that provided large granules (D50 = 302.8 µm) with anthocyanins incorporation (11.79 mg/100g) and high process yield (71.1%). This condition afforded a powder with low moisture content (3.33%), a very good flowability and wetting time reduced in 97%. In-line particle size data provided a better understanding of both growth and breakage of the particles during the agglomeration and drying processes, which were strongly influenced by the binder flow rate and air temperature. Therefore, the fluid bed agglomeration was feasible to produce a highly nutritional powder with improved quality attributes, which can be of special value as an ingredient for application in food formulations.

#7347
Agglomeration of hydrolyzed collagen with blackberry pulp in a fluidized bed

Thayná R Viegas, Osvaldir Pereira Taranto

Hydrolyzed collagen (HC) is a fine powder applied in the pharmaceutical and food industries which has shown good results in the treatment of diseases related to bones, skin and joints. In this study, HC particles were agglomerated in order to increase particle size, optimizing its use as a food ingredient, its handling and its storage. Agglomeration is a process that not only enlarge the size of fine particles, but also improves its properties, such as instantanization time and flowability. The aim of this work was the agglomeration of HC in a fluidized bed having blackberry pulp as a liquid binder. A full factorial design 22 was used to study the effect of the temperature of the fluidizing air (60, 70, 80ºC) and the flow rate of the liquid binder (0.8, 1.2, 1.6 mL/min) on the process yield, mean particle size, water activity and total anthocyanins content. It was observed that anthocyanins content from the blackberry pulp had higher values with lower temperatures. Water activity had lower values with higher temperatures, but in all conditions, it was lower than 0.6. The enlargement of the granules was observed in all conditions studied, increasing up to 275%. Process yield varied from 67,9 to 80,0%. In all conditions, the instantanization time and flowability improved compared to hydrolyzed collagen before agglomeration.

Keywords: hydrolyzed collagen; agglomeration; granulation; fluidized bed; blackberry pulp

#7348
Intermittent–microwave and convective drying of parsley

Justyna Szadzińska, Dominik Mierzwa

The studies present convective drying of parsley with an intermittent microwave application. Eight different drying programs including convective drying (CV) were carried out in a laboratory-scale hybrid dryer. The influence of intermittent conditions on drying time, drying rate, energy efficiency and product quality was analysed. The results demonstrated that intermittent–microwave convective drying improves the drying kinetics and reduces energy consumption. Moreover, a higher retention of vitamin C, smaller color change and a better ability to rehydration were observed for the parsley samples dried using intermittent drying than for CV.

Keywords: intermittent drying, microwaves, energy, vitamin C, rehydration

#7349
Experimental investigation of drying and inactivation of baker's yeast in fluidized beds operated under reduced pressure

Sayali Zarekar, Andreas Bück, Michael Jacob, Evangelos Tsotsas

Fluidized bed drying under partial vacuum conditions is a cost-effective alternative to freeze drying in the formulation of thermo-sensitive substances in the food and pharmaceutical industry. To minimize the inactivation of thermo-sensitive substances, the optimization of drying conditions is crucial. In this study we experimentally investigate the influence of sub-atmospheric pressure on drying and inactivation of baker's yeast in a batch fluidized bed plant. The influence of operating pressure (100 – 50 mbar) on drying and inactivation kinetics is studied for varying fluidization velocities and air temperatures.
In our previous study], a coupled drying and inactivation model for Baker's yeast particles was developed. The kinetics of drying was modelled using van Meel's concept of a normalized drying curve (NDC) of a single particle. This coupled drying and inactivation model is validated using the experimental data obtained from the present study. Inactivation, which is a function of the rate of change of temperature and water activity of yeast, is modeled using the experimental data. The normalized drying curve obtained by down-scaling the batch experimental data is compared with that obtained from single particle drying experiments for varying operating pressures.
At constant inactivation, a kinetically controlled drying process leads to higher drying rates at low operating pressures. This is due to the increase in specific capacity of air for water vapor at low pressures resulting in an increased driving force for evaporation. However, a consideration of inactivation kinetics results in a larger reduction in cell viability at higher drying rates. The competing kinetically and equilibrium (capacitive) controlled aspects of the process are, thus, investigated in order to optimize the process path for drying of baker's yeast at partial vacuum conditions.

Keywords**:** reduced pressure, fluidized bed, baker's yeast, bioactive substances, drying

#7359
The evolution of pore structure during microwave freeze-drying of Chinese yam

Xu Duan

Porous materials are a material that forms a network structure by interpenetrating or closed pores. Porosity is a key indicator of the performance of the material. In this study, the changes of pore structure during the microwave freeze-drying process were investigated by SEM and mercury porosimetry. The results show that the open-pores is changed from the closed-pores in the drying process. In the early stage of drying, the pore size is mainly in the range of 3×102~6×103 nm, and the pore size of the larger pores above 105 nm basically disappeared. In the middle and late drying, the large pore size increased again, and the pore size decreased again from about 5×103 nm to 103 nm and then increased to about 2×103 nm. The effect of shrinkage on the pores was higher in the early stage of drying.

#7361
Influence of process conditions on quality of spouted bed dried okara

Gabriel Alves de Oliveira Scafi, Renan Alex Lazarin, Louise Emy Kurozawa

This study aimed to evaluate the spouted bed drying of okara with inert particles of polypropylene. A central composite rotatable design was carried out to verify the effect of drying air temperature and air flow on moisture content, techno-functional properties and trypsin inhibitors activity of dried product. Higher temperatures decreased emulsifying properties and trypsin inhibitor activity, probably due to thermal protein denaturation. In order to obtain a dried okara with maximum techno-functional properties and minimum moisture content and trypsin inhibitor activity, the optimal drying conditions were suggested: air temperature of 60ºC and air flow of 180 m3/h.

Keywords: soy pulp; spouted bed drying; trypsin inhibitor activity; techno-functional properties; optimization

#7365
Comparative studies of spray parameters in a Vacuum Spray dryer and Spray dryer

Fernanda Melo Ramos, Izaias de Brito Cunha, Bruna Barbon Paulo, Vivaldo Silveira Junior, Ana Silvia Prata

Drying is currently one of the unit operations most commonly used to increase the shelf life of foods, and ends up contributing to reducing the volume to be transported and allowing the more precise incorporation into formulations. Atomization processes, carried out in spray dryers, are employed to produce powdered products from a suspension, solution or emulsion. Due to the contact of small droplets with air at high temperature, although the drying time is considered in the order of a few seconds, some functional ingredients can be degraded. To improve the quality of the product in relation to flavor, color or other thermo-sensitive components the development of new methods is increasingly interesting. In this context, the vacuum spray dryer (VSD) is a spray dryer that operates with a low-pressure drying chamber, coupling advantages of a higher exposed surface area with lower evaporation temperatures, which reduces the time of processing and losses of bioactive compounds. There are few studies in the literature regarding the drying process in VSD. In this context, the relation between some spray parameters, such as rate flow, atomization pressure and physicochemical properties of the solutions, over the size of droplets through the atomizer can vary significantly when using the vacuum or not. This paper deals to develop a physical understanding of the droplets evolution during atomization of solutions as a function of viscosity, pressure and oil content. Under these conditions, the droplets size was evaluated and compared with known performances for water. The droplet size was measured at two axial distances from the nozzle for a range of atomizing pressures and nozzles diameters. The reduction of the droplet was found to be proportional to the atomizing pressure. Hence, the role of liquid viscosity was found to be negligible in the investigated regime. Particle size distribution was dependent on the atomizing pressure. The present approach constitutes a major step towards the tailoring of particles through adjustment of the drying conditions in spray drying processes.

#7366
Effect of temperature and mode of drying on bioactive compounds and quality of germinated parboiled rice

Supaporn Klaykruayat, Busarakorn Mahayothee, Marcus Nagle, Joachim Müller

Germinated parboiled rice (GPR) is recognized as a functional food because it is rich in bioactive compounds, especially gamma-aminobutyric acid (GABA). GPR was produced by soaking, incubating, steaming, and then drying using a high-precision hot air dryer. The results indicated that air flow mode and drying temperature had significant effects on the quality of GPR. Drying at higher temperatures and shorter times conserved GABA content. Using through-flow mode decreased drying time and prevented color change. However, a slightly lower percentage of head rice yield was observed. Moreover, using through-flow mode negatively affected the hardness loss after cooking.

Keywords: germinated parboiled rice; drying mode; gamma-aminobutyric acid; head rice yield

#7367
Comparison of different novel drying methods in terms of some process criteria

Murat Yanat, Taner Baysal

The drying is the most ancient and common method of food preservation. Drying can be examined as a complex thermal process, due to it has many occurrences during the process such as multicomponent moisture transport, change of physical structure, some chemical or biochemical reactions and quality changes. Throughout the history, people have improved many different drying techniques. A technique can be considered novel if it has proven innovative characteristics, shows better results with modifications in existing methodologies or finds new applications in different sectors. That novel drying approaches should bring industrially applicable, reduce energy consumptions and promote sustainability. Nowadays, that techniques such as high electric field drying, ultrasound- or microwave-assisted drying, refractance window drying and heat pump drying can be taken to improve the efficiency and efficacy of drying so that energy consumption can be reduced whilst at the same time preserving the quality of the end product. However, even many researches prove to success of novel techniques, some of them still do not applicable at out of the pilot scale. In this review, some pretreatments which are applied before drying process and recent developments in drying methods were evaluated in terms of different criterions. Each method which can varying for dissimilar foods has different benefits and drawbacks individually.

Keywords: drying, heat pump drying, high electric field drying, microwave-assisted drying, refractance window drying

#7373

Theoretical study and case analysis for a pre-dried pyrolysis coupled lignite-fired power system

Rongtang Liu, Ming Liu, Junjie Yan

Lignite, a kind of low rank coal, has the characteristics of high moisture, high volatile, high ash and low heat value. The low-temperature pyrolysis technology is potential to improve the utilization efficiency of lignite. Therefore, a lignite-based energy system integrated with pre-drying and low-temperature pyrolysis was proposed in this paper. To assess the influence of pre-drying process, theoretical models were developed based on thermodynamics, and a case analysis was then performed to get the quantitative effect of pre-drying on efficiency of energy utilization. Results show that pre-drying on PPPS theoretical model can significantly improve the utilization of lignite by 1.46%.

Keywords: lignite; pre-drying; low-temperature pyrolysis; energy efficiency; case analysis

#7375
The effect of ohmic heating pretreatment on drying of apple

Naciye Kutlu, Merve Silanur Yilmaz, Hicran Arslan, Aslı Isci, Ozge Sakiyan

In this study, effects of ohmic pretreatment on the drying rates and color kinetics of apple were investigated. Apple slices were treated at different electric field strengths (20-30 and 40 V/cm) at 60°C for 1 min. Drying process was applied at 60˚C-2 m/s by using a tray-dryer. ΔE and moisture content were calculated. These values were fitted to the semi-theoretical thin-layer drying and the zero and first-order kinetic model. The shortest drying time was found samples treated with 30 V/cm. Wang&Singh model gave the superior fit to the experimental data. ΔE fitted well to the zero-order kinetic model.

Keywords: ohmic heating, drying, kinetic models, thin-layer models, apple

#7379

Energy performance of an industrial superheated steam heat pump flash dryer for drying of bio-fuel

R. J. I. Renström, H. Johansson-Cider, L. Brunzell

Drying is an energy demanding industrial process and methods for reducing the energy consumption of drying is of interest to industry as well as society. This article presents the drying system of a biofuel factory. Steam is used as the refrigerant. Superheated steam is used as drying gas in a flash dryer with 28.8 tons/h dewatering capacity. The system includes an energy recovering water heat pump that receives its heat from the excess drying steam and heats the dryer. The SMER of the drying process ranges between 3 and 4 and the COP of the heat pump process ranges between 4 and 5.5 during one production season of peat drying. Variations in performance can be explained by variations in inlet moisture content and production rate. The example of this drying system shows the feasibility of drying in superheated steam, heat pump drying and water as refrigerant in high-temperature heat pumps.

Keywords: steam drying; heat pump process; peat; sawdust; industrial operation

#7382
CT-studies during the Conditioning phase of the Wood Drying Process

José Couceiro, Lars Hansson, Margot Sehlstedt-Persson, Dick Sandberg

Computed tomography (CT) during drying of sawn timber is an excellent non-destructive technique to study the moisture flux as a function of drying time. In this study, a climate chamber combined with a medical CT- scanner has been used for non-destructive studies of density changes in sawn timber during drying and conditioning.
Green sawn timber contains large amounts of water and has to be dried before it can be further processed and used in various building applications. The most common drying method is convective air-circulation drying in large industrial kilns, where the relative humidity (RH) of the hot circulating air is gradually reduced until the timber reaches the target moisture content (MC).
Drying of sawn timber is driven by the existence of a difference in MC between the core and the surface, so that moisture moves from the wet inner region towards the drier outer region. During the early capillary stages of drying, the drying rate is high while, at the later stages when all liquid water has evaporated, the drying rate is slow and diffusion-controlled. At the end of the drying process, the timber surface is always drier than its core. In addition to this moisture gradient, internal stresses develop within the cross section with compression stresses in the timber surface and tension in the inner regions. To avoid unwanted distortions, both these stresses and the moisture gradient, need to be eliminated before the timber is further processed. This is achieved in a final conditioning stage within the drying process by moistening the circulating air through steaming or water spraying.
The aim of the present work was to optimize the conditioning stage by developing a method for studying of moisture gradients, deformations and internal and external dimensional changes in sawn timber during the conditioning phase by using a CT-scanner combined with a drying unit for in-situ measurements of moisture flow.
The results show that it is possible to detect the moisture gradient between the surface and core of the timber with satisfactory reliability, but not the internal and external dimensional changes. However, this method creates a potential for increasing the knowledge and understanding of the conditioning phase and makes it possible to optimize and develop this step in the drying process to improve the yield and ensure a higher quality of the sawn timber.

#7397

Mechanistic analysis of spray drying encapsulation of polyphenols by maltodextrin: experimental and modeling approaches

Loucine Mekhitarian, Benjamin Sobac, Benoit Haut

Spray drying is a technique carried out to transform a liquid solution into a dry particulate form by atomizing the fluid in a hot air. Adding an encapsulating agent in the feed solution leads to the encapsulation of the substance of interest. This has many benefits, such as the preservation of the substance stability, its protection from adverse environmental conditions or the control of its liberation. The encapsulated substance studied in this work is a common polyphenol: the gallic acid. Polyphenols are plant metabolites. They have a broad spectrum of biological activities among which the best known is their antioxidant function. They are widely used as additives for the food, pharmaceutical and cosmetic industries. Their extraction from plants results in a liquid solution rich in polyphenols, that can then be spray dried to produce solid encapsulated polyphenols particles. The encapsulating agent used is the maltodextrin. It is widely used in the food industry for polyphenols and flavors encapsulation thanks to its cheapness, large solubility in water and low sugars content.

To the best of our knowledge, most of the studies about polyphenols spray drying encapsulation focused on a particular natural extract and the recommended procedures are thus not universal. Moreover, they rarely or poorly link their experimental observations to theoretical explanations about the physical mechanisms taking place at the drop scale. Therefore, the objective of this work is to analyze the spray drying encapsulation of polyphenols, by comparing experimental observations and mathematical models, in order to highlight and characterize the physical mechanisms behind the drying of the drops.

The experimental approach aims to analyze the influence of operating parameters such as gas inlet temperature, liquid and gas flow rates and maltodextrin concentration in the feed solution on the produced powder quality, in terms of water and polyphenols content, apparent powder density or particle size and surface morphology. The modeling approach is conducted in parallel to explain these experimentally observed effects. In line with our recent modeling works, this approach is based on the development of models of increasing complexity, at the drop scale, in order to be able to highlight the key phenomena governing the process of particle formation. These models consist of equations describing the transport processes (mass and energy) taking place in and around a drop during its drying, as well as equations for the description of the phase changes in the system.

#7403
Effect of a thermo ultrasonic pretreatment on the freeze-drying time and antioxidant caracteristics of guava slices

Sebastian Ospina Corral, Diana L Manrique Lopéz, Carlos E Orrego Alzate

From a nutritional perspective, guava fruits are excellent source of antioxidants such as ascorbic acid, carotenoids and phenols, which meet an important role in the prevention of chronic and degenerative diseases. Lyophilization is considered an important technique to retain most of the nutritional quality, taste, color of dried products and to extend their shelf life. Some of the issues in the application of this technique are the long process time and the energy consumption. Ultrasound (US) is one suitable technique to reduce the total freeze drying time, but has negative effects on the bioactive compounds of the fruits. The aim of this research was to find the correct combination of both US and blanching treatments that allow the reduction of total process time (TPT), total color change (ΔE *), preserving total polyphenols content (TPC) and antioxidant activity (AA) of freeze-dried guava slices. Pretreatment of guava ripe slices consisted in their immersion in an US-bath varying US exposure time (5-10 min) and temperature (65°C). For freeze-drying, the slices were placed on shelves at 20°C and cooled until their temperature decreased to -40°C and then gently warmed profile until 40 °C. TPT reduction was estimated respecting the TPT´s blank (samples without pretreatment). The ΔE * between fresh fruit and dehydrated product, was measured with a portable spectrophotometer. The TPC and AA were measured using the Folin-Ciocalteu's and DPPH methods, for the fresh fruit and dehydrated samples. Pretreated guava samples showed a TPT decrease of 20.0±3% with both exposure times. Just after freeze-drying, the decrease in ΔE * was non-significant. However, after 30 days of storage the ΔE * values for the treated samples were lower than the untreated ones. The TPC among the treated samples was statistically the same, but lower than the observed for the blanks (11% lower). The AA displayed the same behavior, while the blank samples showed TPC and AA results similar to the fresh fruit. The pretreatment proposed is an effective option to reduce the total process time and improving the final product color of guava dehydrated slices. Other complementary studies are necessary to have a better understanding of the phenomena occurred with the thermosonic pretreatment.

