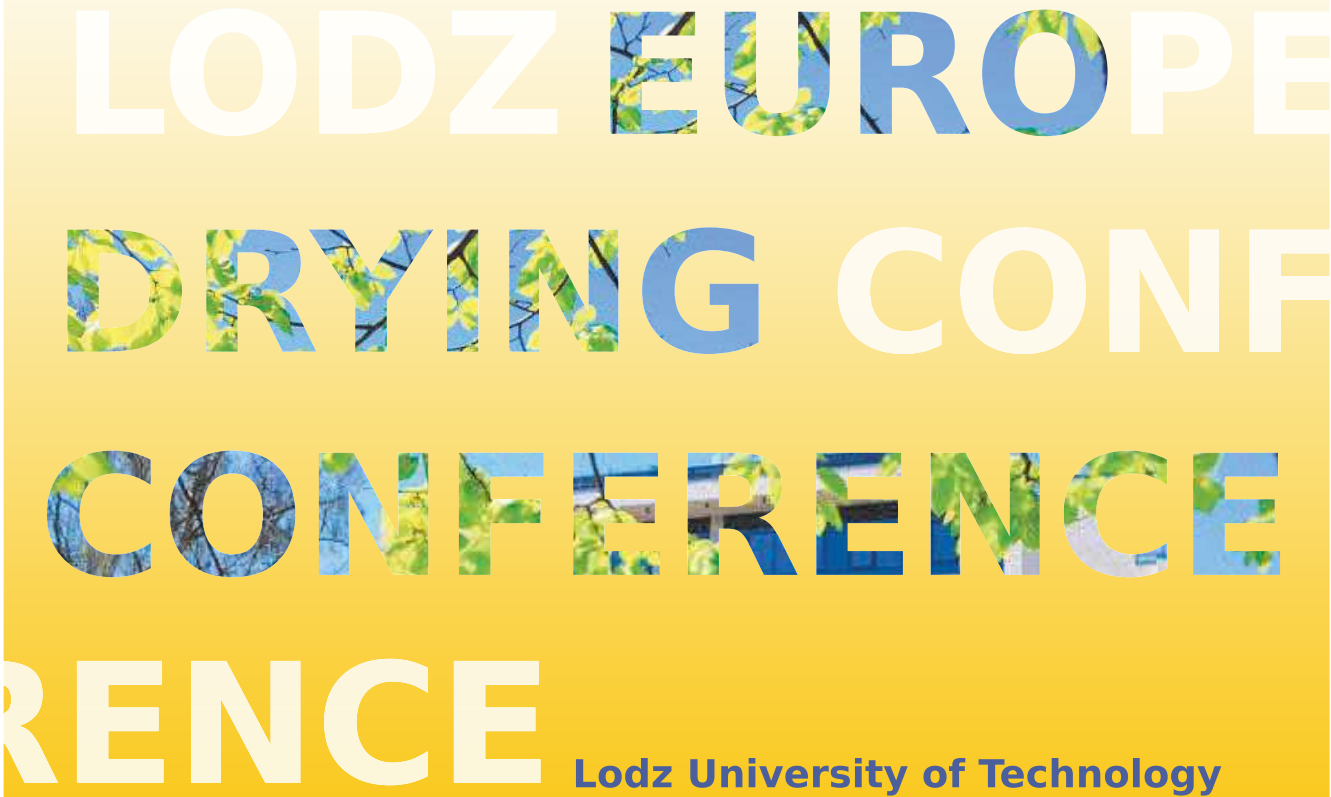
Book of Abstracts

8th European Drying Conference

EuroDrying 2023



Lodz University of Technology
4-7 July 2023, Poland

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Preface

Ladies and Gentlemen, on behalf of the Organising Committee, it is my pleasure to welcome you to the 8th European Drying Conference, which will be held in Lodz, Poland, from 4 to 7 July 2023. The event is jointly organized by the Lodz of University of Technology and Poznan University of Technology, under the auspices of the Working Party on Drying of the European Federation of Chemical Engineers.

The current edition of the conference follows on from previous events successfully held in Greece (2003), France (2007, 2009 and 2013), Spain (2011), Hungary (2015), Belgium (2017) and Italy (2019).

After a difficult period of necessary isolation and limited contact, we can finally meet face to face. Our world has changed considerably since we last met in Turin, presenting us with new challenges.

At this 8th event, our ambition is to present the latest research advances and address new challenges in process efficiency and sustainable energy management.

Table of abstracts

THIN-LAYER DRYING BEHAVIOR OF FOAMED STARCH-ALBUMEN SLURRY: EFFECT OF STARCH INCLUSION, DRYING TEMPERATURE AND BLOWER SPEED

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Abstract: *The drying characteristics of foamed starch-albumen slurry using a convective dryer was studied at varying starch powder (0-30%), drying temperature (40-60 ^{0}C) and blower speed (1-3 m/s) was studied. The entire drying curve was dominated by the falling rate period. The experimental drying data fitted best with the Page's first order drying model* $MR = k_o\ exp\ (-kt)$ *(r^2>0.95). The drying constant values ranged from 0.22-0.51 g H_2O/g solid/h. The drying variable influenced the rate in the order of starch inclusion>drying temperature>blower speed. Increased starch content of the slurry and blower speed reduced drying rate significantly (p<0.05). The converse was observed for drying temperature. The fastest drying was obtained with 0% starch inclusion, drying temperature of 50 ^{0}C and 1 m/s blower speed.*

Keywords*: thin-layer drying, albumen, starch powder, air drying, foam-mat*

LATENT HEAT RECOVERY IN CONVECTIVE DRYERS BY A SEMI-CLOSED LOOP ZEOLITE ADSORPTION/DESORPTION CYCLE

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Abstract: *In the Dairy Industry, spray drying is a core technology used to produce a wide variety of powdered ingredients and consumer products. Convective water evaporation is a high energy demanding process, and as such one of the largest contributors to the carbon footprint in Dairy production facilities.*
A breakthrough innovation is necessary to enable a step change in the energy use of spray dryers. Here we propose a heat pump that can recover both the sensible and latent heat from the dryer outlet air.
The solution to a latent heat pump on spray dryers is not evident due to the large temperature difference between ingoing and outgoing air. We present a zeolite adsorption/desorption-based heat pump that has potential to save ca. 50% energy in our dairy spray drying processes. The crux of this solution lies in optimization of outlet air bleed to inlet air feed ratio.