#7405
Spray drying of soymilk: evaluation of process yield and product quality

Bruna Delamain Fernandez Olmos, Camila Benedetti Penha, Louise Emy Kurozawa

The aim of this work was to evaluate the effect of inlet air temperature and gum Arabic concentration on yield of spray drying of soymilk and powder quality (moisture content, water activity and antioxidant capacity). Since soymilk had a significant lipid content, gum Arabic played a significant role as an emulsion stabilizer, improving process yield and preserving antioxidant capacity. However, temperature did not affect antioxidant capacity. The optimal condition to obtain higher antioxidant capacity was: 30% of gum Arabic and 160°C. The powder obtained under optimized condition was characterized regarding to bulk density, particle size distribution and morphology.

Keywords: soymilk; spray drying; ferric reduction power FRAP; DPPH scavenging ability; scanning electron microscopy

#7409

The prediction model of moisture content's stabilization during tobacco strip drying process

Mingjian Zhang, Feng Huang, Le Wang, Yan Zhu, Haisheng Wang, Qimin Xu, Qing Chen, Bin Li, Bing Wang

A mathematical model was established to predict the mean value and variance of tobacco strip during drying processing, based that the physical and chemical properties of tobacco strip as agriculture products show probability distributions. The results show that the model can predict the mean value of moisture content at different times, and there is a certain deviation in predicting the variance of moisture content at initial stage of drying process. However, the prediction value of the variance of tobacco strip is much more accurate while the moisture content is between 8% and 10%, which is the interval of quality requirements.

Keywords: tobacco strip; drying; mean value;variance model

#7430

Influence of intermittent and continuous microwave heating on drying kinetics and wood behavior of Eucalyptus Gomphocephala

Mariam Habouria, Sahbi Ouertani, Soufien Azzouz, Wahbi Jomaa, Mohamed Taher Elaib, Mohamed Afif Elcafci

The aim of this work was to determine the microwave drying kinetics of Eucalyptus Gomphocephala wood and to investigate the influence of intermittent and continuous heating processes on the end quality of dreid samples. The average moisture content evolution and temperature of wood samples under different microwave powers were analyzed in terms of drying time and internal temperature level. Results show that the increase of microwave power level decreses the drying time and increases the internal wood temperature. Based on qualitative observations on the state of dried samples, the intermittent microwave powers intensity process present the optimal processing parameter in microwave drying of Eucalyptus wood species.

Keywords: microwave drying; power; intermittent; continuous; eucalyptus wood

#7450
Assessment of drying kinetics of complex formulations during convective thin film drying

Eline Both, Remko Boom, Maarten Schutyser

Drying is a dynamic process during which components migrate and the removal of water becomes increasingly difficult because the matrix from which the water is removed becomes stiffer and stiffer. Accurate description of moisture diffusivity is crucial to predict drying behaviour of products. There are different methods (e.g. thin film drying, single droplet drying) to experimentally determine moisture diffusivity. However, often thin film methods are employed at lower air temperatures drying and therefore extrapolation of data to more realistic higher drying temperatures is needed. This lowers the accuracy of the estimated diffusion coefficient and can underestimate the drying kinetics at higher temperature. Single droplet drying methods have also been applied, but monitoring mass changes is challenging and moreover the drying is influenced by the intrusion of a filament in the droplet or by the presence of the acoustic field which levitates the droplet.
Therefore in this study a thin film dryer was developed to measure moisture diffusion coefficients in complex matrices dried at increased air temperatures. In the developed set-up a thin film was convectively dried with hot, nearly dry air (1% RH), while recording the film weight and temperature. The drying behaviour of three components was studied: lactose, maltodextrin DE12 and whey protein. Furthermore, the effect of film thickness (1.4 and 2.0 mm) and air temperature (95°C and 105°C) was investigated. The effective diffusion coefficient of water in the complex matrices was modelled following a regular regime approach. Accurate determination of the diffusion coefficient will lead to more precise predicting of drying behaviour, while at the same time give insight on the component behaviour during drying. Ultimately this will lead to more efficient production of powders of higher quality.

#7456
Drying of acerola residues in a roto-aerated dryer assisted by infrared heating

P.B. Silva, G. D. R. Nogueira, C. R. Duarte, Marcos A.S. Barrozo

Acerola (Malpighia emarginata D.C.) is a tropical fruit which has attracted recent industrial interest, due to its high levels of bioactive compounds and vitamin C. However, acerola processing generates a substantial amount of wastes, which can represent up to 40% of total processed volume. The drying of acerola residues in a new dryer, developed by our research group, named as roto-aerated dryer, has been investigated. This dryer provides a better fluid-particle contact than the conventional rotatory dryer. A pre-drying system with infrared lamps has been installed in the feed of this new dryer. The effect of the pre-treatment of this fruit residues with ethanol was also investigated. The results shown that the roto-aerated dryer assisted by infrared radiation hybrid combined with a pre-treatment with ethanol is a good alternative for processing fruit residues, aiming their reuse. It was possible to identify conditions under which the phenolic, flavonoid, and antioxidant capacity presented high levels after drying. The main phenolic compounds were idenfied by HPLC.

Keywords: drying; roto-aerated dryer; infrared; acerola

#7457
Drying of microalga Spirulina platensis in a rotary dryer with inert bed

D. N. C. Silva, T. C. Silva, A. O. Santos, I. S. Graton, C. R. Duarte, Marcos A.S. Barrozo

The aim of this work is investigate the use of a rotary dryer with inert bed for drying of microalga Spirulina platensis. The influence of air temperature, feed rate, rotation speed and inerts filling degree was quantified. The contents of main bioactive compounds were also analyzed. The results shown that the used drying system proved to be an interesting alternative for a possible use of this microalga, if performed under adequate conditions. It was identified conditions with high drying performance and with the preservation of product quality.

Keywords: spirulina platensis; rotary dryer; inert bed; bioactive compounds

#7466

The effect of intermittent: microwave and fludized bed drying on quality and energy consumption of buckwheat

Gülşah Kızılalp, Tuğçe Türkoğlu, Gülşah Çalışkan Koç, Safiye Nur Dirim

Buckwheat (Fagopyrum esculentum Moench) grouped with cereals since its way of cultivation and the main nutritional value is similar to cereals. The importance of buckwheat is that; it is a gluten-free food. Nowadays, people have some alergy to different group of foods including gluten intolerance. Thus, the preparation of parboiled buckwheat could give an good alternative for these people. In this study, the effect of different drying processes (convective hot air, microwave, and fludized bed drying) and combined drying methods on the drying characteristics and the physical properties (moisture content, water activity and colour) of buckwheat were examined. The energy consumption for whole drying processes were also considered. For this purpose, buckwheat samples was soaked in water (1:10 buckwheat:water ratio (weight:weight), (w:w)) at room temperature (25°C) for 12 hours and was boiled for half an hour in water (1:2 buckwheat:water ratio, (w:w)) and drained. The drying experiments were performed at convective dryer (70°C, 1.6 m/s air velocity), microwave oven (180, 360, 540, 720, and 900 W), and fluidized bed (60, 70, and 80°C, 1.6 m/s air velocity). The minimum energy consumption and drying time were used as the criteria for selecting the combined drying process conditions. The convective drying was not used at further studies due to the high energy consumption (16.705 kWh) and drying time (130 min). The microwave- fludized bed combined drying experiments were performed at 180-360-540 W microwave power and 60°C and 1.6 m/s air velocity fludized bed drying condition with the changing order in application and the other drying conditions were also eliminated due to the same criteria. The moisture content, water activity, colour, energy consumption values of buckwheat were determined. The lowest drying time (32 min) and energy consumption (0.600 kWh) values were observed for the drying experiments as 15 minutes of drying in fluidized bed dryer (60°C) and following 18 minutes in microwave dryer (360 W). In addition at this drying condition the minimum water activity was observed compared to the other combined trials.

Keywords: buckwheat, convective drying, microwave drying, fludized bed drying, intermittent drying

#7467
The intermittent drying of wheat by microwave and fluidized bed drying

Tuğçe Türkoğlu, Hale Baykal, Hira Yüksel, Gülşah Çalışkan Koç, Safiye Nur Dirim

The objective of the study is to investigate the effects of different drying processes (convective hot air, microwave, and fluidized bed drying) and combined drying methods on the drying characteristics and physical properties of the dried wheat and the power consumption of the dryers. The lowest moisture content and water activity values were observed for the 25min of drying in fluidized bed dryer (60°C) and following 16min in microwave dryer (540W). The lowest power consumption was observed in the 60°C-180W fluidized bed-microwave combination (0.77kWh) compared to the other combined trials.

Keywords: wheat; convective drying; microwave drying; fluidized bed drying intermittent drying

#7472
Mechanistic modeling expedites the development of spray dried biologics

Nicholas B. Carrigy, Lu Liang, Hui Wang, Sam Kariuki, Tobi E. Nagel, Ian F. Connerton, Reinhard Vehring

Spray drying can be used to extend the shelf life of biologics stored at ambient temperature. Empirical and statistical design of experiments approaches typically require a relatively large number of experiments to determine suitable formulation and spray drying process parameters. An alternative approach, which may require fewer experiments, is to use mechanistic models to select these parameters. In this paper, mechanistic models are applied to develop a bacteriophage powder expected to have long-term physical stability at ambient temperature. The developed powder may be useful for decreasing incidences of foodborne illness in Kenya.

Keywords: bacteriophage powder; glass transition temperature; supplemented phase diagram; spray drying; stability

#7476
Drying of moist food snacks with innovative slot jet reattachment nozzle

Milad Farzad, Mengqiao Yang, Jamal Seyed Yagoobi, B. Tilley

Drying of moist porous media such as paper, pulp and food products is one of the most energy intensive processes in industry. Impinging jet nozzles are commonly used in various drying processes. There have been many efforts to improve the transport characteristics of impinging jet nozzles. Utilizing innovative Slot Jet Reattachment (SJR) nozzle is an approach to make the drying process more efficient. This is mainly because these nozzles overcome the high flow rate constraint associated with the traditional Slot Jet (SJ) nozzle.

In this paper, the drying characteristics of the SJR nozzle with exit angles of +20˚ and +45˚ are experimentally investigated. The samples used are snack cookies. The results are compared with those of SJ nozzle under the same mass flowrate. The results indicate that significant enhancements in drying rates are achievable with both SJR nozzles compared to SJ nozzle.

Keywords: drying; porous food snack; slot jet reattachment nozzle; slot jet nozzle

#7482

Changing spray-dried lactose-whey protein isolate particle structure with drying conditions

Roger de Souza Lima, Gaëtan Gutierez, Patricia Arlabosse, Maria-Inês Re

Spray drying has become not merely a drying process, but also an important tool for engineering solid structures, specially for multi-component feeds. In that way, it is important to know how the drying conditions and liquid formulations affect the particle final solid structure. In the present study, we investigated the changes on the solid structure of a spray-dried binary mixture of lactose and whey protein isolate under different process and formulation conditions. Particle morphology, diameter, porosity and occluded air were analyzed. Total solid content in the feed was the parameter of highest impact on the spray-dried particle's occluded air volume.

Keywords: spray drying; solid structure; porosity; hollow particless

#7484
Pulsed Electric Fields (PEF) as pre-treatment for freeze-drying of plant tissues

Lubana Al-Sayed, Virginie Boy, Emmanuel Madieta, Emira Mehinagic, Jean-Louis Lanoisellé

The influence of pulsed electric fields (PEF) treatment on freeze-drying for potato and strawberry tissues was investigated. Samples were pre-treated by PEF (400 V cm-1) for different treatment times. Freeze-drying was carried out at -17°C and 18.4 Pa or 30 Pa for potato and strawberry tissues, respectively. The effects of PEF pre-treatment was compared with intact samples. The drying time was reduced by 35% for potato and 30% for strawberry. The sample rehydration capacity and the electrolytes released during the rehydration were higher for pre-treated samples. Strawberries texture was characterized by the hardness, the cohesiveness and the springiness.

Keywords: Pulsed Electric fields; Freeze-drying; Potato; Strawberry; Textural Properties

#7524

Hot air drying characteristics and nutrients of apricot armeniaca vulgaris lam pretreated with Radio Frequency(RF)

M.C. Peng, J.X. Liu, Y. Lei, X.J. Yang, Z.H. Wu, X.L. Huang

Apricot pretreated with RF and then dried with convective hot air at 65℃, 3.0m/s in this research. RF pretreatment time of 20, 30, 40 and 50min were chosen. Results showed that, there is only falling rate period during apricot hot air drying, and the drying rate of apricot is improved significantly; Herdenson and Pabis model is suitable for apricot hot air drying; retentions of flavonoids, polyphenols and Vc in dried apricot were higher than those of fresh apricot; when RF treating time was chosen 30mins, nutrients retentions of Vc, flavonoid and polyphenols were 0.9543mg/100g, 5.4089mg/100g and 7.3382mg/100g, separately.

Keywords: apricot fruit, hot air drying, drying rate, nutrients, radio frequency

#7525
Inclusions and ice growth during film freeze concentration of sucrose solutions

Jan-Eise Vuist, Martijn Van der Vis, Maarten Schutyser, Remko Boom

Freeze concentration is an alternative method to concentrate aqueous industrial streams compared to evaporation or membrane separation. The concentration occurs by freezing part of the water and removing the ice from the system. This can be done in two ways, i.e. suspension or film freeze concentration. During suspension freeze concentration ice crystals are seeded and grown, which are removed via a washing column. During film freeze concentration an ice layer is grown on the wall of a heat exchanger and after removal of the concentrate the ice layer is melted. Our study focuses on film freeze concentration as it eliminates the need for a washing column and allows easier heat integration of the crystallisation and melting stages. Challenges for film freeze concentration are the heat transfer and inclusion of impurities in the ice layer.

The objective of this study is thus to understand the influence of product and process parameters on the amount of inclusions and ice growth behaviour during film freeze concentration. Sucrose was used as a model product. A laboratory scale set up was constructed with a cooling plate as a bottom surface. Thermocouples were used to monitor the temperature near the freezing surface and different stirring could be applied.

Stirring speed and sucrose concentration were found correlated to the amount of inclusions in the ice. Inclusions decreased with stirring until a minimum was achieved. Increasing concentration and thus viscosity corresponded to larger amount of inclusions. Numerical modelling of the fluid flow dynamics in the freeze cell supported the experimental observations. A clear link with the shear rate near the surface and the amount of inclusions could be found. The ice growth rate and ice morphology were strongly affected by the set wall temperature, which can be explained by the degree of supercooling. Results reported contribute to better understanding of the required conditions to scale up film freeze concentration processes.

#7526
Quality analysis of fresh and dried mangoes

S. Arendt, K. Joedicke, W. Hofacker, W. Speckle

AOrganic acids, sugar and colour define the quality and the taste of mangoes. The quality deteriorates during drying on a single-layer-dryer. Quality losses can be reduced by using drying parameters that influence the quality less. In this research, the contents of ascorbic acid, organic acids and sugar as well as colour changes and shrinkage are analysed. Analyses are carried out at different temperatures, dew point temperatures and air velocities using HPLC, IC and UV/Vis- spectrometry. The quality criteria showed the lowest changes at a temperature of 60°C, dew point temperature of 20°C and an air velocity of 0.9 m/s.

Keywords: organic acids; sugars; colour; shrinkage; thin-layer-dryer

#7528

Experimental investigation and comparison of internal pressure in wood of willow Salix viminalis during convective drying in air and superheated steam

Robert Adamski

The aim of this work is to investigate and compare transport mechanisms of moisture and determinate transport coefficients during convective drying in air and in superheated steam of wood on the basis of experimental data and formulated models. The element of novelty consists of using directly measured internal pressure in the models.
The investigated wood samples in the form of 2-year-old stems 20 mm in dia. were collected from a Salix viminalis plantation during Winter. They were cut into 50 mm cylinders. Air drying was performed in a wind tunnel at 40°C, 50°C, 60°C and wind speed 1 m/s. The mean MC, solid temperature in four radial locations and internal pressure (axial and mid-radial) were monitored.
Superheated steam drying was performed in a column equipped with steam generator and superheater in temperatures 120 to 180°C and steam velocity of 0.05 m/s. This time two samples were used: one to measure mean MC , the other for radial temperature and axial pressure measurement.
Besides the obvious differences between air and steam drying it was noticed that the internal pressure evolution differs substantially. In air drying axial pressure slowly rises to a maximum value then drops to the initial value and follows even further to reach underpressure, which slowly relaxes at the end of the process.
In superheated steam pressure rises rapidly, due to fast heating to boiling point temperature, it reaches the maximum (higher than in air) an then relaxes down to the initial value. Underpressure was not observed.
The suggested model includes simultaneous Darcy flow and diffusional terms. Balance equations are formulated in 1D cylindrical geometry. Heat transfer equation includes conducive and convective terms. Balance of forces uses the elastic solid model. Shrinkage of green willow wood is moderate and was neglected. The mass transfer BC on the sample surface for air drying uses drying rate formulated as a product of mass transfer coefficient in gas phase and driving force equal to difference of equilibrium and gas core values of absolute humidity. In steam drying it is the product of heat transfer coefficient in gas phase and driving force being the difference of equilibrium and gas core temperature divided by the heat if vaporization. Sorption isotherm/isobar was measured directly, other model parameters were identified by the inverse problem solution using all experimental data.
The simulated results satisfactorily describe the experimental MC, temperature and pressure data points.

#7532
Salting kinetics, salt diffusivities and proximate composition in osmotically dehydrated Pirarucu muscle

Tiago Luís Barretto, Lilian Fachin Leonardo Betiol, Elisa Rafaella Bonadio Bellucci, Javier Telis-Romero, Andrea Carla da Silva Barretto

Pirarucu (Arapaima gigas Schinz) farming has been encouraged and, among meat preservation techniques, the salting process is a relatively simple and low-cost method. The objective of this work was to study the sodium chloride diffusion kinetics in Pirarucu during wet salting. Limited volumes of brine (20% w/w) were employed with wet salting assays carried at 3, 4 and 5 brine/muscle ratios, and brine temperatures of 10, 15 and 20 oC. The analytical solution of Fick's second law considering one-dimensional diffusion through an infinite slab in contact with a well-stirred solution of limited volume was used to calculate the effective salt diffusion coefficients. Salt diffusivities in muscle were found to be in the range of 2.07 and 8.80 ´ 10-10 m2/s. The wet salting of Pirarucu is greatly influenced by temperature and by the brine/muscle ratio by volume.

Keywords: Pirarucu; Arapaima gigas Schinz; salt diffusion coefficients; brine

#7533
Influence of fat level reduction in the drying of Italian salami

Camila Vespucio Bis Souza, Marise Rodrigues Pollonio, Ana Lúcia Barretto Penna, Andrea Carla da Silva Barretto

The aim of this study was to evaluate the influence of fat reduction in the drying process of Italian salami. Two Italian salami formulations: HFS (High Fat Sausage) with 20g/100g of pork back fat and LFS (Low Fat Sausage) with 11.2g/100g of pork back fat were analyzed as water activity, weight loss, proximate composition and pH. The evaluation times were 0, 3, 7, 10 and 13 days of drying.The reduction of more than 25% in the fat content of Italian salami affected the weight loss in the drying process, but did not affect the moisture, pH and water activity.

Keywords: Low-fat; fermented sausage; weight loss; healthier meat products; ripening time

#7541

Process of parboiling rice by microwave-assisted hot air fluidized bed technique

S. Prachayawarakorn, E. Saniso, T. Swasdisewi, S. Soponronnarit

In this work the new process of producing parboiled rice (PB) by combinatintion of microwave and hot air fluidized bed (MWFB) was proposed and investigated. Results showed that the drying time was shorter with smaller bed depth, higher drying temperature and higher microwave power. The initial grain temperature, drying temperature, bed depth and microwave power strongly affected the gelatinization of rice starch. The PB produced by MWFB caused a very small broken kernel (1-2%). The whiteness was decreased with increase in drying time, initial grain temperature, drying temperature and microwave power. The specific energy consumption was increased with increasing such operating parameters.

Keywords: drying; parboiled rice; fluidized bed; microwave

#7542

Fine Particle Drying in a nonporous draft tube conical spouted bed with fountain confiner

Mikel Tellabide, Idoia Estiati, Aitor Pablos, Haritz Altzibar, Martin Olazar

Drying is one of the most energy consuming industrial operations. Accordingly, energy consumption should be optimized even in the process of designing the dryer, i.e., only the air required for drying should be used for spouting and devices for increasing the contact between the gas and the solid should be provided.

The conical spouted bed is an interesting technology for drying fine particles due to its simple and efficient design. This contactor performs well for drying fine solids when fitted with a draft tube, given that it is stable in a wide range of operating conditions. Conical spouted beds fitted with a draft tube have proven to be an efficient dryer (Kfuri and Freitas, 2005) providing a large interface area for gas and solid contact, high heat and mass transfer coefficients, and high production rates. Moreover, the advantage of the spouted bed technique for drying lies in its capacity for handling granular products that are too coarse to be readily fluidized (Cui and Grace, 2008). Thus, conical spouted beds are an interesting alternative to standard but more expensive and less efficient rotary dryers.

The principal aim of this work is to assess the potential use of the fountain confiner for the drying of fine particles in a draft tube conical spouted bed. Accordingly, batch runs have been carried out in conical spouted beds provided with fountain confiner and without it and using different nonporous draft tubes under ambient conditions. The performance of the different alternatives has been compared in order to ascertain the optimum configuration for drying. The material used for operation has been building sand with an average particle size of 600 mm.

The results show that the fountain confiner improves the drying of fine particles since it provides a better contact between the gas and the solid, and reduces the drying time. In addition, among the nonporous draft tubes used the device with the highest entrainment zone is the best option because it allows attaining the lowest drying time. This is explained by the large amount of particles entering the spout at the bottom of the contactor, which leads to a high solid circulation rate in the bed.

#7543
Modelling batch drying of fine sand in a fountain confined conical spouted bed

Aitor Pablos, Mikel Tellabide, I. Estiati, Jorge Vicente, Roberto Aguado, Martin Olazar

A rigorous model based on hydrodynamic considerations and mass and energy balances has been proposed for batch drying of fine sand in a fountain confined conical spouted bed. The results show that the proposed model predicts acceptably the evolution with time of moisture content in the solid and the final moisture content for the different operating conditions, with the mass transfer coefficient being the only adjustable parameter.

Keywords: fine sand; spouted bed; batch drying; modelling

#7545

New options in particle design for high performance applications - Glatt´s APPtec advanced pulse powder and high temperature fluidized bed technologies

Michael Jacob

The worldwide increasing demands on the functionality and service life of components, devices and appliances leads to constantly new challenges in material and substance development across the entire value-adding chain.
In this presentation, a detailed introduction to different particle technology principles from powder synthesis in nano or sub-micron range up to particle enlargement technologies in micron or millimeter size range will be given.
Besides process basics, the potential for thermal powder synthesis using APPtec and thermal treatment as well as spray granulation using fluidized bed technologies at high temperatures will be explained. This portfolio of unique particle technologies offers new options for innovative product design. Case studies will be discussed.
APPtec is a powder technology developed by Glatt that allows powder composition and particle design to be adjusted to meet a customer's specific application needs. By synthesising the powder in a pulsed hot gas stream, product structures can now be generated that were not accessible with conventional techniques.
For size enlargement processes or thermal treatment of particles Glatt also has developed a very flexible high temperature fluidized bed granulation system up to 700 °C. The process temperature can be adjusted between 50°C up to 700 °C, if required gradually in different temperature steps. Therefore granulation and chemical reaction may be executed simultaneously or in sequence, as required. Based on the long time experience of the Glatt-group in the field of fluidized bed technology a new lab-scale test plant has been developed and installed at the Glatt Technology Center in Weimar. Various configurations can be selected to carry out different processes.

#7549

Superheated steam drying: Drying characteristics of single particle and fluidized bed drying

Nelli Hampel

Drying is one of the most important, common and energy-intensive unit operations used for thousand years. This process plays a major role in the agricultural, biotechnology, chemical, ceramics food, paper, pharmaceutical, polymers, pulp, mineral and wood processing industries. Currently, conventional dryers use hot air as the drying medium, which is the simplest among the various methods. However, this conventional drying method has several disadvantages. Besides those drying technologies superheated steam is another attractive alternative drying technique which is recently getting attention continuously as the technology has developed.

In this study, we present experimental works and models of the super headed stream drying process for single particles and drying in fluidized bed into account several important drying characteristics and product quality aspect. Simulation results are presented and compared with experimental data of brown rice and wood particles.

#7555
Study of the behavior of a multistage dryer provided with downcomer

Luis Verduzco Mora, Carlos Martínez Vera, Mario Vizcarra Mendoza

We study the behavior of a multi-stage fluidized bed dryer operated continuously with dowcomers. With the kinetics of silica gel drying depending on the mass of solids in the dryer and the gas feeding temperature, E = 14.5 KJ/mol, and the distribution of residence times of solids through the dryer, modeling by N tanks agitated in series, the experimental moisture content of the solids coming out of the dryer is compared with the predicted by the Vanecek model.

Keywords: fluidization; gel of sílice; continuous multistage dryer

#7556
Strawberries hybrid drying combining airflow, dic technology and intermittent microwaves

Ezzeddine Amami, Colette Besombes, Nabil Kechaou, Karim Allaf

1-cm strawberry slices were partially airflow-dried at 50 °C, to reach 0.25 g H2O/g db. Optimized DIC treatment was performed at 350 kPa for 10 s. The final drying stage of these DIC-expanded slices was achieved from 0.25 to 0.1 g H2O/g db (dry basis) using intermittent Pulsed Micro-Wave Drying PMWD to prevent from the paradoxical step of coupled conduction heat transfer with deep generation and transfer of vapor. PMWD was defined at constant 100 W for 3.25±0.05 g with constant active time ton maintained at 2 s, and tempering time toff ranged between 2 and 10 s, or with a continuous way. By decreasing both energy consumption and total drying time of DIC-expanded slices using intermittent microwave, the whole cost significantly decreased to be much lower than the conventional MWD drying, with a great increasing of the quality.

Keywords: airflow drying; instant controlled pressure-drop dic; swell-drying; pulsed micro-wave drying; physical and chemical characteristics

#7557
Bubble behavior of fructooligosaccharides syrup during the belt drying process

Lijuan Zhao, Dandan Wang, Tengfei Du, Junhong Yang, Jianguo Li, Zhonghua Wu

This paper is aiming to study experimentally the bubbling and drying characteristic of fructooligosaccharides syrup in the belt drying process. A series of bubble images were acquired by a high-speed image acquisition system during the drying process. By analyzing the characteristics of bubble and drying, the drying process of fructooligosaccharides was divided into three periods: boiling transfer, natural convection and conduction and diffusion period. The drying rate in different transfer stage was: boiling transfer > natural convection > heat conduction and diffusion. The results of the study are of reference value to belt drying.

Keywords: fructooligosaccharides; belt drying; digital image processing; heat and mass transfer

#7566
Investigation of spray agglomeration process in continuously operated horizontal fluidized bed

Jaijie Du

Spray fluidized bed agglomeration is an important process in particle formation and is widely used in the chemical, pharmaceutical and food industry. In the spray fluidized bed agglomeration process, fluidized particles are wetted by spraying a liquid; agglomeration occurs when a wet particle collides with another particle forming initially a liquid bridge which solidifies by drying.
Compared to batch process, continuous process holds the advantages of low labor, low dead time and high product throughput, however, the wide residence time distribution (RTD) causes the distribution of product quality especially for heat sensitive products. So besides the product quality, RTD also draw a lot of attentions.
In this study, a agglomeration in continuously-operated horizontal fluidized bed with three top spray nozzles is studied. The process is conducted with glass beads (dst=200 µm) and water-based binder hydroxypropylmethylcellulose (HPMC). Coated glass beads in the same size range are employed as tracers to characterize RTD by a kind of conductivity method. The steady state in continuous operation is reached and samples are taken periodically. The influence of operation conditions such as temperature, fluidization air speed, mass fraction of binder, binder to particle ratio, configuration of outlet weir and influence of inside baffles are studied. By characterizing the product properties, e.g. size distribution, moisture content, particle surface, conductivity, the interaction of properties and process conditions are studied. In addition, the Bodenstein number, which is defined as the dimensionless ratio of convective to dispersive particle transport is used and compared with the existing correlations.

Keywords: horizontal fluidized bed, agglomeration, continuous process, residence time distribution

#7588
Analysis of particle formation during drying of very small droplets

Isabel Siemons, Remko Boom, Maarten Schutyser, Ruud Van Der Sman

Spray dryer operations and design are largely based on the combination of experience and empirical design rules. To move away from trial-and-error approaches, it is imperative to have better understanding of underlying physical phenomena related to drying behaviour of droplets in spray dryers. In particular, particle formation during drying is crucial as it can govern final powder characteristics, including bulk density, particle size, and reconstitution behaviour. Single droplet drying techniques can aid in monitoring morphology evolution as a function of time. Hitherto, most single droplet drying methods employ larger initial droplet sizes (500-1000 µm) as compared to industrial spray dryers (10-150 µm) due to experimental constraints, affecting the dynamic processes occurring during drying.
In this study we introduce a novel sessile single droplet drying platform, enabling drying of droplets with smaller initial droplet sizes than can be obtained using most existing single droplet drying techniques. During sessile single droplet drying, a single droplet is deposited on a hydrophobic surface and subsequently dried by contacting it with well-defined drying air. A piezoelectric droplet generator is used to produce droplets, from various liquids with varying initial dry matter content (up to ~45% (w/w)), of similar size range (~150 µm) as during spray drying. Subsequently, a convective air flow is supplied to dry the droplet. Variations in droplet size, drying conditions, and formulations are analysed to characterize changes in physical state and morphology. Depending on material properties, large variations in morphology evolution and surface properties are expected. Results from this study may contribute to better control of product quality and process behaviour, increasing overall performance of spray drying operations.

#7590
Towards a novel strategy to increase probiotics survival after spray drying

Evelien Vaessen, Heidy den Besten, Remko Boom, Maarten Schutyser

Some (micro)organisms can survive extreme conditions in nature, like dehydration or freezing. Intracellular accumulation of the disaccharide trehalose is a well-known protection mechanism to survive such harsh conditions. An analogous strategy could be employed to make probiotics more robust towards the spray drying conditions. So far, protection of probiotics during spray drying is mainly done via encapsulation. Studies have been performed on the effect of probiotics encapsulation in carbohydrates, proteins or mixtures of components such as reconstituted skim milk, on their survival after spray drying. As discussed, additional intracellular accumulation of protectants, could perhaps lead to even higher survival of probiotics after spray drying. There are several options to incorporate these in microorganisms, for example via natural induction by exposure to sub-lethal doses of a stress or via overexpression using genetic modification. The latter is however less desired from a consumer acceptance perspective.

Therefore, in this study we focus on development of a novel physical pre-treatment of bacterial cultures; namely a pulsed electric field treatment to increase the intracellular solutes concentration. These intracellular solutes could, together with a protective matrix extracellular, enhance survival of probiotics during spray drying. We made an extended evaluation on how to increase the intracellular protective solutes concentration. Pulsed electric field treatment conditions were optimised to establish operating conditions with enhanced intracellular trehalose concentration in Lactobacillus plantarum WCFS1 and high retention of culture viability. Future research will be directed at combining this pre-treatment with drying.

Keywords: Spray drying; Probiotics; Survival; Pulsed electric field

#7611
Drying characteristics and water desorption isotherm of Ulva spp. using different drying methods

Elsa Uribe, Antonio Vega-Gálvez, Vivian García, Alexis Pasén, Gabriela Goñi Mail

Green algae belonging to the genera Ulva (Chlorophyta) are common seaweeds distributed worldwi de. They possess an interesting nutritional composition making their commercial exploitation attractive to produce functional food ingredients. However, to obtain a product suitable for industrial processing it is necessary to control the preservation and drying conditions. The aim of this work was to establish the effect of different drying methods on drying characteristic, desorption Isotherms and color of green seaweeds genus Ulva from Region of Coquimbo, Chile. Four different drying conditions were used: freeze-drying (FD) at a vacuum pressure of 200 mTorr for 73 h; vacuum drying (VD) at 70 °C and 15 kPa for 390 min; sun drying (SD), approximately at 50 °C for 480 min and convective drying (CD) at 70 °C and constant air flow of 1.5 m/s for 120 min. The equilibrium moisture content was determined by a gravimetric technique. The surface color of the samples were measured using a HunterLab colorimeter and the CIE L*, a* and b* colour scale. Drying results showed that different drying methods had significant effects on the drying characteristics and kinetics. The CD had the best drying characteristics with the shortest drying time and the fastest drying rate. Monolayer moisture content evaluated by the BET model corresponded to the moisture content at which local minimum integral entropy value was observed for sorption processes. Brightness parameter (L*) of the product increased its value independent of the applied drying method, where FD stood out due to its increase, whereas the chromatic coordinates (a* and b*) showed a different pattern, these values decreased in all treatments compared to the control sample ($p < 0.05$). This work provides an important information about the drying characteristics by application of different drying methods to the Chilean edible green seaweed, Ulva spp.