Keywords*: heat pump, latent heat, heat recovery, spray drying, dairy, zeolite, adsorption, desorption, steam*

EXTENDED VAN MEEL MODEL TO PREDICT THE DRYING BEHAVIOUR OF HIGHLY DEFORMABLE PRODUCTS

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Abstract: *A previous work of our team proposed an extended van Meel model to predict the drying behaviour of highly deformable products (Marques et al. 2023). Motivated by the excellent results obtained with this model and its ease of use, the present work applies this mode to products presenting different anatomical structures and drying behaviours, namely apple, which is an anisotropic and non-isovolume product. In the van Meel approach, the physics of drying is embedded in the concept of Characteristic Drying Curve (CDC) and the critical moisture content (X_{cr}). Rigorously, CDC and X_{cr} depend only on the drying conditions and on the product size: easy-to-obtain data. This model allows the change of sample volume to be easily deduced from the drying rate. In addition, it allows the exchange surface area to be predicted from the volume change, hence from the moisture content change. Therefore, no shape measurement is needed to calculate the exchange surface area, a key quantity to obtain the drying rate. Results obtained proved that the extended van Meel model can be used to predict the drying behaviour of any highly deformable and highly hydrated product.*

Keywords*: cell collapse, constant drying rate, exchange surface, van meel model, vegetable*

IS MULTISPECTRAL IMAGING A POTENTIAL ALTERNATIVE TO HYPERSPECTRAL IMAGING TO MONITOR THE DRYING PROCESS OF FOODSTUFF?

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Abstract: *RealTimeFood, a project funded by German Research Foundation (DFG-Deutsche Forschungsgemeinschaft), sought how feasible it is to replace Hyperspectral by Multispectral Imaging. First, spectral information (400-1700 nm) of apple, carrot, cocoyam, and celeriac commodities exposed to the hot-air drying process was acquired during the drying process. Predictive models accurately estimated the dynamic changes of moisture content, vitamin C content, soluble solids content (SSC), color, and shrinkage. However, the estimations for total polyphenols content, antioxidant activity, total carotenoids content, and rehydration ratio were less accurate. The project was continued by the identification of optimal wavelengths. Surprisingly, it was noticed either 980 nm or 1450 nm is informative enough to predict moisture content, vitamin C content, SSC, and shrinkage. Afterward, four imaging systems i.e., LED, Band-pass Filters (BPF), Laser-light Backscattering Imaging (LLBI), and Biospeckle Imaging (BSI) were developed at 980 nm and 1450 nm. It was noticed that predictive models accurately estimated the forgoing quality attributes. The RealTimeFood introduced a very simple, low-cost, and promising monitoring system.*

Keywords*: biospeckle imaging, laser-light backscattering imaging, NIR LEDs, moisture content prediction*

FREEZE-DRYING OF PHARMACEUTICALS IN VIALS NESTED IN A RACK SYSTEM

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Abstract: *The distribution of biopharmaceuticals often requires lyophilisation. The drug product is first frozen and potentially exposed to stress conditions that can be detrimental to its quality. These stresses are also encountered when a drug product has to be distributed under ultra-cold conditions. Adjusting the formulation and/or freezing conditions allows for limiting the impact of these stresses on the final product. This paper investigates two loading configurations, vials directly resting on the shelf and nested in a rack system, and their impact on the freezing and drying behaviour of a sucrose-based formulation. First, two key freezing parameters, i.e., ice nucleation temperature and cooling rate, were studied as they can affect the product behaviour during drying. The product freezing rate and the ice nucleation temperature distribution were affected by the loading configuration, resulting in larger ice crystals in the case of vials nested in a rack system. The analysis was also extended to the drying phase, showing that the loading configuration impacted the product temperature during drying and the overall heat transfer coefficient between the equipment and the product.*

Keywords*: freeze-drying; rack system; proteins; cryopreservation; heat transfer*

UNDERSTANDING THE OPERATING LIMITATIONS OF AN INNER-MIXING AIR-CORE-LIQUID-RING (ACLR) NOZZLE FOR PROCESS INTENSIFICATION IN SPRAY DRYING

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Abstract: *Spray drying is a popular technique that can produce large quantities of food powders. Unfortunately, it also has a high energy demand with only limited possibilities for energy recovery. Therefore, an important area of research in spray drying is to increase the solid content of the liquid feeds as much as possible. This creates, however, the additional challenge of atomizing high-viscosity liquids into fine droplets with a narrow size distribution. The Air-Core-Liquid-Ring (ACLR)-nozzle is a possible solution for this problem. It has the ability to handle highly viscous liquid feeds by inducing an internal annular flow. Operating limits for industrial use arise from internal flow instabilities, particularly at high liquid viscosities. Therefore, this study focused on the investigation on how the internal flow conditions of the ACLR-nozzle relate to the spray performance, and how both factors are affected by process conditions and liquid viscosity. The variations in the internal lamella thickness and the range of the drop size distribution (DSD) decreased with pressure and increased with viscosity and liquid volume flow, as expected. The pressure seems to be the limiting operating factor, since increasing viscosities require higher pressures to keep the performance parameters as desired. On the other hand, the atomization uniformity, which we evaluated with the modality of the DSD, showed that the Air-to-Liquid Ratio (ALR) might be more decisive on the resulting distribution than the individual operating conditions (pressure and liquid volume flow) or even the viscosity. This will have to be investigated with higher viscosities. Due to the operating limits for this case, simulations of the internal and external multiphase flow will be necessary to gain insights leading to further improvements of the nozzle design. For this purpose, a CFD model was successfully validated.*

Keywords*: spray drying; high viscosity; ACLR; inner-mixing nozzle; spray performance*