Keywords: Ulva spp., drying methods, water desorption isotherm, surface color

#7620

Low-temperature vacuum drying (LTVD) of papayas (Vasconcellea pubescens): Drying characteristics and kinetics

Antonio Vega-Gálvez, Elsa Uribe, Macarena Vega, Alexis Pastén

Chilean papayas (Vasconcellea pubescens) have lately received considerable attention, since they are naturally rich in functional nutrients and bioactive compounds, which are claimed to exert many health benefits. However, papayas are highly perishable commodities due to rapid deterioration of their chemical components. Drying is one of the most common applied fruit processing which is known to induce adverse effects. Nevertheless, it is possible to enhance the quality of the dried products by decreasing temperature or shortening drying time. Low-temperature vacuum drying (LTVD) is a novel drying technique developed for the drying of sensitive food ingredients, but its application for fruit drying has been little investigated to date. This experimental study is focused on the influence of temperature in the low-temperature vacuum drying (LTVD) process of Chilean papayas (Vasconcellea pubescens).

The experimental study results of the drying kinetics are presented. The drying kinetics was studied at five different temperatures (10, 15, 20, 30 and 40 °C) and one vacuum pressure (10 mbar). Evaluation of drying behavior showed that equilibrium moisture content at 40 °C is reached after 1350 min, while at 10 °C a drying time of 5305 min is needed. As expected, the increase of temperature reduced drying duration. Out of five models proved for simulation, Weibull model was found as best fitted thin layer drying model when simulation was done for all the drying data. In the ranges covered, the effective moisture diffusivity values (Deff) were obtained between 0.42×10^{-13} m^2/s and 1.88×10^{-13} from the Fick's diffusion model. The Arrhenius relation, with an activation energy value of 39.81 kJ/mol, expressed the temperature effect on the diffusion coefficient. From these results, it is possible to estimate dryer conditions of this novel technique; however, it is necessary to carry out more prospective studies on the possible nutritional and functional changes that may occur during LTVD of this fruit at different temperatures.

Keywords: vasconcellea pubescens. low-temperature vacuum drying (LTVD), drying kinetics, effective moisture diffusivity

#7626
Production of dry-cured pork loin using water vapour permeable bags

A. Fuentes, S. Verdú, C. Fuentes, R. Grau, J. M. Barat

The aim of the present study was to develop an alternative method to the traditional curing process using water vapour permeable bags to obtain a dry-cured pork loin product. The dry-cured pork loins obtained by this mew process showed an adequate hygienic quality and good sensory acceptance. The salting-curing process using water permeable bags requires less manipulation, reduces waste generation and allows greater control during processing. This technique could be an interesting alternative to the traditional processes, improving the hygienic quality of the products and minimizing the environmental impact.

Keywords: Dry-cured loin; Salting; Water vapour permeable bags; Physicochemical properties; Sensory

#7627

Reducing sodium content in dry-cured pork loin. A novel process using water vapour permeable bags

A. Fuentes, S. Verdú, C. Fuentes, R. Grau, J. M. Barat

The objective of the present study was to test the feasibility of a new salting-curing process using water vapour permeable bags to obtain a reduced sodium dry-cured loin. The process was applied with and without partial substitution of sodium chloride by potassium chloride. The developed methodology allows to obtain a dry-cured pork loin with partial sodium substitution similar to the product without reduced sodium content, regarding to their physicochemical parameters, texture and colour. The results indicated that the new process allowed to obtain a cured meat product with 50% less sodium and similar characteristics than the traditional products.

Keywords: sodium replacement; water vapour permeable bags; dry-cured loin; salt content; physicochemical parameters

#7640

Influence of back mixing on the pilot-scale convective drying of sewage sludge: evolution of the volume and exchange surface

Jie Li

The influence of the back mixing operation (40%, 60%, and 70% on a dry basis) on the pilot-scale convective drying of sewage sludge was studied. X-ray macrotomography was used to research the evolution of the volume and exchange surface of sample bed during the drying process. Results first confirm the back mixing has a positive impact on the drying process from the mass fraction of 40%, with drying rates higher than that of the original sludge. The evolution of the volume and exchange surface, obtained from X-ray tomography experiments, was investigated. The relationship between the volume (exchange surface) and water content is nearly linearly for the original sludge and back mixing sludges. The 2D cross-sections of the single extrudate after drying of the original sludge and back mixing sludges, obtained from the X-ray microtomography experiments, show the shapes of the particles inside the extrudates of four sludges are similar, which are almost blocks.

#7641
Study on the general dynamic model of biomass drying processes

Le Wang, Xu Li, Qiaoling Li, Duanfeng Lu, Bin Li, Wnkui Zhu, Mingjian Zhang, Ke Zhang, Nan Deng

Nowadays most studies of drying processes dynamics are established on empirical models without clear physical meanings, which could not predict the drying characteristic on different dryers. In order to describe the change of temperature and water content in the cut tobacco in different dryers, a mathematical model based on heat and mass transfer phenomena was developed, and the model employed the relationship of equilibrium moisture content and air humidity as basis, the difference of moisture between biomass and wet air as mass transfer driver, and the difference of temperature between biomass and wet air as heat transfer driver. The drying experiments under different air temperature and humidity are carried out on the batch rotary dryer, and the variance of temperature and moisture content in the biomass is obtained by using infrared thermometer and oven. The model is validated by two parameters with experiment data under each condition of air temperature and humidity. The results show that the drying dynamic model is well on accuracy and universality, and it could be applied on different drying device to predict the characteristic of kinds of drying processes.

Keywords: cut tobacco; drying dynamics; equilibrium moisture content; heat transfer; mass transfer

#7660
Development of a CHES-FBD dryer for paddy rice

Adesoji Matthew Olaniyan, Adesola Adebanjo Satimehin, Nonzo Dickson Ani

Moisture removal isan essential pre-requisite for food preservation and one of the methods thathave been adopted since many centuries is drying which is the application ofcontrolled flow of heated air to the products. Drying is one of the most complex and energy-consuming unit operations infood processing which has contributed immensely to food preservation, reductionin post-harvest losses, reduction in weightand volume of food thus minimizing packing, storage, and transportation cost.It is complex in the sense that it involves the combination of heat and masstransfer and physical property change of the food material. In thisstudy, a combined Combustion-Heat Exchanger-Suction-Fluidized Bed (CHES-FBD) dryer was first designed, constructed and tested for paddyrice drying in the rural communities in order to make the commodity available allthe year round at affordable cost. The designconsiderations included technical simplicity, maintainability, ease of operation,storability of the product after drying, and techno-economic status of the smallholderfarmers in the rural communities. The dryer has five major functioning units,which are the heating (combustion) chamber, heat exchanger, suction unit, distributorand the drying chamber. The dryer was designedto dry 50 kg of paddy rice per operation in 60 minutes. Design calculations includedmass of moisture to be removed from the product including the quantity of air toremove the moisture. Others included energy required for heating the air. A preliminarytest carried out showed that the dryer was able to dry paddy rice to safe moisturecontent of 14 percent which is an evidence of satisfactory performance.Key words: CHES-FBDdryer, energy transport, food processing, paddy rice, post-harvest loss.

#7672
Evaluation of Izmir Tulum cheese pieces by drying with tray drier at different air flow rates and temperatures

Gulsah Kizilalp, Izel Polat, Müge Urgu, Nurcan Koca

Izmir tulum cheese pieces were dried using a tray dryer at different air flow rates (1.0 and 1.8 m/s) and temperatures (45°C, 55oC and 65°C). The increase in temperature and air flow rate increased bulk and tapped bulk densityand decreased the water holding capacity. The lowest lightness and highest redness were obtained in samples dried at 65°C. The samples dried at 55°C and 1 m/s had the highest flavor and overall impression scores. As a result, a dried cheese product to benefit from left-over pieces obtained during packaging was developed, having advantages such as easy to transport, store and package.

Keywords: Izmir Tulum cheese; tray dryer; physical, chemical and sensory properties

#7673

Stability, microstructure and rheological characteristics of low-fat and full-fat cheese emulsion with different emulsifying salt concentration for production of spray-dried cheese powder

Muge Urgu, Sevcan Unluturk, Nurcan Koca

Cheese powder can be used as a flavoring agent and nutritional supplement in many food products, such as dressings, baked foods, chips, snacks. Spray drying technology can be generally used to produce cheese powder by removing the water from the feed, which is in liquid state form. Therefore, it is necessary to prepare cheese emulsion before spray drying for producing powder.
Cheese emulsion is produced by heating the grated cheese in the presence of mainly water and emulsifying salt, and preferably different additives such as dairy ingredients, maltodextrin, starch, flavor enhancers. In the production of cheese powder, it is necessary to produce stable, homogeneous and pumpable emulsions with higher dry matter due to technological and economic necessity, and these parameters need to be considered before drying. In the study, we produced full-fat and low-fat white cheese emulsions with different dry matters (15-25% excluding emulsifying salt) and emulsifying salt concentrations (0-3% based on cheese amount) to figure out the effects of emulsifying salt concentration on the stability, microstructure and rheological properties cheese emulsions with different dry matter contents. Stability results showed that reduction in the emulsifying salt concentration significantly reduced the stability degree of emulsion. Full-fat cheese emulsion with 25% dry matter and low-fat cheese emulsion with 20% and 25% dry matters prepared by using 3% emulsifying salt concentration evaluated as stabile emulsions showing no phase separation by centrifugation. When compared to full-fat cheese emulsions, low-fat cheese emulsions had higher stability because of their higher protein content. Power Law and Herschel-Bulkley Models were tested to ascertain the flow behavior of stabile emulsions and pseudoplastic non-Newtonian flow behavior were found. The microstructure of emulsions was indicative for emulsification degree and stability of emulsions. Increasing of emulsifying salt content led to the development of more homogeneous and compact structure in both full-fat and low-fat emulsions. The sizes of fat particles were smaller when the concentration of emulsifying salt increased for all emulsion groups. Increase in dry matter contents of emulsions with the same amount of emulsifying salt also affected the stability and microstructure of emulsions positively. Emulsifying salt concentration is a key factor for producing stabile emulsion without protein precipitation prior to the atomization. Optimum emulsifying salt concentration, dry matter content and flow characteristics of emulsion for each cheese type are need to be determined for a fine atomization to produce high quality powder

#7683

LNT microwave-multiphase transport model for the microwave drying of lignite thin layer

B. A. Fu, M. Chen, Q. H. Li

The LNT microwave-multiphase transport model has been applied to the microwave drying of lignite thin layer. Microwave energy, temperature and moisture distribution were obtained to gain a comprehensive understanding on the heat and mass transfer mechanism of the drying process. The required drying time of experiments decreased by 50, 63, 67, and 83%, respectively, with the power level rising from 119 to 700 W, while that decreased by 60, 72, 76 and 86%, respectively, for simulation results. The temperature values of the corner and edge of the lignite thin layer were higher than that of the center region, which corresponded to the microwave energy distribution. The moisture ratio profiles, temperature profiles and temperature distribution indicated good agreement between the experimental and simulation results, providing confidence in the modeling approach, which made it possible to obtain the moisture distribution successfully via simulation method.

Keywords: microwave; lignite; thin layer

#7688

Combined drying technologies and the effect on the quality attributes of carambola slices (averroha carambola L.)

Rosa I. Castillo

Carambola (Averrhoa carambola L.) is an exotic fruit with an important nutritional contribution that is reflected by its high concentration of bioactive compounds, however, is a highly perishable product. The objective of the study was to analyse the influence of high power ultrasound (HPU) during osmotic dehydration pre-treatment (DO) on convective drying of carambola sleces (SC), to obtain chips as a conservation technique alternative. Carambola fruits grown at the Campus Veracruz Postgraduate College were used. Slices of carambola of 5 mm were immersed in solutions of sucrose solution of 50 and 60 ° Brix. The DO-HPU treatment was performed using ultrasound power bath. Drying kinetics (SC) were performed at 50 and 60° C in try dyer by air velocity of 1.5 m/s. in order to evaluate the effect of combined technologies on quality parameters, after convective drying at 60 ºC, the analysis of phenolic compounds, antioxidant activity, oxalic acid content, color (L, a*, b*), moisture and total solids, water activity, and texture were determined in the carambola silences. In addition, a sensorial analysis of the finished product was carried out. The results showed that the HPU assisted to DO significantly ($p<0.5$) decrease the moisture content of carambola compared with DO without US. The treatment at 60 ° Brix(DO), with US and SC at 50 ° C, allowed to reach a value of aw = 0.469 in less time than the treatment without ultrasound. Regarding global variation color (ΔE), no significant difference was obtained between the different treatments. since they are statistically the same and have a lower color variation than the natural fruit. The dates showed that regarding total phenolic compounds, the 60 ºBrix-DO without US and SC at 50 ° C, is the one that degrades less to these compounds; even the treatment (50ºBrix-SUS-60ºC) shows significant ($p<0.05$) increase for% IRD DPPH and % IR ABTS values. On the other hand, the treatment that presents a lower value in texture in center was 60 ºBrix-SUS-60ºC treatment reached 0.736 KgF, and 0.345 KgF value in th periphery sample. Nevertheless, these values were according with the values of other fry food. In addition, the sensorial analysis allowed us to know that the combination of the three technologies was very satisfactory, and this was reflected in the high acceptability of the food. It can be concluded that the combination treatment represents a good alternative to reduce the energy cost for the subsequent convective drying process.

#7696

Description of atmospheric freeze-drying of brown seaweeds (Saccherina Latissima) with respect to thermal properties and phase transitions

Ignat Tolstorebrov, Trygve Magne Eikevik, Inna Petrova, Michael Bantle

Thermal properties of brown seaweeds (Saccharina latissima) were determined using DSC technique in the temperature range between -150.0 and 50.0 °C. The following phase transitions were detected: glass transitions, incipient point of ice melting and freezing point. The ice content and amount of unfrozen water was detected by analysis of the melting peak. The ice content reduction in the product was predicted for different moisture contents and temperatures for atmospheric freeze-drying process.

Keywords: brown seaweeds, ice fraction, freeze-drying, glass transition

#7697
Description of atmospheric freeze-drying process of organic apples using thermo-physical properties

Ignat Tolstorebrov, Trygve Magne Eikevik, Inna Petrova, Yulia Shokina, Michael Bantle

This study discusses the influence of temperature and total moisture content on ice fraction in organic apples during atmospheric freeze-drying process. The ice formation of glass transition events were described by Clausius-Clapeyron and Gordon Taylor equations. The obtained data is essential for design the drying process and for understanding the limiting factors.

Keywords: ice fraction, organic apples, atmospheric freeze/drying, glass transition

#7708
Exploring drying conditions for Mexican mesquite pods (Prosopis laevigata)

S. S. Torres, D. López, J. Rodríguez, L. Mendez, L. V. Aquino

Mesquite pods contain a high nutritional content, then a protein rich flour can be obtained. Prosopis Laevigata pods were collected from Oaxaca and Durango. Three stages of maturity were identified. The internal structure of the pods was analyzed by scanning electron microscopy (SEM). The pods were dried at 40°C, 50°C and 60°C, 10% relative humidity and air velocity of 2.6 m/s. From experimental data, the characteristic curve was obtained. SEM Images showed a heterogeneous and tortuous structure. The internal structure of the material is a limiting factor for mass transfer. The effective coefficient diffusion for each drying experiment was determinated.

Keywords: drying; mesquite; pods

#7711
Effects of thermal intermittence on fruit characteristics and drying time in convective drying of mango (Mangifera indica L.)

Laís Ravazzi Amado, Keila Souza Silva, Maria Aparecida Mauro

This study investigated the influence of the intermittent drying conditions on drying kinetics and on color and carotenoid retention of mangoes. The drying conditions were 95°C (40 min) and 80°C (40 min) in the first stage combined with 70°C and 60°C in the second stage, and continuous drying (70°C and 60°C) as control. Drying time was reduced by thermal intermittence and carotenoid retention was more affected by temperature than drying time. The results also highlighted the carotenoid sensitivity to 70°C temperature, showing the importance of limiting the temperature of the mango to 60°C during the two drying stages.