INFLUENCE OF SOLUTION PROPERTIES ON POWDER MORPHOLOGY DURING CO-CURRENT SPRAY DRYING

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Abstract: *Spray drying is a widespread drying technique used in a variety of industries. The process conditions have a great influence on the quality of the final product. In this study, the influence of temperature and concentration of maltodextrin solution on the moisture content and bulk density of powders obtained by co-current spray drying was investigated. It has been shown that there is a relationship between the temperature and concentration of the solution and the moisture content and bulk density of the product. In addition, conditions were identified under which the process could not be carried out. In order to fully analyse the effect of the feed properties on the morphology of the powder, the study needs to be complemented by measurements of the particle size distribution and microscopic images.*

Keywords*: spray drying, powder morphology, moisture, bulk density, maltodextrin*

IS IT POSSIBLE TO REDUCE CARRIER CONTENT IN RASPBERRY POWDER BY THE APPLICATION OF DEHUMIDIFIED AIR-ASSISTED SPRAY DRYING?

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Abstract: *"Clean label" products have gained more recognition over last years as consumers have become more aware of the food formulation. To obtain powders by conventional spray drying, it is necessary to apply high amount carrier to lower the risk of stickiness and powders' low quality. Dehumidified air-assisted spray drying has become a solution to drying of materials with high content of low molecular weight sugars.*
This research aimed to investigate the process performance of raspberry juice concentrate spray drying with the application of dehumidified air in order to lower carrier content and to check the possibility of applying prebiotic nutriose as a carrier. Dehumidified air spray drying was compared to conventional high temperature spray drying to determine the significance of low drying air humidity. Using dehumidified air and lower drying temperature, carrier content was reduced and variants with as little as 20% carrier content were possible to dry.

Keywords*: spray drying, dehumidified air, clean label, prebiotic*

INFLUENCES OF EXTRACELLULAR POLYMERIC SUBSTANCES (EPS) ON SETTLING, DEWATERING AND DRYING OF SEWAGE SLUDGE TREATED WITH INDIGENOUS MICROALGAE

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Abstract: *This study evaluates the efficiency of a sustainable process, which includes microalgae-bacteria interaction, for sludge treatment. Therefore, special attention was paid to the EPS profile in order to investigate their role in sludge settling, dewatering and drying. the results of previous study have shown that at the end of the experiments (25 days), the algae biomass production was 0,11 mg/gDM/day, with a mean biomass of 3,036mg/gDM. A considerable change in the EPS profile was observed. Protein concentration was increased by 13.2%, and 68.8% in tightly bound EPS and soluble EPS, respectively. However, loosely bound EPS content was decreased by 26.85%. The carbohydrate concentration was increased in soluble EPS by about 5% , decreased in tightly bound EPS by 20.71% and remained relatively stable in loosely bound EPS. These variations explain the enhanced settability properties of the treated sludge shown by the decrease rate of Sludge Volume Index (SVI) from 145.86 to 86.06 mL/g. The results coming from ongoing experimental work are promising and will be presented.*

Keywords*: Sewage sludge, Microalgae, Extracellular polymeric substances, Settling, Dewatering, Drying*

Acknowledgments*: H. Ben Hamed is grateful to the Belgium FNRS (National Fund for Scientific Research) for the funding support*

THERMODYNAMIC ANALYSIS OF WATER SORPTION OF POMEGRANATE PEELS AS FUNCTION OF MOISTURE CONTENT

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Abstract: *The present study investigated the thermodynamic properties of pomegranate peels at four temperatures (20, 30, 40 and 50°C) based on the experimental sorption data determined earlier in a previous study. The net isosteric heat of sorption and the differential entropy were found to decrease as the water activity increases. The isokinetic temperature (675.5K) was differed significantly from the harmonic mean temperature (307.7K) implying a linear enthalpy-entropy compensation and enthalpy driven sorption process. Gibbs free energy (4136.59J/mol) was positive for the temperature studied, which described a non-spontaneous process.*

Keywords*: thermodynamic properties, pomegranate peels, differential enthalpy, enthalpy - entropy compensation theory*

PROTOTYPE OF AN ARDUINI-CONTROLLED CONVECTIVE GEOTHERMAL DRYER

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Abstract: *A forced convective geothermal dryer consisting of radiator type heat exchanger (plate and fin type), centrifugal fan, electric water heater, and Arduino-controlled dryer chamber. Drying experiments carried out at six different temperatures (40 °C, 50,60,70,80 and 90 °C), and under different controlled air flow rates, in order to determine the drying velocity, the characteristic drying curve, the effective diffusion coefficient and the activation energy. A mathematical model based on thermal and mass balances over the component of the heat exchanger and the dryer chamber is developed. Simulations are carried out for meteorological data of Algiers (Algeria).We analyze the effect of air mass flow rate, air temperature, products mass, and water heater operating temperature on the drying time, Significant performance improvement was achieved on efficiency and drying performance of a convective food dryer by using a geothermal heat recovery heat exchanger.*

Keywords*: Arduino, curve drying characteristics, drying efficiency, simulation, heat exchanger, controlled dryer chamber*

INVESTIGATION OF EFFECTIVE MEDIUM THEORIES IN THE FAR INFRARED FOR PULP AND PAPER APPLICATIONS

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Abstract: *In this paper we discuss the use of terahertz-based moisture sensors with a focus on their use in paper drying applications. We seek to develop and assess physics-based models to relate terahertz beam properties to moisture content in a wet paper sample. We investigate two effective medium theories, the Bruggeman and the Looyenga method, to model the moisture dependent dielectric properties at frequencies from 0.3 THz to 2.2 THz. We then measure the moisture dependent dielectric properties of paper using time-domain spectroscopy and compare these results to our models. We find that for tracking high moisture contents, monitoring the refractive index is more effective and tracking absorption is more effective at measuring low moisture contents.*