Keywords: Intermittent drying; thermal intermittence; carotenoid; color

#7718
Modelling the drying kinetics of sucrose droplets with different initial concentrations using the Reaction Engineering Approach (REA)

Nan Fu

Drying of droplets containing dissolved or suspended solids as typically in industrial spray drying may involve complicated physiochemical transitions, for example, crystallization, inactivation of bio-active substances and segregation of ingredients. These transitions largely depend on the properties of the solids, which impact the droplet drying behavior such as drying kinetics and crust formation and further influence the properties of final dried particles. The Reaction Engineering Approach (REA) is a "fingerprint" model that establishes a master activity-energy curve to describe the drying behavior of a specific material. The master activity-energy curve could accurately describe droplet drying history for varied temperature and humidity conditions, and thus explicitly relates the drying kinetics to the property of solids. A previous study suggested that the REA is sensitive to initial solids concentrations. In this study, we show that when the initial solids concentration minimally affects the drying behavior of the droplets, a master activation-energy curve can be established for varied initial solids concentrations, with accurate description on changes in droplet temperature and moisture content during drying. Experiments were performed with the Single Droplet Drying (SDD) technique, to quantitatively measure the mass, diameter and temperature changes of sucrose droplets with initial solids concentrations of 10, 30 and 50 wt.%. Three drying temperatures of 70, 90 and 110 °C were studied. The REA model was modified slightly to correlate the activation-energy of evaporation to the average moisture content of the droplets. A master activation-energy curve capable of describing the drying histories for all three initial concentrations was established for each temperature. The results indicated that when drying of 10 wt.% sucrose reached the later stage, the drying behavior is similar to that of 30 wt.% and then 50 wt.%. The findings supports the REA as a suitable approach to study the droplet drying behavior as influenced by the properties of solids. The master-activation energy curves of sucrose were compared to that of other sugars to discuss how the different properties of sugars influences their droplet drying behavior.

#7720
Development of cost-effective protocol for preparation of dehydrated paneer (Indian cottage cheese) using freeze drying

S. S., P. H. Nema, N. Emanuel, S. Singha

Nowadays, there is high consumer demand in the market for simple to prepare, convenient, healthy and natural foods. Paneer or Indian cottage cheese is an acid and heat coagulated milk product which serves as a rich source of animal proteins for the vegetarians. Due to high moisture content (58-60 %), it is highly perishable in nature. Drying of paneer would undoubtedly extend the shelf life of paneer and also help in value-addition of paneer. Dehydrated paneer would find numerous ways to be use. Drying of paneer by conventional methods poses threats including case-hardening and non-uniform incomplete drying, poor rehydration characteristics, longer drying time, yellow discoloration and oiling off during drying. Freeze drying remains the best in retaining the quality of dried food products. Though it is highly expensive due to high processing and operation costs. The present study focuses on developing cost-effective protocol for freeze-drying of paneer. Efforts have been made by use of pre-treatments prior subjecting to freeze drying. The dehydrated product would be shelf-stable and can be rehydrated to its original state having flavor and texture comparable to the fresh form. Moreover, the final product after rehydration would be more fresh and softer than its frozen counterparts. The developed product would be easily kept well for few years at room temperature without any addition of preservatives.

Keywords: paneer; freeze-drying; color; rehydration ratio; pre-treatment

#7721

The effect of different wall materials on the production of suppressed-pungent capsaicin microparticles

Emine Varhan, Zehra Kasımoğlu, Mehmet Koç, Hilal Şahin Nadeem

The aim of this study was to investigate the effects of wall materials types on the production of double-layered and suppressed-pungent capsaicin microparticles via spray chilling method. For this purpose, palm oil and different proteins (gelatin, sodium caseinate and whey protein) were used as wall materials, while soy lecithin was selected as stabilizer. Sample encapsulated only with palm oil (single-layered) was used as control. Centrifuge stability and kinetic stability were analyzed on the prepared emulsions. Total and surface capsaicin, microencapsulation efficiency, melting point temperature and fusion enthalpy analysis were carried out on the capsaicin microparticles obtained by spray chilling.

Keywords: capsaicin; spray chilling method; pungency; double-layered microparticles

#7728
Microbial load reduction using modified Solar Conduction Dryer with composite filters

P. Jadhav, S. Ashokkumar, N. Nagwekar, B. Thorat

The present work studies the microbial load reduction in sapota and beet root by three different drying methods i.e. Open Sun Drying (OSD), Solar Conduction Drying (SCD) and a modified SCD with filters (SCDF). Parameters analyzed were water activity, moisture content, drying kinetics, Total Viable Counts, Total Fungal Counts and ash content. It was found that the samples dried in SCDF showed least microbial counts, faster drying times and lower ash content as comparison to OSD. This study shows that SCD and its modification provide a better alternative for low cost drying of fruits and vegetables for quality retention.

Keywords: microbial reduction; SCD filters; sapota; beetroot

#7729
Pressure drop characteristics of adjustable slotted distributor in fluidized bed

T. Zhao, C. Liu, Q. Xu, Z. Li, W. Juan

In this paper, a fluidized bed with a adjustable slotted gas distributor was used to study fluidization in a 230 mm×200 mm rectangular fluidized bed by adjusting the spacing between the two slotted gas distributors. The pressure drop of the distributor at different inlet gas velocities was obtained and the change law between pressure drop and distance between distributors was summarized. This study provides a theoretical basis for the application of adjustable slotted gas distributor fluidized bed.

Keywords: geldart D; adjustable slotted gas distributor; pressure drop

#7734
Coating effect of micro-sized droplets impacting on low temperature spherical particles

Xiusheng Wu, Xiaoyu Ma, Qing Xu, Zhanyong Li, Ruifang Wang

In this paper, the effect of spray droplets on the coating of cold spherical particles was studied. The microcapsule granulator produces micron-sized droplets to coat the spherical particles in cold storage, and the high-definition camera and precision balance are used to photograph and weigh the particles before and after the spraying. The droplets are obtained by using the image and data processing technology coating area and coating quality, the droplet coating effect was evaluated by a number of dimensionless parameters such as coating ratio and mass ratio. By orthogonal design experiment and uncertainty analysis, the effects of droplet size and flow rate, spherical particle temperature and diameter on coating effect were studied, and the effect of droplet group coating on low temperature spherical particles was obtained.

Keywords: spray freeze drying; droplets; Coating; spherical particles

#7735
Superheated steam spray drying for food applications - a feasibility study

Tobias Balke, Reinhard Kohlus

Drying processes in industry belong to the most energy consuming processes. The replacement of hot air by superheated steam as drying medium can significantly improve the energy efficiency of the process. The exhaust air stream of a regular hot air spray drier is too low in temperature for further use and the latent heat of evaporation is released to the environment. The approach to reduced energy requirements by use of superheated steam instead of hot air is of high interest also to spray dried food products. In addition, superheated steam creates an oxygen free environment with advantages for oxidation-sensitive products or products that can create an explosive atmosphere.
A prerequisite for this approach is that the product to be dried is not too sensitive to high temperatures for a short period of time. This study proofs experimentally the applicability to food products by using a pilot plant scale superheated steam spray drier with an evaporation rate of 10kg/h. Several food products and ingredients have been selected for this study. The group of products includes starches, proteins, thickener i.e. gum arabic and food applications such as tomato and coffee. The applicability of the process was evaluated in terms of yield, degree of fouling, water activity and water content of the powders. Impact of process conditions was tested especially with respect to outlet steam temperature. To avoid process conditions that may cause sticky point induced fouling or insufficient drying, high temperature isotherms of the tested products were determined by a specially designed measurement device. Furthermore, quality aspects of the powders such as color and product specific properties like viscosity in solution are assessed. The contact angle of the obtained powders was measured to gain information about the surface energy. This is especially of interest for material with a hydrophilic and hydrophobic character, such as proteins that can re-arrange upon surrounding conditions during drying. Scanning electron microscopy gives insight into the impact of superheated steam on the powder particle morphology.
A modified GEA SD 4.0 pilot plant spray drier with an evaporation capacity of 30kg/h was used to prepare reference material for comparison to quality of products generated by standard drying.

Keywords: superheated steam, spray drying, food powders, quality aspects, pilot scale

#7736
Hybrid and intermittent drying of carrot (Daucus carota var. Nantes)

Justyna Szadzińska, Dominik Mierzwa, Krzysztof Bukowski

A combination of high power airborne ultrasound and microwaves in hot air drying was developed to investigate the effect of intermittent mode on process effectiveness and quality of carrot. The drying experiments were carried out in an innovative hybrid dryer. The course of moisture ratio, drying rate, specific energy and water consumption, colour, water activity and shrinkage were discussed. The results showed that intermittent ultrasound and microwaves in convective drying accelerate the heat and mass transfer, leading to shorter drying time and faster drying rate. It was found that hybrid-intermittent drying can improve the energy efficiency and product quality.

Keywords: intermittent drying; ultrasound; microwaves; energy; shrinkage

#7740

Determination and modelling of the particle size dependent residence time distribution in a pilot plant spray dryer

Nora Alina Ruprecht, Reinhard Kohlus

The residence time distribution (RTD) in a pilot plant spray dryer was characterised for two kinds of air distributors (centrifugal and parallel flow) and for different atomizing air pressures. To determine the RTD - and the RTD of different particle size fractions - the particle concentration and size at the dryer outlet was measured continuously using a particle counter. Results were modelled using the Bodenstein number and the CSTR in series model. An increasing nozzle pressure leads to a decrease in mean residence time and a more narrow distribution. The influence of nozzle pressure is more pronounced than of air distributor and particle size fraction.

Keywords: residence time distribution; particle size; bodenstein number modelling; nozzle influence; mechanism of air distribution

#7749
Application of microwaves in the convective drying of ceramic

Kinga Rajewska, Andrzej Pawłowski

The paper demonstrates microwave and convective drying processes in different combinations of kaolin cylindrical samples in laboratory scale. Analysis of the kinetics and sample temperature evolution show that the moment of application and electromagnetic field duration have the biggest influence on characteristics of the drying curve and quality of dried material. Dried samples were subjected to strength tests using the Brazilian method in order to determine the relation between its quality and different drying programs.

Keywords: ceramic, convective drying, microwave drying, strength test

#7751

The effect of the different drying techniques on the antioxidant activity of orange peel

Canan Kartal, Gamze Sonkaya, Aygün Şanlı, Büşra Çakaloğlu, Semih Ötleş

Nowadays, citrus fruits constitute one of the large production portion of fruits through their remarkable bioactive compound contents including antioxidants. Orange represents the major part of this production throughout the world. However, this huge amount of production gives rise to a considerable waste production in the same time. Orange peels, as the primary waste by-product of the orange juice industry, have a great potential via phytochemicals that are abundant in peel structure and can have an important contribution to the human health by utilizing in proper ways.

The main aim of the current study is to determine the difference in the antioxidant properties of orange peels after applying different drying methods. For this purpose, sun drying, tray drying and microwave drying techniques are evaluated and compared with fresh samples. After drying step, the methanolic orange peel extracts was compared considering the drying effect on the total phenolic content, antioxidant activity and carotenoid content. Besides, the effect of ultrasonication application to the methanolic extraction step of dried orange peels was investigated. In this part of the study, 10, 15, and 20 minutes ultrasonication were applied at the extraction step of the microwave dried orange peels and the optimum sonication time was determined considering the total phenolic content, antioxidant activity and carotenoid content.

Total phenolic content was expressed as mg gallic acid per g orange peel (dry basis), ABTS and DPPH values were expressed as micromol Trolox per g orange peel (dry basis) and carotenoid content expressed in terms of beta-carotene. According to the results of the study, microwave drying was chosen among applied drying methods and the optimum ultrasonication time was determined as 20 minutes.

Key words: drying, orange peel, antioxidant, waste valorization

#7754
Optimization of drying condition of instant matooke chips

John Bosco Kawongolo

Banana is an important crop in Uganda; it is a staple food for more than 70% of Uganda's population and contributes to about 42% of household income in rural areas. The most common type is the green bananas locally called matooke, a Musa sp triploid acuminate genome group East African Highland bananas (AAA-EAHB) which is steamed and served as a main course. Matooke are perishable and are traded in fresh form which leads to high postharvest losses ranging from 22-45%. Drying of fruits is a widely applied process to increase shelf-life and reduce bulk transportation, thus, value addition/processing. It was important to understand the controlling parameters in this complex process and to understand the drying behavior of a given product for use in improving the existing drying systems, controlling the drying process and to improve on the quality of the dried product. PIBID is centered on adopting the research findings on matooke flour, in order to diversify its utilization. However, the conditions for drying instant matooke chips have not been optimized, therefore, this study has focused on optimizing the drying conditions for instant matooke chips from which Instant Tooke Four (ITF) is obtained in order to minimize the cost of commercial production since drying in an energy intensive process. The objective of the investigations described in this paper was to establish the effect of processing parameters on the drying characteristics of matooke and the specific objectives are: to determine the effect of process parameters on drying characteristics and to optimize the drying condition for drying instant matooke chips. Fresh samples were harvested by picking five fingers from each bunch, washed, steamed, peeled and sliced to specified uniform thickness using slicing machine. The thickness of sliced samples was continuously monitored by physical measuring using a Vanier Clippers to confirm the actual thickness. All experiments were carried out at the Presidential Initiative on Banana Industrial Development (PIBID) - Technology Business Incubator at Bushenyi, Uganda. The independent variables (processing parameters) are: Air temperature (50, 60 and 70˚C); and Slice thickness (3, 5 and 7 mm). The dependent variables are: Drying time (min) and sample weight. The results showed that the drying rates increase with temperature in increase and decreases with increase in thickness.

#7761
Drying of algae by various drying methods

Bhaumik Bheda, Manoj Shinde, Rajaram Ghadge, Bhaskar Thorat

Algae drying was carried out using Vacuum Tray Dryer and an Innovative Solar Conduction Dryer. Algae was dried in a Vacuum Tray Dryer at 60°C under varied pressure conditions and makes use of specially designed double condenser system. The open sun drying and solar conduction dryer (SCD) was also used for algae drying. Comparison between open sun drying and solar conduction dryer were done and it was found that the solar conduction dryer gives high performance than the open sun drying. It was also found that, the conductive heat transfer mode plays a crucial role in the solar conduction dryer.

Keywords: vaccum dryer; solar conduction dryer; algal drying

#7768
Morphology evolution during single droplet drying of hydroxypropyl methylcellulose at high temperatures

Wael Ahmed Mohammed Ebrahim, Andrew Bayly

Spray drying is not solely a process for removing water; it is a particle formation process, the product of which will have certain properties and performance requirements. Control and manipulation of the created particle structure during spray drying is critical for the successful development of products with enhanced properties. For this reason, the study of particle structure during drying has attracted significant interest along the years, focusing on predicting dried particle structure, properties and drying rate based on droplet drying history. In the case of drying above the boiling temperature, the estimation of final size, structure/morphology and density of the dried particle becomes even more challenging. This is because when the temperature of the particle rises above the boiling point, bubble nucleation, growth and collapse within the droplet can have a significant effect on the final structure and the drying rates of the droplets. For these systems, only limited studies were reported and a deeper understanding of behaviour across a wide drying history, drop size, initial slurry concentration and material property space is still lacking. Therefore, this study aims to investigate the effect of boiling on the drying behaviour and the developing morphology with emphasis on the role of material properties.

A single droplet drying rig has been developed to enable the measurement of drying kinetics and visualisation of the developing morphology across a broad range of drying conditions and composition space. Initially, the drying rig was validated by conducting experiments on droplets of pure water. Drying experiments were then conducted on Hydroxypropyl Methylcellulose water solutions to map the morphology evolution at a range of air temperatures and initial solid concentrations. Drying at lower temperatures showed three distinct drying stages; homogenous shrinkage, skin formation and skin deformations. At high temperatures a secondary bubble growth and collapse was observed. It was noted that the skin formation is the main factor that drives the resulting morphology. Therefore, the next stage of the study focused on evaluating the mechanical characteristics of the skin and linking these measurements to the drying behaviour observed. The method involved preparation of thin films on glass substrates and conducting mechanical tests using Atomic Force Microscopy. Other methods including Nano-indentation and Dynamic Mechanical Analysis (DMA) are currently being evaluated. Further drying experiments using solvents such as Acetone or Methanol are to be conducted. The experimental data from this work will be used to develop a morphology regime map which will link material properties, particle size, initial moisture content and drying history to morphology.

#7772

The influence of ethanol on the convective drying and on the nutritional quality of dekopon slices

Ronaldo Elias de Mello-Júnior, Nathane Silva Resende, Jefferson Luiz Gomes Corrêa, Leila Aparecida Salles Pio, Elisângela Elena Nunes Carvalho

Dekopon or Hallabong (Citrus reticulate "Shiranui") is a hybrid fruit that belongs to the citrus fruits. The scientific and commercial interests in dekopon is due to its nutritional composition. The objective of the study was to verify the influence of ethanol as a pretreatment in reducing drying time as well as maintaining nutritional quality (vitamin C, total phenolic compounds, and antioxidant activity) of dekopon slices. The drying with ethanol at 70 °C promoted the greatest reduction in drying time, but the processed pretreated samples at 50 °C presented the highest level of nutritional quality parameters.