Keywords*: sensing; THz; mm wave; effective medium theory*

ON THE DRYING SHRINKAGE OF CONCRETE STRUCTURES

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Abstract: *Drying is a phenomenon that accompanies the hardening of hydraulic materials. It can, if it is not prevented, lead to significant spontaneous dimensional variations, in which the cracking is one of the events. In this context, cracking promotes the transport of aggressive agents in the material, which can affect the durability of concrete structures.*
Drying shrinkage develops over a long period of almost 30 years although most occurred during the first three years. Drying shrinkage stabilizes when the material is water balanced with the external environment. The drying shrinkage of cementitious materials is due to the formation of capillary tensions in the pores of the material, which has the consequences of bringing the solid walls into each other. Knowledge of the shrinkage characteristics of concrete is a necessary starting point in the design of structures for crack control. Such knowledge will enable the designer to estimate the probable shrinkage movement in reinforced or prestressed concrete and the appropriate steps that can be taken in the design to accommodate this movement.
This study is concerned with the modeling of drying shrinkage of hydraulic materials and the prediction of the rate of spontaneous deformations of hydraulic materials during hardening. The model developed takes into consideration the main factors affecting drying shrinkage. There was an agreement between drying shrinkage predicted by the developed model and experimental results. In last we show that the developed model describes the evolution of the drying shrinkage of high performances concretes correctly.

Keywords*: drying, hydraulic concretes, shrinkage, modeling, prediction*

MICROWAVE HEATING AS A POSSIBLE ROUTE FOR THE DEFOSSILIZATION OF GREEN BRICK DRYING

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Abstract: *Defossilization of industrial processes, such as drying of green bricks (GBs) for the brick and tile industry, can be achieved when the heat required for evaporation of water is generated based on renewable energy sources, thereby replacing the currently used fossil fuels. Electrification of heating is thus one option to realize sustainable production processes. In this context, microwave heating has great potential to additionally intensify drying processes due to the volumetric heating of the material. This, however, requires optimal process control to avoid material damages caused by the achievable high heating rates. Intermittent heating, based on temperature profiles predicted or measured inside the product, has been proven a suitable method. This will be discussed, taking into account the moisture and temperature dependent dielectric properties of the GBs and the resulting location of hot spots, which additionally depend on the GB geometry and its position in the electromagnetic field.*

Keywords: *microwaves, green brick drying, intermittent heating, dielectric properties, loss factor, hot spots, electromagnetic field*

A NEW METHOD FOR DRYING TIME DETERMINATION OF REFINED SALTS IN A CONTINUOUS FLUIDIZED BED DRYER

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Abstract: *This method is based on a similar approach to the thermal conduction and moisture diffusion equations, considering the case of thermal diffusion and moisture diffusion as independent phenomena with distinct boundary conditions. This paper utilized the mathematical-physical foundation of this method to determine the refined salt drying time in a continuous fluidized bed dryer. The scope of the article involved applying the determined method of the thermal Biot criterion (Bi_q), the thermal Fourier criterion (Fo_q), and the moisture transfer coefficient (a_m). Additionally, the authors acknowledged the publication of certain thermal physical properties of the refined salt in various journals, including the moisture diffusion coefficient (βm), the thermal conductivity coefficient (λ), the specific heat capacity (C), and the kinematic viscosity (μ) of the drying hot air. The research resulted in the determination of the drying time for refined salt particles, with a mean radius of R = 476.10-6m, in a model of a continuous fluidized bed dryer under the condition of hot air supplied at 170°C for 18 minutes.*

Keywords*: refined salt drying, continuous fluidized bed dryer, drying time, thermal diffusion, moisture diffusion.*

CFD SIMULATIONS OF AGGLOMERATION IN COUNTER-CURRENT SPRAY DRYING WITH FINES RETURN

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Abstract: *In the present study it is investigated how the reintroduction of fine powder fractions into the drying chamber influences agglomeration in spray drying. The overall aim is the elucidation of the micro-scale mechanisms involved and the development of strategies to control final product properties such as the particle size distribution. First steps undertaken include the principal setup of computational fluid dynamics (CFD) simulations of a technical-scale spray dryer. Submodels accounting for the drying kinetics of the feed, heat losses of the spray dryer to the environment and the outcome of particle/droplet collisions extend these simulations. In later stages, these submodels will be gradually modified and improved. Extensive single droplet drying experiments are carried out and used to develop a spatially and temporally resolved model of the drying process, which in condensed form will be implemented into the CFD simulation.*

Keywords: *spray drying, fines return, agglomeration, computational fluid dynamics, micro-scale mechanisms*

SIMULATION OF WALNUT DRYING UNDER HOT AIR USING A MULTI-LAYER NONEQUILIBRIUM MULTIPHASE TRANSFER MODEL

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Abstract*: A nonequilibrium multiphase moisture and heat transfer model was developed to simulate a single walnut drying under hot air. A 3-layer geometry was developed to represent the multi-layer structure of walnut, differentiating the shell, kernel, and air gap between them. Walnut drying characteristics at 43, 55, 65, and 75 °C and 1.4 m/s air velocity were simulated using a finite element method. Simulation results agreed well with experimental data, and the model showed good predictability for drying of walnuts with different initial moisture and dimension characteristics (Radj3 > 0.996 for moisture and Radj3 > 0.983 for temperature). The distributions of liquid moisture, water vapor, and temperature in the walnut were determined in a temporal-spatial manner. The developed model served as a 'digital sensor' to provide important insights to understand the mechanisms of drying. Findings from this study established theoretical basis for improving the walnut drying process and determining the suitable drying conditions.*

Keywords*: multiphase moisture transport, nonequilibrium approach, multilayer geometry, walnut drying; mechanistic modeling*

EVOLUTION OF PORE STRUCTURE DURING THE DRYING OF POROUS MEDIA

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Abstract: *Removal of moisture from porous media during drying leads to changes in pore structure, which in turn affects moisture transport dynamics or drying kinetics. Modeling of this coupled phenomenon requires solving equations of the fluid domain and solid domain simultaneously. This problem has been solved in the framework of the discrete approach to drying porous media, but for situations where drying kinetics is essentially not influenced by changes in pore structure that occur during the drying process. This investigation is extended in the present work to also account for the role of pore changes in drying kinetics. To this end, a discrete pore network model is developed that takes into account intraparticle mass transfer in a drying porous medium, morphological changes of its pore structure, and the connection to the medium's surroundings. The pore network model is defined on, initially, a regular three-dimensional lattice of spherical pores and cylindrical throats, and it accounts for forces caused by the capillary pressure acting on the solid matrix, causing pore and throat radii to expand or contract, or even close. During the drying process, the liquid is redistributed, and pore/throat sizes are updated accordingly. The drying kinetics predicated by our shrinking pore network model differs from those predicted by classical stationary pore network models, with the former showing, for example, a decrease in evaporation rate at the beginning of the drying process but a considerably prolonged first drying period later on.*

Keywords*: adaptive pore network model, pore expansion, pore contraction, drying kinetics, liquid redistribution*

MICROWAVE DRYING OF MINT LEAVES WITH VOLATILES RECOVERY

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Abstract: *The conventional drying method has been used to dry the highly aromatic, flavouring leafy spices for ages. However, this may possess certain disadvantages like colour loss, volatile loss, non-uniform drying, longer drying time, etc. In this regard, microwave drying with volatile recovery has been proven to produce better-quality dried products and proper quality retention. Fresh* Mentha spicata *leaves were dried using a domestic microwave oven with a modified condenser unit. Almost, 7.80g of dried leaves and 11.5 mL of condensate were recovered while drying 20 g of mint leaves at 1 Wg^{-1} power density for 4-5 minutes. The dried product was found to be highly flavoured, aromatic with high colour retention and recovered volatiles (condensate) were found to have a strong flavor.*

Keywords*: condensation; drying; power density; quality*

UTILIZING RESIDUAL RAW MATERIAL FROM MARINE BIOMASSES AND SUGAR KELP (*SACCHARINA LATISSIMA*): PREPROCESSING, DRYING AND CONSUMER ACCEPTANCE

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Abstract: *Utilization of marine bioresources and sustainable processing of the blue values is essential in achieving food security for a growing population. An increased utilisation of fish residues (RRM) for food purposes is important due to the content of essential vitamins, proteins and polyunsaturated fatty acids, such as omega-3. Sugar kelp contains also valuable proteins, minerals, fibres and other nutrients essential for human health.*

Drying of RRM from the seafood industry and sugar kelp has been performed using conventional tunnel drying, and microwave assisted vacuum freeze drying. Thermo-physical properties of dried material are analysed. Sensory analyses (acceptance tests) with dried material in bread and snacks products are completed. The results show a consumer acceptance of 3% algae in bread and 6% in snacks, while addition of FPH (fish protein hydrolysate) was limited to 1.5% in bread and 3% in snacks, due to pronounced aroma.

Keywords: *sugar kelp, marine residual raw material, microwave assisted drying, thermophysical properties, sensory analyses*

MODELLING OF WATER SORPTION ISOTHERMS OF DEHYDRATED COFFEE BEANS USING MACHINE LEARNING TECHNIQUES

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Abstract: *The main aim of this work was to assess the feasibility of different machine learning techniques for describing the water sorption isotherms of green and parchment dehydrated coffee beans. For this purpose, experimental sorption isotherms were determined via the Dynamic Dewpoint Isotherm (DDI) method at three different temperatures (25, 35 and 45 ºC) and in a wide range of water activity (0.1-0.9). Water sorption isotherms were modeled using the classical model of Guggenheim-Anderson-de Boer (GAB) and the machine learning techniques such as Support Vector Machines (SVM), Random Forest (RF), and Artificial Neural Networks (ANN). Model training and validation was performed with 75 and 25% of experimental runs, respectively. The goodness of the fit was evaluated by means of the relative error (MRE) and coefficient of determination (R^2). The results revealed the potential of the SVM and RF in order to faithfully predict the sorption isotherms achieving R^2_{adj}>99% and MRE<1% in both experimental data sets.*

Keywords*: hygroscopicity; artificial intelligence; optimization; modelling*

ENCAPSULATION OF BIOACTIVE COMPOUNDS EXTRACTED FROM APPLE BY-PRODUCTS BY FREEZE-DRYING AND SPRAY-DRYING USING DIFFERENT COATING MATERIALS

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Abstract: *A water extract of bioactive compounds from apple by-products has been encapsulated by freeze-drying (FD) and spray-drying (SD) with maltodextrin and gum arabic as coating materials to improve their stability. The extract was also dried without coating by using both techniques as control. The obtained powders with maltodextrin as coating material presented the highest TPC and AA contents in all conditions (50-70% encapsulation efficiency). Long-term stability of the bioactive compounds in the stored obtained powders under different conditions (-4 ºC in darkness, 25 ºC in darkness and 25 ºC with light was studied for 3 months). The total phenolic content (TPC) and antioxidant activity (AA) were determined every 30 days. TPC and AA were better maintained in samples encapsulated by SD after 90 days of storage (35-50%) than samples encapsulated by FD (50-70%). The method that best retained the bioactive compounds was the encapsulation with maltodextrin by SD (30%).*

Keywords*: apple by-product, encapsulation efficiency, freeze-drying, spray-drying and antioxidant compounds*

MODELLING OF THE PAPERMAKING PROCESS UNDER AIR-LESS DRYING CONDITTIONS

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Abstract: *The majority of energy used in papermaking is related to evaporating water from the paper web. This latent heat can be recovered by extracting heat from the ventilation air below the dew point, which is typically around 60 °C for a modern, enclosed paper machine. However, with typical cylinder temperatures of 150 °C or higher, the temperature lift is too high to use heat pumps efficiently, both in terms of investment costs and operational costs. By drying the paper web in an air-less environment, the dew point is increased to nearly 100 °C. At the resulting temperature lift, heat pumps can be applied economically.*
To determine the impact of drying the paper web under air-less drying conditions, a COMSOL model has been developed. This model describes the heat and mass transfer within the paper web as well as the air flow on top of it. By changing the boundary conditions in accordance to those in a paper machine, the complete, multi-cylinder paper drying process is simulated. The article will show the impact of airless drying compared to conventional paper making.