Keywords: drying time; vitamin C; phenolic compounds; antioxidant activity

#7775
Influence of drying on the recovery of phosphorus from wastewater sludge

Laurent Fraikin, Zaheer Shariff, Andreas Pfennig, Angélique Léonard

The North West Europe (NWE) Interreg Phos4You (P4Y) project addresses the phosphorus (P) challenge. P is a nutrient essential for all living organisms. Though it is a finite resource on earth, P is largely wasted today. The EU acknowledged this by adding phosphate rock to its list of critical raw materials in 2014. There is a need to boost the use of secondary raw P. The project addresses rural, urban and port areas in NWE. P is needed in rural areas as fertilizer or feed additive (often produced in port areas). P is transferred within food to urban areas where 82% of NWE-citizens live in (World Bank, 2015), and wasted there, via sewage and waste. P4Y specifically targets recovery from municipal waste water treatment plants.

In 2015 NWE imported 100% of its mineral P-needs. 45% of the demand could be supplied by circular economy. The project will exploit the recovery potential of P in municipal sewage water (113,000 t/y P), estimated to cover 26% of the mineral P-demand in NWE. To achieve this change, P4Y supports 44 enterprises by producing demonstrators in real life conditions of 6 P-recovery technologies for municipal sewage water.

One of these new technologies for P recovery will be developed at ULiège. The novelty of this process is that it treats directly the raw sludge instead of ashes obtained from incineration, as encountered in many processes. The idea is to directly leach the sludge with acids and to remove the solid residue. Afterwards, the aqueous liquor is purified thanks to an organic extraction to remove the heavy metals. Finally, the phosphorus is precipitated in calcium salts.

For the development of this process one key issue is to find the optimal water content at which sludge will be leached. Indeed, the water present in the sludge will dilute the acid and reduce the leaching capacity while increasing the consumption of raw acids. On another side, a dried sludge has other properties such as wettability or porosity developed during the drying. However, dry sludge may need an additional grinding step and request other technologies to handle the so formed powder.

The first leaching tests performed on sludge with different levels of dryness obtained by a combination of dewatering and convective drying are running. The influence of the drying step on the whole P recovery process will be illustrated during the presentation.

#7781
Drying of Murraya koenigii leaves using microwave heating and moisture-volatiles condensation

Om Prakash Suryawanshi

The volatiles of Murraya koenigii leaves carries pharmaceutical potential because of its medicative components such as carbazole, polyphenols and tocopherols. Drying is most common method of processing of Murraya koenigii leaves. During drying of Murraya Koenigii leaves the cell structure ruptures and releases the volatile components to the atmosphere along with moisture. Murraya koenigii leaves were dried using microwaves (0.5, 1.0, 1.5 and 2.0 W/g) along with moisture and volatiles condensation. The best dried product and maximum condensate was obtained at 1.0 W/g. The mass of volatiles and moisture condensed was 12.5 mL/20 g of fresh leaves. Drying by microwaves coupled with condensation retains good colour and flavour in the product. The combined process of heating and condensation was found to be an alternative to microwave vacuum drying as the condensation was helping the drying process in the microwave cavity.

#7782
Improving bioaccessibility of bioactive compounds in beetroot (Beta vulgaris) through drying

Maria Esperanza Dalmau, Carme Molinas, Gustavo Barrera, Antoni Femenia

Beetroot samples were subjected to convective drying (CD) at 60 °C and 2 m/s and freeze-drying (FD) at -50 °C and 30 Pa. Dried beetroots were rehydrated prior to digestion by immersion in distilled water at 37 ºC during 90 min. The in vitro digestion involved incubation in simulated saliva followed by incubation in simulated gastric juice. Bioaccessibility of total polyphenol content (TPC) and antioxidant activity (AA) of gastric juice were measured at different times during digestion. The TPC was determined by means of the Folin-Ciocalteu assay and AA was determined by using the ABTS, FRAP and CUPRAC assays. Bioaccessibility refers specifically to the quantity of nutrients which are released from the food matrix and presented to gastric juice (Garrett, Failla, & Sarama, 1999). Results showed that convective and freeze drying induced decreases in total polyphenol content (TPC) (42 and 29% for CD and FD samples) and antioxidant activity (AA) (66 and 63% for CD and FD samples). However, the bioaccessibility of biocompounds in CD and FD samples was higher than in raw samples (17% for TPC and 18% for AA).

The Weibull model was used to mathematically describe the bioaccessibility kinetics for the release of the total polyphenol contents and the antioxidant activity during in vitro digestion. By using the experimental results obtained at different digestion times, the α and β parameters of the Weibull model were identified for TPC and AA releases in raw, CD and FD samples. Also, the mean relative error was calculated by comparing experimental and predicted values. The obtained MREs were similar or lower than 9% in all cases. The α figure for the change kinetic of TPC from the FD sample reflecting the slower process of TPC release from this sample to the gastric juice. This high value was probably due to a scarce effect of freeze-drying on the food matrix structure. On the other hand, β parameter was higher than 1 for the extraction rate of TPC from the raw sample but lower than 1 for the rest of the samples. Results of AA in gastric juice during in vitro digestion followed similar trends than those observed for the TPC. The gastric juice from FD sample digestion exhibited the lowest AA, together with those for the CD sample, both with higher α figures and lower equilibrium values than those obtained for the raw sample. These results further confirm the above-mentioned finding that drying of beetroots promoted the extraction of polyphenols and antioxidant compounds from the beetroots matrix during in vitro gastric digestion.

#7787

Osmotic dehydration of eggplant, carrot and beetroot slices: Effect of vacuum on phenolic acid composition

João Renato de Jesus Junqueira, Jefferson Luiz Gomes Corrêa, Kamilla Soares de Mendonça, Ronaldo Elias Mello-Júnior, Lucas Barreto de Carvalho.

The aim of this work was to evaluate the influence of vacuum application on the phenolic acid content of osmodehydrated eggplant, carrot and beetroot samples. The contents of catechins and chlorogenic acid were determined by HPLC analysis. Changes in the contents of phenolic acids after the osmotic processes were observed. It was found a reduction in catechins and chlorogenic acids, probable due to the migration and degradation losses. In a general way, the vacuum reduced the catechin and chlorogenic acid contents, compared to the osmotic dehydration at atmospheric pressure.

Keywords: Pulsed vacuum osmotic dehydration; chlorogenic acid; catechins

#7790
Drying characteristics of wastewater sludge according to outside air inflow conditions

Sang Hyun Oh, Ki Ho Park, Byoung Hyuk Yu, Sung Il Kim

The purpose of this study is to analyze the changes of drying efficiency according to the inflow conditions of outside air into the drying equipment during the drying process in order to reduce the energy used in the drying process of sludge. We conducted the experiment using a vertical thin film dryer. Materials used for the experiment are sewage sludge. As a result of the study, higher drying efficiency was obtained in the case of outside air inflow than in the case of no outside air inflow. In addition, optimum condition of outside air inflow was derived.

Keywords: drying; sludge; drying efficiency; air inflow condition

#7792

Impact of processing temperature on drying behavior and quality changes in organic beef

Gardis J.E. Von Gersdorff, Luna Shrestha, Sharvari Raut, Stefanie K. Retz, Oliver Hensel, Barbara Sturm

The drying of beef has gained an increasing interest and the organic market shows an increasing demand for dried beef products. In this study, organic beef meat slices were dried at 50 °C, 60 °C and 70 °C. Moisture content and color was measured throughout the drying process alongside Vis/VNIR hyperspectral images of the slices. The results of the total color difference (ΔE) showed the biggest change for samples dried at 50 °C (ΔE = 25.6). The aw value was the lowest for slices dried at 50 °C (0.744). The hyperspectral data gave promising results regarding non-invasive prediction of moisture content and color.

Keywords: beef drying; drying behavior;color; hyperspectral imaging; quality

#7798
Thermal - Vacuum dehydration and dispergation of dispersed materials

Volodymyr Alexandrovich Kutovyi, Victor Tkachenko, Alice Nikolaenko

Scientific and technical studies on the intensification of removal moisture from dispersed materials and their simultaneous dispergation in the hollow heating element of a thermo-vacuum apparatus is researched. Continuous thermo-vacuum dehydration and dispergation process of zirconium hydroxide, brown coal, graphite, sawdust, biological materials is considered. Based on conducted studies was made conclusions about perspective to use this technology. Thermo-vacuum technology is different from the other by low-temperature heating, low time processing, humidity indicators controlling and nano-dispersion grinding.

Keywords: dehydration, dispergation, energy saving

#7804
Development of polyphenols-enriched maple sugars by freeze- and vacuum drum drying technologies

Sagar Bhatta, Tatjana Stevanovic, Cristina Ratti

Hot water extract of sugar and red maple bark was added to maple syrup and dried by freeze (FD) and vacuum drum drying (VD) techniques. Addition of maple bark extracts to syrup helped to develop polyphenols-enriched maple sugar. X-ray diffraction revealed that sugar obtained from FD was amorphous in nature, while crystalline when dried by VD. Furthermore, the observation of maple sugar samples under scanning electron microscopy showed smooth and porous surface for FD sugar, while rough and grainy surface for VD sugar. Hausner ratio indicated that sugar produced by VD showed better flow characteristics than FD sugar.

Keywords: drying techniques; maple syrup; phenolics; microstructure

#7807

Effect of incorporation of blackberry particles obtained by freeze drying on physicochemical properties of edible films

Gislaine Ferreira Nogueira, Farayde Matta Fakhouri, Rafael Augustus de Oliveira

This research work aimed to evaluate the physicochemical properties of arrowroot starch films plasticized with glycerol and incorporated in film-forming solution directly (D) and by sprinkling (S) with 0%, 20%, 30%, 40% (mass blackberry solids / biopolymer mass) of blackberry pulp (BL) powder and freeze dried microencapsulated blackberry pulp (ML) using mixture of gum arabic and arrowroot starch (1: 1, mass / mass). Thickness, water solubility and water vapour permeability of the films significantly increased with increasing concentration of blackberry powder. Compared to arrowroot starch film (0%), the surface of films with BL and ML powder became irregular and rough.

Keywords: lyophilization; microstructure; water solubility; water vapor permeability; packing

#7809
Investigation of spray agglomeration process in continuously operated horizontal fluidized bed

J. Du, A. Bück, E. Tsotsas

Spray fluidized bed agglomeration is an important process in particle formation and is widely used in the chemical, pharmaceutical and food industry. In this study a continuously operated horizontal fluidized bed is employed to obtain a continuous agglomeration process. It is conducted with glass beads (d_{st}=200 µm) and water-based binder hydroxy-propyl-methyl-cellulose (HPMC) sprayed by three top nozzles. The steady state is reached and samples are taken periodically and analyzed. The influence of fluidization air temperature and configurations of internal weirs are studied.

Keywords: horizontal fluidized bed, spray agglomeration, continuous process

#7819
Agglomeration of spray dried spinach juices powder: powder properties

Gülşah Çalışkan Koç, Safiye Nur Dirim, Hira Yüksel Mail

Spray drying technique is widely used in the food industry and allows liquid products to be converted into a powder product in a short time. The particle size of the powder products obtained by the spray drying method varies between 10-100 μm. This small size of the particle size leads to some difficulties such as deterioration in the reconstitution properties of the powder products, separation from other materials during processing and transportation, and agglomeration. Agglomeration can be applied to powder products produced by spray-drying to achieve these problems. During the agglomeration process, the particles come together and agglomerates are formed. The aims of this study are to obtain spray dried spinach (Spinacia oleracea) juice powder (SJP) and to apply agglomeration process with a fluidized bed drier in order to improve the powder properties as solubility, wettability, and cohesiveness. In this study, the physical (moisture content, water activity and, color) and powder properties (solubility times, bulk and tapped densities, hygroscopicity, dispersibility, screen analysis) of SJP and the agglomerates as well as the efficiency (%) of the agglomeration operation were determined. Spinach juice was dried in a spay dryer at 160/100°C inlet/outlet temperature. The agglomeration process was performed at 1.6, 1.8, and 2 m/s air flow rate at 50°C temperature for 20 minutes in a fluidized bed dryer (Sherwood Scientific). During the agglomeration process, water (1:0.1 weight SJP: weight water) was added to the powders as a binder. Consequently, the efficiency values which ranged between 60.0-80,4% at different air velocities were calculated as the ratio of the amount of obtained agglomerates to the spinach powder. Moreover, the moisture contents (9,53-13,72%, wet basis) and water activity values (0.31-0.33) of all powders were determined. Solubility is an important feature of SJP because poorly soluble powders can cause processing difficulties and economic losses. Solubility times are very long for SJP whereas the solubility times of the agglomerates ranged between 118-161s. Therefore solubility times decreased according to powders. In addition, wettability times of SJP are longer than agglomerates. Agglomeration process improved the flow properties (Carr Index and Hausner Ratio decreased) of SJP and increased the bulk density values as expected.

Keywords: Agglomeration, agglomerate, spinach juice powders, powder properties, efficiency

#7821
Fluidised bed agglomeration of black carrot juice powders

Safiye Nur Dirim, Hira Yüksel, Gülşah Çalışkan Koç

Agglomeration process has been commonly used to improve functional properties of powders such as flowability, solubility. Fluidized bed agglomeration is one of the most common agglomeration methods due to the fact that, agglomerates produced by fluidized bed have high porosity, low density, and good mechanical resistance during handling and packaging and exhibit better solubility and compression behavior.The aims of this study are to obtain a spray dried black carrot juice powder (BCJP) and to apply agglomeration process with a fluidized bed dryer in order to improve the powder properties as solubility, wettability, and cohesiveness. In this study, the physical (moisture content, water activity and, color) and powder properties (solubility times, bulk and tapped densities, hygroscopicity, dispersibility, screen analysis) of BCJP and the agglomerates, as well as the efficiency (%) of the agglomeration operation, were determined. Black carrot juice was obtained by the hydrolic press at (6374.3 kPa), then was filtered by crude filter paper (Whatmann No:1) and was dried by the spray dryer (160/100°C inlet/outlet temperature at 392kPa). In addition, the agglomeration process was performed at 1,6 m/s air velocity at 60°C temperature in a fluidized bed (Sherwood Scientific). During this process, binder solution (1:0.1, 1:0.2, 1:0.3 weight BCJP: weight binder) added to black carrot powders. Distilled water and the Gum arabic, maltodextrin and, whey powders solutions (1:1 weight binding agent: weight water) were used as the binders. The moisture content, water activity and color values of BCJP were found to be as 9.18% (wet basis), 0.256, and 32.50 (L*), 9.02 (a*), and 3.10 (b*), respectively. The average wettability and solubility times of BCJP were measured to be as 2491s and 2150s, respectively. The bulk and tapped densities, Carr Index and Hausner Ratio were found to be as 360 and 510 kg/m3, 29.11 (fair), and 1.41 (high), respectively. The agglomeration process decreased the wettability and solubility times, increased bulk density and improved the flow properties.

Keywords: agglomeration, agglomerate, black carrot juice powders, powder

#7822
Finish drying and surface sterilization of bay leaves by microwaves

Ashish Kapoor, Parag Prakash Sutar

Bay leaves (Laurus nobilis L.) refers to aromatic leaves which are native to minor regions of Asia. In order to extend the shelf life of the bay leaves its water activity and the surface micro-organisms were reduced using microwave heating at different power densities in the range 32.14 to 142.85 Wg^{-1}. Treatment time at each power level was maintained constant at 150 s. The maximum reduction in water activity and moisture content occurred at highest power density. The heating time-temperature profile was obtained at all power levels. TPC, color change and browning index (BI) of bay leaves were measured in order to determine the effect of microwave treatment on microbial reduction and quality. The highest reduction in TPC was found in leaves heated at 142.85 Wg^{-1} power density along with acceptable quality parameters of the treated bay leaves.

Keywords: bay leaves; microwave heating; TPC; colour change

#7826
Moisture sorption characteristics of pistachio

Banu Koç, Gamze Atar, Nazan Çağlar

In this study, the moisture adsorption isotherm of pistachio was determined at 25°C and relative humidity (10-90%), using the standard static, gravimetric method. Eleven sorption models were tested to fit the experimental data. A non-linear regression analysis method was used to evaluate the constants of the sorption equations. The GAB equation gave the best fit to the experimental data for a wide range of water activity, while BET gave the best fit for a water activity range of 0.1-0.5. The agreement between experimental and predicted values of these models was found to be satisfactory.

Keywords: moisture adsorption isotherm; sorption model; pistachio

#7831
Drying kinetics and quality attributes of fruit and vegetable pomace dehydrated by different methods

Malwina Siudek, Adam Figiel, Anna Michalska, Krzysztof Lech, Aneta Wojdyło

The aim of the study was to evaluate the effect of drying parameters on drying kinetics, bioactive potential, density and color of beetroot, carrot and pear pomace dehydrated by hot air drying (HAD), spouted bed drying (SBD), vacuum-microwave drying (VMD), contact drying (CD) and combination of hot air drying followed by vacuum-microwave drying (HAD-VMD). The drying kinetics was described using basic drying models which were ranked taking into account the values of coefficient of determination and root mean square error. The fastest method of drying was VMD in the case of carrot and beetroot pomace, whereas CD ensured the shortest drying time for the pear pomace. For each product, the highest values of bulk, apparent and specific density were obtained by VMD and the lowest by HAD. The highest value of absolute color difference was observed for carrot and beetroot pomace dehydrated by HAD, whereas the lowest value was reached for pear pomace dehydrated by CD. The highest water activity was found for beetroot and carrot pomace dried by SBD and for pear pomace dried by CD. The bioactive potential of dried product in terms of the content of polyphenols and antioxidant capacity was evaluated taking into account the course of dried material temperature. It was found that the increase in microwave power from 240 to 480 W during VMD resulted in increasing the maximal temperature of dried material in the range from 55 to 68°C for pomace from beetroot and carrot and in the range from 80 to 97°C for pomace from pears. The drying procedures of fruit and vegetable pomace were recommended in terms of quality of dried product and energy consumption.