Keywords*: papermaking, air-less drying, energy efficiency, heat pump*

THE EFFECTS OF MICROWAVE ON THE DRYING AND PHYSICOCHEMICAL CHARACTERISTICS OF RAMPS AND RHUBARB

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Abstract: *This study aimed to dry ramps (Asphodelus aestivus) and rhubarb (Rheum ribes) with microwave as an innovative drying method and to determine the effects of this method on the bioactive compounds (color, phenolic-flavonoid content, antioxidant activity) and drying characteristics (drying rate, rehydration ratio, effective diffusion coefficient (D_{eff}), activation energy (E_A)) of the dried products. The experimental data were adapted to eight different thin-layer drying models. Drying processes using three different microwave powers (140, 280, 420 W) were applied. All results of the microwave drying were compared to those of the control group, in which drying was performed at 70 °C in an oven. It was observed that microwave drying better preserved the green color of the products and positively affected some properties. The best-fit model was determined as that described by Midilli et al. The D_{eff} increased with increasing microwave power, and the E_A was calculated as 29.92 and 18.24 W/g for ramps and rhubarb, respectively.*

Keywords*: Asphodelus aestivus; Rheum ribes; microwave drying; modelling*

ELECTROSTATIC EFFECT ON THE DRYING OF A SINGLE DROPLET

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Abstract: *In the last few years, a new process named the electrostatic assisted spray dryer (ESD), combining two main technologies, electrostatic assisted hybrid atomization and spray drying, has been the interest of different experimental studies. This process works continuously at large scale and at low drying gas temperatures compared to those required in a conventional spray drying process. Our objective is the understanding of the drying mechanisms and kinetics in an ESD process using a single droplet drying setup. The chargeability of model solutions and charge retention in time were first evaluated in this article with a future objective to investigate the drying kinetics of a charged multicomponent droplet.*

Keywords*: Electrostatic assisted spray drying, single droplet drying, Faraday cup, specific charge*

VACUUM STEAM PULSED BLANCHING AND REFRACTANCE WINDOW DRYING OF FRESH SPINACH

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Abstract: *In the present work, the effect of blanching and drying on the quality characteristics of fresh spinach was evaluated. Vacuum steam pulsed blanching (VSPB) was used as a novel pre-treatment method on fresh spinach, to analyze the impact of different cycles (1 - 5), on the enzyme inactivation, drying characteristics, and quality changes. The results showed that VSPB inactivated peroxidase and polyphenol oxidase activities to 11 % and 8 % within four cycles, respectively. The chlorophyll content, total phenolic content, and antioxidant activity were enhanced compared to fresh leaves whereas the ascorbic acid was decreased with the treatment cycles. The blanched and untreated spinach paste was further subjected to refractance window drying. The VSPB aids in enhancing the drying rate by opening the pores resulting in faster moisture evaporation and lesser drying time. Page model showed the best fit to the drying kinetics. The better retention of the color, phenolic content, and antioxidant activity of the dried spinach powder was observed. The functional properties of the dried powder showed a better water absorption index, percentage solubility, dispersibility, and swelling capacity.*

Keywords*: enzymes; page model; phenolic content; total phenolic content*

NOVEL SINGLE DROPLET DRYING SET-UP TO SIMULATE TEMPERATURE-TIME TRAJECTORIES OF A SPRAY DRYER

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Abstract: *Spray drying allows formulation of food ingredients into shelf-stable powders. Typical optimization procedures for industrial spray drying processes aim for high product quality, production capacity and energy efficiency, while relying on trial and error and empirical understanding. Mechanistic understanding of the drying process can be obtained using single droplet drying approaches, yet they generally use different drying conditions. For example, during single droplet drying droplets are exposed to a constant air temperature, whereas in a spray dryer, droplets experience a variable air temperature, which decreases from the inlet to the outlet. In this paper, we report on the development of a new, custom-built sessile single droplet drying platform, which can dry droplets by exposing them to varying air temperature trajectories. Accurate temperature measurements showed that different temperature profiles could be generated. Subsequently, single droplets of solutions containing maltodextrin and β-galactosidase were dried while mimicking inlet (220 °C) and outlet (80 °C) air temperatures. Drying at the inlet air temperature after the locking point increases the droplet temperature, resulting in a reduction of the enzymatic activity. The gained insights in drying behaviour at the single droplet scale can help to predict optimal drying conditions during spray drying. This will not only optimize energy efficiency, but also allow for the production of high-quality powders with a desired level of enzyme activity.*

Keywords*: single droplet drying; temperature trajectory; β-galactosidase*

INTEGRATION OF HEAT PUMPS IN DRYING SYSTEM

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Abstract: *In the perspective of reducing CO_2 emissions from industrial activity, the processes and systems using thermal energy must transfer from utilizing oil and gas into environmentally friendly and efficient energy use. The heat pump is one of the solutions, operated from low to high temperatures. High temperature heat pumps gives possibilities to approach temperature levels of 130 to 150°C. This will cover most of the request from the drying processes in the industry. The development off high temperature heat pumps, using naturally friendly working fluids, makes sustainable systems with no environmental impact. Working fluids like Ammonia, Carbon dioxide, Hydrocarbon and Water, are fluids with no ozone deployment and no greenhouse warming potential and will fulfill the environmental requirement. The efficiency of the heat pump processes is given by the temperature lift, from the heat source to the heat sink. In closed loop drying systems, the temperature lift can be relatively small and the COP of the system will be high. Different system solutions will be discussed.*

Keywords*: heat pump, natural working fluid, energy efficiency,*

MODELING HEAT AND MASS TRANSFER FOR CAKE BAKING

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Abstract: *This article deals with the development of a numerical model to study heat and mass transfer phenomena as well as the swelling during the baking of a cake. The aim of this study is to provide an effective numerical tool, experimentally validated, for a better understanding of mechanisms leading to the desired end product. In this approach, the medium is assumed to be a deformable porous medium containing three phases. Based on the governing equations and under few assumptions (homogenous medium, local thermodynamic equilibrium, gas phase assumed to be an ideal gas mixture…), the problem consists in solving a system of five coupled partial derivative equations. At the same time as numerical approach, experimental tests are carried out on a laboratory oven. The numerical results are next compared with experimental data and analysed. Various operating conditions are tested to check the robustness of predictions.*