Keywords: waste management, energy consumption, bioactive potential, color, density

#7835
Counter current spray drying of sugar rich food

Yongmei Sun, David Kannar, Bernard Chen, Meng Wai Woo

Spray-drying technology has been used for decades in food industry to make instant and easy dissolving sugar rich food powders. Most of sugar rich food powders are studied and reported utilized the co-current spray drying process. There is minimal report on the spray drying of sugar rich food powders with counter current drying process. It is noteworthy that the counter-current drying process may have significant benefit in terms of thermal efficiency and is widely used in the production of laundry powder. Counter current spray drying has a contrasting overall mechanism in which the droplets experience an initially lower drying temperature followed by a progressively hotter environment; in contrast to co-current spray drying. There is no report systematically examining how these affect stickiness control and subsequently the yield from the process. In this paper, the research aim was to develop a strategy of spray drying process in count-current dryer for sugar rich food material. The main limitation encountered in the counter current spray drying process was the need to maintain a minimum threshold of particles size which added complexity to existing strategies in controlling particle stickiness. There was a need to simultaneously control stickiness and product loss due to particle entrainment by the upward moving hot air. An operation algorithm was defined as a guide for future worker in this area.

#7837
Different methods of drying and extraction for utilization of hemp seeds pomace

Klaudia Urbanska, Joanna Majerska, Adam Figiel, Anna Michalska, Krzysztof Lech, Aneta Wojdylo

The aim of the study was to propose an effective technological process for utilization of hemp (cannabis sativa) seeds pomace using drying of raw material, extraction of valuable compounds from the dried material and microencapsulation of obtained extracts by spray drying. The quality of products obtained in particular stage of the pomace processing was evaluated in terms of color, water activity, density and bioactive potential. The fresh pomace was dehydrated by hot air drying (HAD) at temperatures 50, 60 and 70°C, vacuum-microwave drying (VMD) at microwave power 240, 360 and 480 W and combination of hot air drying at 60°C followed by vacuum-microwave drying at 360 W (HAD-VMD). The drying kinetics was described using standard drying models which were ranked taking into account the values of coefficient of determination and root mean square error. The bioactive potential of dried product in terms of the content of polyphenols and antioxidant capacity was evaluated taking into account the course of dried material temperature. The best drying method was used to prepare dried material for extraction experiments. Standard methods of extraction were assisted by microwaves and sonication. The method of extraction which provided the best quality of extracts were used to prepare material at sufficient amount for microencapsulation by spray drying. Different carriers and spray drying parameters were tested to ensure the highest productivity and quality of microencapsulated product. It was suggested that the extraction residues can be processed into high quality biochar by torrefaction. The processing procedure of hemp seeds pomace was recommended in terms of quality of final products and energy consumption.

#7839

Drying of particle polymer composite films – an experimental and simulation study on particle-polymer and porous battery electrode films

Wilhelm Schabel

Polymer particle composites have raised increasing interest of the material research community within the last decade.
Incorporation of particles in a polymer matrix is a way to modify material properties. The functionality of these composites depends on the material selection as well as on the component distribution. The latter is strongly affected by the process and boundary conditions during drying. In this work the influence of drying conditions on the component distribution was investigated experimentally and numerically for particle polymer composite films. To predict component distribution, a model was developed, including evaporation, sedimentation of particles and diffusion of particles and polymer in the early drying stage. The formation of particle gradients during drying was evaluated by cryogenic scanning electron microscopy experiments. In the dried film, the component distribution was evaluated by means of 3D Confocal Raman Spectroscopy.
Lithium-ion battery electrodes are typically composed of graphite particles, polymer binders and conducting additives. Their properties strongly depend on the complex microstructure, which is defined by the pore structure and the distribution of functional additives throughout the film. Polymeric binder is added in small amounts in order to provide the film with mechanical integrity, while carbon black constitutes a conductivity enhancing agent. The microstructure essentially evolves during solvent removal, which makes drying an important processing step. In the present work new experimental approaches are introduced that allows for optical evaluation of microstructure during drying and a new method to determine pore emptying and component migration as a function of process parameters.

#7850
Influence of ultrasound assist during combined drying on ceramic materials quality and drying kinetics

Andrzej Pawłowski, Weronika Trawińska

Presented in this article studies show the investigation of ultrasound application as a new method for improvement of ceramic materials processing and their influence on mechanical properties of dried samples. Ultrasound were applied during convective and convective-microwave processes carried out in two different temperatures. Obtained results indicate increase of drying rate due to sonification and what's more interesting they affect the material strength parameter. The experiments indicate that the effectiveness of ultrasound assist depends on the drying temperature and such dependency is observed mainy when considering dry product quality parameter.

Keywords: ceramics; hybrid drying; material strength

#7852
Microencapsulation of passion fruit extract (Passiflora biflora) by spray drying

Daniela Aguilar, Olivia Rodriguez, Guadalupe Luna, Gregorio Zarate, Licet Bello

Anthocyanins pulp and peel passionfruit extracted by leaching using water as a solvent where the operating conditions of spray drying were evaluated for a microencapsulated. The variables were temperature input (180, 200 and 220 ° C), MD (6, 8 y 10%), AP (1, 3 y 5%) and outlet temperature 80 °C, was achieved noted that during the drying process moisture decreased to 85% due to this high in MD and AP, this also increases the content of ST. Color significantly was not affected by spray drying..

Keywords: passionfruit, abstract, encapsulants, spray microencapsulatio

#7854
Microwave drying in fluidized bed to dehydrate microencapsulated Saccharomyces cerevisiae cells. Temperature control strategies

J. Mardaras, J. I. Lombraña, M. C. Villarán

Alginate microcapsules containing cell yeasts of the species Saccharomyces cerivisae, used as a reference microorganism, were studied here to improve the protection of cell activity during food processing. Here a novel drying process was proposed to optimize processing conditions.
The dehydration of microcapsules by microwaves and under near fluidizing conditions (NFMD), allows performing dehydration employing lower temperatures to maintain high viability levels and a high quality end product. Thus, strategies based on the combination of different thermal gradients and processing temperatures were analysed through a series of NFMD experiments.

Keywords: microwave drying, fluidization, probiotics, cell viability

#7889
Influence of the temperature and ultrasound application in drying kinetics of apple skin

Matheus P. Martins, Edgar J. Cortés, Carmen Rosselló, Ramón Peña, Juan A. Cárcel

The great amount of waste produced by food industry contains interesting bioactive compounds. The extraction of these compounds requires the by-products previous stabilization being the convective drying one of most used techniques to this end. Drying conditions can affect both drying kinetics and final quality of products. The apple skin, byproduct of apple juice or cider industries, is rich in functional compounds such as polyphenols or vitamin C. The main goal of this contribution was to quantify the influence of temperature and ultrasound application in drying kinetics of apple skin. For this purpose, drying experiments at different temperatures (-10, 30, 50 and 70 ºC) and with (20.5 kW/m3) and without application of ultrasound were carried out. Drying kinetics were modelled by using a diffusion based model. As can be expected, the higher the temperature the faster the drying. Ultrasound application accelerated the process at every temperature tested being the influence slightly lower than found from the literature for other products. This can be attributed at the physical structure of the apple skin, less porous than the pulp. In any case, the application of ultrasound significantly reduced the drying time.

Keywords: by-products; dehydration;diffusivity; mass transfer

#7961
Drying intensification by vibration: fundamental study of liquid water inside a pore

Wangshu Chen, Julien Colin, Joel Casalinho, Mohamed El Amine Ben Amara, Moncef Stambouli, Patrick Perré

Vibration is a promising way to intensify the drying process through heating-up due to viscous dissipation, activation of internal liquid transfer and increase of external transfer. To better assess the possible contribution of these effects, we choose a multiscale approach. This paper is focused on the pore scale, simulated by a capillary tube partially filled with water subjected to sinusoidal vibrations. We studied the displacement of water inside this tube through image analysis. This configuration mimics the moisture transfer inside the pores of a porous media during drying.
The experimental device developed in this study is applicable to a wide range of configurations, such as symmetrical or asymmetrical vibrations.

Keywords: drying intensification, acoustic vibration, pore scale, symmetrical and asymmetrical signals, image processing

#8270
Wall deposition experiments in a new spray dryer

Xing Huang, Chao Zhong, Timothy A. G. Langrish

Wall deposition tests have been conducted on a new spray-drying sytem. Solutions of salt and skim milk powder have been dried with different inlet temperatures (170 °C and 230 °C) and solid contents (8.8 wt% and 30 wt%). The experiment showed that increasing the temperature caused an decrease in the amount of deposition for salt solution, but an increase for skim milk. The experiments also showed that a higher solid content caused an increase in deposition. The trends agreed with the studies using a conventional spray dryer, but the amount of deposition appeared to be lower in the new spray dryer at the same operating conditions.

Keywords: Spray drying; wall deposition

#8270
Wall deposition experiments in a new spray dryer

X. Huang, C. Zhong, T. A. G. Langrish

Wall deposition tests have been conducted on a new spray-drying sytem. Solutions of salt and skim milk powder have been dried with different inlet temperatures (170 °C and 230 °C) and solid contents (8.8 wt% and 30 wt%). The experiment showed that increasing the temperature caused an decrease in the amount of deposition for salt solution, but an increase for skim milk. The experiments also showed that a higher solid content caused an increase in deposition. The trends agreed with the studies using a conventional spray dryer, but the amount of deposition appeared to be lower in the new spray dryer at the same operating conditions.

Keywords: spray drying; wall deposition

#8281
Usage of emerging pre-treatment technologies in food drying

Senem Suna, Nihal Türkmen, Ömer Utku Çopur

Drying which is one of the oldest forms of food preservation, is commonly used to increase the stability and shelf life of food by reducing the water activity to a level that is sufficiently low to inhibit the growth of microorganisms, enzymatic reactions and other deteriorative reactions. However, the traditional air drying process can cause quality loss of heat sensitive products, such as fruits and vegetables due to the oxidative damage, browning, and flavor decrement especially when high temperatures are used. In order to prevent or reduce the heat damage, and thus improve the quality of dried products, emerging pre-treatment applications such ultrasound power (UP), ohmic heating (OH) and pulsed electric field (PEF) in food drying processes have gained importance. These various pre-treatments all have an important effect on the cellular permeability and, thus, on the mass transfer within the product. Among these methods UP has no significant overheating of the material and may shorten the drying time by generating a successive compression and expansion of the material, leading to stress of the structure (sponge effect) because of the high-amplitude vibrations. OH is an another alternative pre-treatment to preserve nutritional quality of dried vegetables. It is a thermal procedure in which heat is created inside by the entry of a substituting electrical current through a food system that performs an electrical protection. PEF has also been proposed for enhancing or assisting dehydration by allowing increased mass transfer from plant tissues, being based on a very short time (μs to ms range), but high-voltage (1–10 kV/cm) treatment. All these applications could significantly increase the drying efficiency and thus save production cost. In this review, potential usage of these emerging pre-treatments on food drying process and their effects on nutritional components of food will be discussed in details.

Keywords: Drying, pre-treatment, ultrasound power, ohmic heating, pulsed electric field

#8365
Drying kinetics and selected physico - chemical properties of fresh cranberries preserved with microwave – vacuum process

Jan Piecko, Dorota Konopacka, Monika Mieszczakowska-Frąc, Dorota Kruczyńska, Karolina Celejewska

A one stage drying process for dried cranberry production, employing a vacuum microwave technique, is proposed. The process consists of a specific sequence of microwave energy dosage at a given vacuum level. During the 60 minute process, three sub-stages can be identified: osmotic dehydration, intensive water evaporation and stabilization. Mass transfer, as well as quality changes during the process, has been described, and the final product quality compared to purchased control. The proposed method of dried cranberry production resulted in a microbiologically stable product (a_w=0.62) of a decent sensory quality, with an antioxidant potential three times higher than traditional products.

Keywords: vaccinium macrocarpon; microwave-vacuum drying; ready-to-eat snack

#8369
Influence of drying technique on physicochemical properties of bimodal meso-macropore structure of silica support

Noppadol Panchan, Chalida Niamnuy, Thanaphat Chukeaw, Anusorn Seubsai, Sakamon Devahastin, Metta Chareonpanich

Drying process directly affect in structure of the silica support for catalysts. Therefore, we herein prepared bimodal meso-macropore structure of silica by sol-gel method and investigated the silica support obtained from various drying techniques, namely, hot air drying (HA), microwave drying(MW)and freeze drying (FD)by means of BET and BJH N_2-sorption, and SEM. The results showed a significant effect of drying technique on the textural properties of the dried bimodal porous silica support. In addition, it was found that freeze drying could enhance surface area of silica support with higher than 500 m^2/g.

Keywords: bimodal meso-macropore structure silica support: drying technology: freeze drying: hot air drying: microwave drying

#8533

Superheated Steam Dryer application for drying of sticky and pastry materials – particluar referens to distillers wet grain and solubles (DWGS)

Prem Verma, Himart Suneb, Weis Aaron

Swedish Exergy AB commercialised Super-Heated Steam Drying (SHSD) technology – an invention from Chalmers University of Technology. New application for drying and valorisation of Distillers Wet Grain and Soluble (DWGS) has been sucessfully developed and deployed at one of the sites in Europe. The SHSD technology has been adapted to this application. Key development includes novel and innovative concept of back-mixing in pressurised loop.

Keywords: Super-heated steam drying; DWGS, DDGS, Back-mixing.

DRYING & ENVIRONMENT

Oral Presentations

#7842

Biodrying process: a sustainable technology for treatment of municipal solid wastes organic fraction

N. Kechaou, E Ammar

The Municipal Solid Waste of Agareb (Sfax –Tunisia), characterized by high organic fraction and moisture contents is the most worrying pollution source that must be managed by innovative treatment and recycling technologies. Bio-drying, as a waste to energy conversion technology, aims at reducing moisture content of this organic matter. This concept, similar to composting, is accomplished by using the heat generated from the microbial degradation of the waste matrix, while forced aeration is used. The purpose of this work was to reduce the moisture content of the waste, by maximizing drying and minimizing organic matter biodegradation, in order to produce a solid recovered fuel with high calorific value.

Keywords: Municipal solid wastes; organic matter; biodrying; composting; energy recovery.

#7963
Efficient sludge drying by addition of drying accelerator

Nobusuke Kobayashi, Kenji Kamiya, Kazuki Okada, Yuma Tachibana, Takumi Ito, Hironari Ooki, Yoshinori Itaya

High moisture content sludge is one of the unwanted waste, but dried sludge is paid attention as one of the bio-fuels, on the other hand in recent years in Japan, for the reason of waste treatment and CO2 emission control. For using the sludge as the fuel, efficient drying is necessary, drying experiments of sludge with drying accelerator was conducted and effect of drying accelerator addition on drying rate of sludge was evaluated. In the experiment, amount of drying accelerator addition was changed and types of drying accelerator was also changed. Then, the drying behavior during the drying process and dried sludge characteristics with or without drying accelerator was compared. Drying rate of the sludge mixing with drying accelerator improved, since drying area increased by adding drying accelerator. But increase of the drying accelerator amount, one the other hand, did not always improve drying rate. It was very sure that the drying gas rate influenced on the drying rate, but drying rate of sludge with the drying accelerator addition significantly improved the drying rate than non-addition sludge. Drying rate also varied depending on the types of drying accelerator, drying accelerator with high glass-transition temperature showed more influence on sludge drying rate

Keyword: Sludge, drying accelerator, drying rate.