Keywords*: baking process, experiments, modeling, porous media*

USING OF A MICRO-DRYING SYSTEM TO CHARACTERIZE THE CONVECTIVE DRYING BEHAVIOR OF HYDROXYDE SLUDGES

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Abstract: *Drying appears as a major step prior to the valorization of sludge produced within Drinking Water Treatment Plants (DWTP), but this thermal operation is energy consuming. Deeper knowledge about sludge drying behavior is required to improve drying efficiency.*
Factorial experimental design is used to characterize the drying behavior of three different sludges. The studied ranges are a temperature from 70 to 110°C, a velocity from 1 to 3m/s and an absolute humidity from 0.005 to 0.2kg_{water}/kg_{dry_air}. The selected sludges are different by the location, the DWTP population-equivalent (P.E.), the sludge treatments and the dewatering system. Moreover, the sludges are extruded into an individual cylinder (diameter = height = 15mm). A monitoring of the mass and the surface/volume is performed continuously during drying
The influence of drying conditions are shown on the maximum drying flux, the time to reach 95% of dryness, the final volume and the critical moisture content. Furthermore, the slowing-down phase is described by a simple coefficient to be compared with each other
The results show that the temperature and the velocity of air both increase the maximum drying flux and the final volume, and reduce the drying time. Air humidity produces opposite effects. The most important result is the absence of influence of these operating conditions on the drying curve shape, proving the existence of a characteristic curve for a specific sludge

Keywords*: convective drying, sludge, characteristic curve, experimental design*

MODELLING OF SINGLE DROPLET IN DRYING PROCESS

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Abstract: *A diffusion based single droplet drying model in the solute-fixed coordinate system was solved using a fully implicit backward method to predict the moisture distribution and temperature profile during the drying process. The approach allows for predicting the concentration gradient within the droplet and tracking the shrinkage and temperature of the droplet during the drying process. The key contribution of this model is tracking the crust formation at each grid nodes of the droplet/particle. The material system of interest applied to the simulation is lactose and maltodextrin in an aqueous solution. The model prediction followed the predictions and experimental measurement from the literature reasonably well. This study's perspective concerns the simulation with and without the iterative steps and the outcome predictions compared with the literature. Overall, the iterative model gives better prediction compared to the non-iterative as it helps narrow the output value discrepancy.*

Keywords*: single droplet drying, particle formation, numerical simulation, spray drying*

COMPUTER VISION TO CHARACTERISE SHRINKAGE OF MEDICINAL PLANT

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Abstract: *The aim of this study is to track the contraction and the change that accompanies the drying of Warionia saharae medicinal plants. Description of the shrinkage process was done using the commuter vision technique and estimating the area of the leaves with a special program at specific interval along drying and the measure of mass loss. The computer vision is one of the modern techniques that are used to study the shrinkage of Warionia Sahara leaves because of the fragility of the structure and the impossibility of classic methods used to study this type of physical phenomenon. Image analysis enables objective, precise and often-automatic extraction of the information contained in an image. The result of drying of the leaves in the shade show the increasing of area with the increasing of moisture content.it was observed important modification in the first period of drying. The migration of water by the effect of ambient temperature causes the cell walls to collapse. It was observed that the shrinkage was not a homogenous, the shrinkage was greater over the width of the sheet about 35% compared to the length.*

Keywords*: medicinal plant, drying, shrinkage, computer vision, Warionia saharae*

ENERGY ASPECTS OF HYBRID FREEZE-DRYING

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Abstract: *Frozen samples of strawberries were dried in a prototype hybrid freeze-dryer (HFD) with the use of two energy sources delivered by a heating plate and magnetrons. Control samples were obtained in the traditional way of freeze-drying (FD) using energy supplied only by the heating plate. The microwave-emitting magnetron was turned on at the critical point of the drying kinetics reached after the end of the sublimation phase in order to significantly accelerate the desorption phase. The earlier activation of the magnetron contributed to the melting of the ice crystals due to the internal heating of the material characteristic for microwave penetration. When determining the energy consumption, the processing time and the power of devices involved in traditional and hybrid freeze-drying were taken into account. The results revealed that HFD system significantly reduced both time and energy consumption of the drying process compared to the traditional FD.*

Keywords*: freeze-drying, hybrid heating, strawberries, energy consumption*

IMPACT OF FOAM-MAT DRYING ON WATER VAPOUR ADSORPTION ISOTHERM OF STARCH-ALBUMEN POWDER

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***Abstract**: The water vapour adsorption characteristics of starch-albumen powders produced with convective drying with (FSAP) or without foam-mat (SAP) were compared. Type II isotherm curves were observed for both samples. The result indicated that the equilibrium moisture content (EMC) of FSAP (22.91-24.54 %, db) were higher than that of SAP (20.12-21.23 %, db). There was significant ($p<0.05$) difference in the EMC of SAP and FSAP when t-test was used. Peleg's Model gave the best fit with an accuracy (r^2) of 99.1-99.8 % and Root Mean Square Error (RMSE) of 0.035 and 0.497. The percentage error (e%) values also ranged between 0.397 and 6.631 %. The isosteric heat of adsorption ranged from 1.09 to 8.33 kJ/mol for FSAP while that of SAP ranged from 1.52 to 11.83 kJ/mol. The higher EMC values of FSAP may predispose the product to shorter shelf when compared with SAP.*

***Keywords**: egg powder, cassava starch, convective drying, foam-mat drying, adsorption isotherm*

EXPERIMENTAL AND NUMERICAL STUDY OF MODELING OF SPRAY GENERATION BY SPRAY DRYING PROCESS

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***Abstract**: Drying is one of the most important and at the same time the oldest areas of process technology. One of the most established forms of drying is spray drying, which is very often present in the food, pharmaceutical and chemical industries. In this research, we focused to the characterization of the spray formation on the spray nozzle and the implementation of numerical simulation with included secondary breakup of the spray. The characterization of the spray on the nozzle was performed on the Oxfor laser system, while the Ansys Fluent software package was used to perform the numerical simulations. A comparison of the results showed a good agreement between the particle size distribution obtained in the experiment and in the numerical simulation.*

DETERMINATION OF MOISTURE CONTENT IN FOOD PRODUCTS

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Abstract: *Determination of moisture content in food products is a key method for monitoring their quality and shelf life. Depending on the range of moisture content in the product, the test can be performed by several methods, including Karl Fischer titration.*
In this study, the moisture content using the Karl Fischer method was determined in 18 food samples of various types, both dry and semi-liquid. Each experiment was repeated twice for two different samples.
The results were compared with the guidelines issued by the Polish Food and Nutrition Institute. In order to confirm the moisture content, the food samples were tested using the drying to constant weight in accordance with the Polish Standard. Similar results were obtained from both methods. The Karl Fischer method is a fast method for determining the trace moisture content of food products.