#7888
Energy analysis of an ultrasound-assisted atmospheric freeze-drying process for food

Daniele Merone, Domenico Colucci, Davide Fissore, Neus Sanjuán, Juan A. Cárcel

Power ultrasounds have been proposed and extensively investigated as an effective way to speed up the atmospheric freeze-drying process, thus making this dehydration process attractive from an industrial viewpoint. Nevertheless, a rigorous investigation on the impact of power ultrasounds on the energy consumed by the process is still missing. This paper aims to investigate this issue. Apple, carrot and eggplant were chosen as representative products with different textures and water content. A mathematical model of the whole plant required to carry out the atmospheric ultrasound-assisted drying process was developed to assess the effect of the operating conditions on the energy consumption. Model parameters were tuned on the basis of the results obtained in a pilot-scale unit, thus allowing the use of the model to simulate the whole industrial dehydration process. Life Cycle Assessment (LCA) was used as a complementary tool to gain an insight on the environmental impact of the process. Results showed that due to differences in the water diffusivity for the analyzed products, substantial differences in energy consumption can be highlighted. In fact, when the water diffusivity increases, the capacity of the material to move water away also increases and the time to obtain a dry product is thus reduced. Moreover, although the use of ultrasound causes an increase in the hourly energy consumption (kWh·h-1), the total energy consumption of the whole process (kWh) is lower, since the total operation time is reduced. The LCA results highlighted the cooling system as the most critical stage for all the impact categories studied. This is mainly due to the use of ethylene glycol and R-404 in the refrigeration cycle. Nevertheless, when dehydrating low porosity products the energy consumption of the air dryer increased and this stage becomes, the most critical from an environmental point of view

Keywords: atmospheric freeze-drying, ultrasounds, process modeling, LCA.

DRYING & ENVIRONMENT

Poster Presentations

#7295

Preservation of mesophilic mixed culture for anaerobic palm oil mill effluent treatment by convective drying methods

S. K. Chin, D. T. Tan, H. M. Tan, P. E. Poh

While anaerobic digestion is a reliable method that treats the waste and produces renewable biomethane fuel, the necessary sludge in liquid form is difficult to handle due to the constant biogas generation. Therefore, this study investigates the possibility of convective air drying, namely heat pump and hot air circulation oven as preservation methods for anaerobic microbial sludge. Drying was conducted at various temperatures, ranging from 22°C to 70°C. The study found that heat pump drying at 22°C resulted in highest COD removal of 55.3% as well as the least log reduction in methanogens and anaerobes at 1.4 and 2.4, respectively.

Keywords: Chemical Oxygen Demand (COD); Heat pump drying; Hot air drying; Log reduction; Methane yield

#7352
Application of the intermittency on the drying process in the spouted bed: an energy analysis

Ronaldo Correia Brito, Rodrigo Béttega, José Teixeira Freire

Drying is one of the oldest and most important operations involving preservation and storage of several kinds of materials. Present in numerous industry sectors and processing stages, the drying process reduces to suitable levels the moisture content of the material, retarding and avoiding the biological activity and deterioration. Among the dryers currently available, the spouted bed has stood out due to its advantages and properties. The high degree of agitation and mixture between the phases are some of these advantages. However, the spouted bed has a number of limitation and disadvantages that restrain an effective industrial application. Some of them are the low energy efficiencies and high energy consumption that involve the utilization of spouted bed. Thus, different methodologies and techniques have been proposed in the literature to overcome such problems. The intermittency consists basically in a method where drying periods and periods of rest or total interruption of the process occur alternatively. Intermittency can be incorporated into the process by varying drying operating conditions over time, such as inlet air temperature and air flow. The utilization of intermittency can provide advantages related to the energy and quality aspects. Despite its advantages, the intermittency hasn't been used in the spouted bed. In addition, applying the intermittency of air flow in the spouted bed, the advantages and characteristics of the fixed bed could also be harnessed. In this context, the objective of this paper was to analyze the application of intermittency in the spouted bed from the energy point of view. For this purpose, it was carried out an experimental study of the drying of alumina in the spouted bed under five intermittent profiles. The intermittent profiles were defined based on four intermittency ratios constant and one variable. Two different types of intermittency were evaluated: periods of rest and total interruption of the air flow. In the periods of rest, the air flow was varied between values below and above the minimum spout. Energy efficiency (EE) and specific energy consumption (SEC) were the parameters calculated for the realization of energy analysis. The increase of intermittency ratio resulted in a reduction of the effective drying time. Thus, higher energy efficiencies and lower energy consumption were obtained by increasing the intermittent ratio. The process with periods of rest allowed a better utilization of energy supplied. Besides, the results indicated that the process with intermittency ratio variable provides the best energy performance.

Keywords: Spouted bed; intermittency; energy efficiency; energy consumption; alumina.

#7690

Enhancement of Cu(II) adsorption on walnut shell by H_2O plasma modification

Long Wu, Zhongsheng Shang, Jiayong Tu, Zhanyong Li

To explore a high-efficiency and low-cost way to remove the Cu(II) from aqueous solution. A simple and efficient non-chemical treatment method was proposed: Non-thermal H2O-plasma was used to modify the surface functional groups of walnut shell, which was used to adsorb the Cu(II). Scanning electron microscopy (SEM), Brunauer-Emmett-Teller (BET) surface area, Fourier Transform-Infrared Spectrometer (FT-IR) and X-ray photoelectron spectroscopy (XPS) technique were used to characterize the physical and chemical properties of raw and plasma modified walnut shell. The results show that H2O-plasma treatment increased the surface groups of walnut shell. The Cu(II) removal efficiency of walnut shell was signifiantly increased with H2O-plasma treatment. This can be ascribed to the increase of carboxyl groups (-COOH) with plasma treatment, which plays an important role in the adsorption process of Cu(II). This indicates that non-thermal H2O-plasma treatment could be a promising modification approach for Cu(II) removal on walnut shell.

#7780

Assessment of the conditions of the thermoplastic extrusion process in the bioactive and mechanical properties of flexible films based on starch and Brazilian pepper

Farayde Matta Fakhouri, Fernando Freitas deLima, Claudia Andrea Lima Cardoso, Silvia Maria Martelli, Marcelo Antunes, Lucia Helena Innocentini Mei, Fabio Yamashita, Jose Ignacio Velasco

The objective of this work was to produce, through the thermoplastic extrusion process followed by blowing, manioc starch-based flexible films added with Brazilian pepper oil as an antioxidant and plasticizer agent, and verify if the bioactive compounds contained in the fresh pepper oil are present after the drying step of the thermoplastic extrusion. After analysis by gas chromatography-mass spectrometry volatiles compounds were identified in the films. Pepper oil also influenced the mechanichal properties of the films.These results suggest that the temperatures used in the process, kept some of the existing compounds in the Brazilian pepper essential oil adhered to the packages.

Keywords: Termoplastic extrusion, temperature, bioactivs compounds.

#7797
Preservation of cookies with use of edible packaging

Viviane de Souza Silva, Farayde Matta Fakhouri, Luna Valentina Angulo Arias, Rosa Helena Aguiar, Rafael Augustus Oliveira

Cookies are products that can be obtained after several processes, and are one of most popular foods in the world. Defined as a product obtained by kneading and convenient cooking of pastas prepared with flour, starch, fermented or not and other food substances, it is widely consumed worldwide. One of main requirements to ensure quality of a food is its shelf-life conservation, which is time period in which a food is safe for consumer, maintaining its desired sensory, physical, chemical and functional characteristics, and fulfilling with the nutritional characteristics evidenced in labeling, under recommended storage conditions. Changes in quality of cookies involve physical-chemical, microbiological and sensorial changes generally related to the type of packaging used, initial moisture content among other factors. Sensory changes affect the color, taste, and consistency of cookies. These changes may occur in food during processing and storage when they are exposed to different environmental conditions, which can trigger a series of reactions that can lead to degradation and consequent rejection by consumers. Use of biopolymers for the production of packaging has become an innovation for the market, since these can be biodegradable and / or consumed together with the product. Objective was to develop biodegradable packages, obtained by casting followed by drying, produced with potato starch and pumpkin starch, and to determine if use of the packaging with these constituents is viable in the storage of cookies, preventing the migration of moisture and consequently preserving its texture. Packaging were produced of casting method, one with potato starch as macromolecule base (3%), glycerol as plasticizer (25%) and other with pumpkin starch (3%) and plasticizer as previous sample, dried in ovens with controlled air circulation at 45 °C for 6 hours. The drying time and temperature were determined in preliminary tests because until this temperature, there were no significant changes in properties of films, decreasing drying time of films in 18 hours. Products packaged when compared to without packaging on first day of analysis showed lower mass gain than product without packaging, however on third day of analysis packaging developed with pumpkin starch showed lower mass gain than the other treatments. However, when the texture values were observed, samples with packaging showed a higher value than treatment without packaging. Them have been shown to have gained less mass, which has maintained more firmness of the product and consequently maintaining a better quality of product when compared to the without packing.

#7799
Bread preservation with use of edible packaging

Viviane de Souza Silva, Farayde Matta Fakhouri, Luna Valentina Angulo Arias, Rosa Helena Aguiar, Rafael Augustus Oliveira

We live in a world that usually use plastic bags either to go shopping or to pack the snack for a short trip. However, packaging makes life easier and serves as protection for products such as food. Bread is a common food product that needs packaging in order to be protected at storage and transportation. Therefore, with aim of reducing petroleum derived packagin g consumption it was developed an edible film from potato starch to packeg bread and some quality characteristics like water content, firmness and weight loss were evaluated, showing that edible film can be used as a packaging.

Keywords: biopolymers; edible coatings; packaging materials; starch; storage.

INDUSTRIAL DRYING

#7764
Spray drying technology for detergent powder production: study of an industrial reality

Rosaria Augelletti, Sonia Panzieri, Sinan Al Qudah, Mohammad Al Qudah

Detergent spray drying is one of the core technology of Marsina Engineering. Marsina is one of the leading company in design and supply of spray drying plants aimed to the production of detergent powder. Many efforts have been and continue to be done by Marsina in order to guarantee rigorous standards of quality maintained throughout the design and supply phases. At the same time, particular attention is given to the development of innovative technologies, which plays a key role in continuing satisfy the Client requests under even more different operating conditions.
In this framework, the development of a model able to predict the behaviour of a spray drying tower and the effect of various operating and environmental parameters is essential and can represent a useful tool to better understand the process; on the other hand, it can be used for preliminary design and control of spray drying, so as to improve the ability of the Company to face the request of increasingly diversified specifications to be matched by detergent powder.
This article reports experiences in the Spray Drying of powdered detergent in Marsina, by highlighting the influence of both process parameters and process equipment design on product characteristics. Moreover, the article uses a mathematical model reported in the available literature to simulate the behaviour of the spray drying tower; the model validity is then verified by using industrial field data collected from spray drying plants supplied by Marsina

#8279
Freeze drying and current challenges

Maria Santafé, Ignacio Cantera, Robert Bullich

Nowadays, among all drying techniques that are in place within the pharmaceutical and chemical industry, freeze drying might be considered as the gentlest one. Freeze-drying, also known as lyophilisation, consists of the product freezing to a solid phase and then, the removal of solvent through the sublimation by exposing the frozen product to a low partial solvent vapour pressure. Freeze-drying is composed by three main stages. The freezing of product, the primary drying stage in which free water is sublimated, and the secondary drying stage in which adsorbed water is removed by desorption. The freeze dryers, focused on pharmaceutical products, are required to follow the Good Manufacturing Process (GMP) guidelines, both in its design and during manufacturing to ensure that products are consistently produced and controlled according to quality standards. The adoption of these guidelines ensures that the quality and the purity of drug products are maintained along the production chain. Freeze drying, even though it is a stablished process and a well-known technology, it is still in continuous evolution, improving not just from the point of view of the process itself but also from the surrounding technology. In order to understand how the GMP guidelines impact the final design of the process, some specifications of the CIP system (Cleaning in place) and the SIP (Sterilization in place) will be presented. In addition, the constant improving research of automated loading-unloading vials systems (which its market is expected to increase exponentially in the following 3-4 years) will be explained. In terms of the freeze drying process, the industry is now focusing on how to control and monitoring the process. Some of these tools are product temperature devices/methods and induced nucleation methods. Knowing the product temperature is highly interesting in order to analyse the process and check if it is succeeding or problems have appeared. Depending on the freeze dryer unit and its accessories/properties (laboratory or industrial) the range of possibilities are different since wire temperature probes (pt100 and thermocouples) cannot be used in industrial units with automated loadingunloading vials system. Other options to gather the temperature data are the wireless temperature probes and the software which allow knowing the batch product temperature through the pressure measurement. The nucleation is the most important stage in the freezing step of the freeze-drying cycle. Spontaneous nucleation is stochastic and its duration is very high. So, the induced nucleation will allow to control this moment and to choose the best conditions. There are three different known technologies to control the nucleation: an ice crystal seeding nucleation, a depressurization nucleation and a vacuum induced nucleation.

Freeze drying is a process which requires a huge know-how. Each product is different from any other so designing/having an optimized freeze-drying recipe for a specific product is one of the main goals of all companies.

#8354

Current needs of the pharmaceutical industry: opportunities and challenges for implementing novel drying technologies

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Commercial drying methods are limited either by high production costs or significant quality loss due to process-related stresses. The near-ubiquitous use of freeze-drying in the pharmaceutical industry makes it the standard to which other drying technologies are compared. However, the shortcomings of lyophilization warrant evaluation of new techniques and the benefits they offer, such as compatibility with continuous manufacturing. Novel drying technologies must also overcome barriers to commercial implementation including, but not limited to, scalability and integration into a GMP environment. There remain several opportunities for further research which direct focus and investment strategy for the next generation pharmaceutical drying technologies.

Keywords: pharmaceuticals; manufacturing technology; implementation; lyophilization; scalability.

#8355
Power ultrasonic technology for drying heat sensitive products

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High-intensity ultrasound is deemed an appealing green tool for drying heat-sensitive materials, where micro-vibrations could prevent spoilage due to damaging produced by high temperature levels. Ultrasonic dehydration performed via air-borne radiation or in direct contact with the materials has proven to be an effective procedure. High-intensity airborne ultrasound introduces pressure variations at gas-liquid interfaces that increase the evaporation rate of material moisture. Moreover, in forced-air drying systems the ultrasonic wave produces an oscillating-velocity effect, which can increase the drying rate at stable air velocity. In addition, high-intensity airborne ultrasound causes micro-streamings at the air/material inter-faces that reduce the diffusion boundary layer, increasing mass transfer. Also ultrasonic vibrations produce a kind of "micro-sponge" effect inside the material that favors the quick migration and release of the moisture

The introduction by PUSONICS SL of the novel plate-transducer technology for air-borne high-intensity ultrasound, has opened up new possibilities for enhancing drying. These devices are characterized by higher electro-acoustic efficiencies compared with former sound sources, and have already shown promising results in several drying operations.

The simultaneous combination of ultrasound and other drying methods such as forced-air at low temperature, electromagnetic microwaves, infrared, etc., has also shown to be a promising avenue to enhance drying. The developed ultrasonic techniques for drying are the following: forced-air drying assisted by air-borne ultrasound, ultrasonic drying by applying ultrasound in direct contact with the material and use of air-borne ultrasonic transducers as fluidized bed dryers. The ultrasonically assisted forced-air drying could be applied in two different ways, one in hot-air convective drying by using low speed air flow at moderate temperatures and another in low-temperature drying (below and above product´s freezing point) at atmospheric pressure by intensifying and accelerating the process.

Ultrasonic vibration applied via direct contact between product samples and the ultrasonic plate radiator favors the deep penetration of ultrasonic energy and increases the effectiveness of the process.

Finally, the use of the air-borne ultrasonic transducers for applying the ultrasonic energy in a fluidized bed dryer has been effectively done by designing cylindrical radiators.

To conclude ultrasonic drying has shown to be a flexible process of low energy consumption in which the product qualities are well preserved. The application of these new technologies to food drying has been validated in cooperation with the group ASPA of Food Technology Department of the Unviersitat Politècnica de València (Spain).

#8359

Influence of process conditions on product performance for industrial fluidized bed applications

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Development of innovative products requires state-of-the-art technologies. Fluidized and spouted bed processes offer almost unlimited possibilities in terms of particle structure of dry product forms. Most of these possibilities are strongly linked to drying or solidification mechanisms. Such processes are usually multiphase problems and must be designed accurately.

Optimal evaluation of process conditions and parameters as well as material properties allows to directly design particulate products like homogeneous grains, porous agglomerates or layered products having hierarchical structures. With making use of this knowledge innovative products can be developed and manufactured effectively. That offers benefits for producers as well as for users.

For instance, spray agglomeration makes products easier and more safe to handle, better to dose, better in homogeneity. Using fluidized bed agglomeration technology, stability, functionality and processability as well as instant properties can be significantly improved. Main fields of application are the food, feed and pharmaceutical industry as well as fine chemicals, where high performance products are needed.

The contribution shows actual status of research activities at Glatt applying various processing principles, creating different particle structures and using different technical configurations of plants. Additional industrial case studies demonstrate how different drying principles and technologies are used to achieve optimal product performance.

#8360
Dryer performance – Reducing energy consumption, improving the product and sharing information

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The evaporation of water is a major energy consumer around the world where the evaporation of water from agricultural products, natural resources, processed foods and feeds, and petrochemical products is required for long term storage, subsequent processing or other desired attributes.
The control of product attributes associated with drying can also be challenging in terms of measurement and modelling which may lead to inefficiencies in the operation of a dryer.
This discussion below will address solutions to improve the thermal efficiency of dryers and to control the critical properties of the product being dried. In addition, the benefits of haring information between the dryer supplier and the dryer operator will be discussed through the use of the Industrial Internet of Thing

Keywords: heat recover; design; control.