Keywords: *moisture content, food products, drying, chemical analysis, quality*

INFLUENCE OF THICKENING AND DRYING PROCESS PARAMETERS ON SELECTED PROPERTIES OF FOOD LACTOSE OBTAINED UNDER INDUSTRIAL CONDOTIONS

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Abstract: *Lactose is a sugar of major industrial importance and its production involves crystallization from a high-density solution, separation, and drying. The aim of this study was to determine the influence of selected industrial process parameters on the properties of food grade lactose powder. The effects of temperature and the degree of concentration of the raw material on the size distribution of α-lactose monohydrate crystals were determined. The bulk density, Hausner coefficient, and water content and activity were determined in the finished product. The effects of temperature, humidity, and drying air volume on the water content and water activity of the product were analyzed.*
Statistical analysis was used to determine the relationship between the physicochemical parameters of the finished product. It was found that there was a correlation between the particle size distribution of food grade lactose powder and bulk density.

Keywords*: food lactose, physico-chemical properties*

IN-SITU ANALYSIS OF THE 3-D MICROSTRUCTURE AND ITS IMPACT ON THE FREEZE-DRYING KINETICS

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Abstract: *The influence of the microstructure on drying kinetics is investigated based on X-Ray tomography. For that, in-situ freeze-drying experiments are conducted in the 4D X-Ray tomography system DynaTom with a custom made freeze-drying stage. Here different freezing protocols (different solid concentrations, annealing treatment) were used to generate different microstructures. The freeze-drying took place at different drying temperatures (-11°C, -15°C and -33°C) and the pressure was set to 10 Pa. During the experiments continuous tomographic scans were conducted to observe the movement of the sublimation front in 3D during the whole freeze-drying cycle. After the drying is completed high resolution scans are made, for a more detailed microstructure visualization. An inhouse python script analyzes all data. It can be shown and analyzed how different microstructural parameters, namely pore size, shape and orientation influence the movement of the sublimation front. The results show that depending of the pore shape not only pore size is important, but pore orientation plays also a crucial role.*

Keywords: *freeze drying, X-ray tomography, microstructure, sublimation front*

INTENSIFICATION OF SPRAY DRYING BY ABSORPTION AND DESORPTION OF SOLUBLE GASES INVESTIGATED EXPERIMENTALLY AT THE LEVEL OF SINGLE LIQUID DROPLETS

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Abstract: *In this work, a series of drying experiments with single slurry droplets is carried out at room temperature and atmospheric pressure. The droplets are millimeter in size and made from aqueous slurries of silica particles. Gas mixtures composed of air and ammonia with different concentrations are used as drying agents in a single-droplet drying setup. The results show a strong influence of ammonia absorption and desorption on the drying characteristics of the droplets. In addition, the temperature profiles of the droplets are impacted by the exothermic effect of ammonia absorption that occurs at the beginning of the drying process. A comparison of our findings with available model predictions reveals a good agreement and thus, paves the way for spray drying of products that are sensitive to thermal stresses.*

Keywords: *active gas absorption/desorption, single droplet, drying kinetics, temperature profile*

ENERGY EFFICIENCY IMPROVEMENT BY BIOMASS PREDRYING WITH UTILIZATION OF WASTE HEAT FROM DRYING IN BIOMASS FIRED POWER PLANTS

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Abstract: *This article deals with the possibility of using fuel predrying in the biomass power plant cycle. The concept of an indirect dryer integrated into the cycle of biomass steam power plant was designed. The dryer is heated by steam extracted from turbine and the latent heat of the waste vapour released from the indirect dryer is used for feed water preheating. However, the use of waste vapour is often complicated by the infiltrated air into the dryer. The potential of energy utilization of waste vapour was experimentally verified for drying of wood chips in the steam heated indirect dryer. Based on these results, the proposed cycle of the biomass steam power plant was evaluated. The efficiency increases by a few percentage points in the dependence on the initial water content of raw biomass, the degree of using waste vapour condensation, and the feed water temperature.*

Keywords: *biomass, drying, power plant, waste vapour, energy efficiency*

MODELING AND ELECTRIC ENERGY-SAVING CONTROL DESIGN OF HYBRID SOLAR DRYER — EXPERIMENTAL VALIDATION

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Abstract: *A hybrid solar dryer (HSD) is composed of a solar collector, a drying chamber, and an electrical heating system. The modeling of the corresponding system was studied. The three input parameters of the dryer are solar irradiation, electric power heating, and ambient temperature. Experimental tests were performed under real irradiation conditions to collect input-output data for system identification. The least squares identification method was chosen to ensure a minimized output error. A global transfer function model relating solar irradiation, the heating resistor, and the drying chamber temperature has been synthesized. The performance of the deduced model has been evaluated through experimental tests carried out under different weather conditions. The resulting model was used for designing an electric energy-saving controller for the HSD.*

Keywords*: solar dryer; hybridization; temperature control.*

IMPACT OF THE DRYING RATE ON PRODUCT PROPERTIES OF SPRAY DRIED EMULSIONS TO ENABLE A TARGETED PRODUCT DESIGN

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Abstract: *Spray drying of emulsions is a widespread encapsulation technique to produce a large variety of powdered formulations. The oil droplet size (ODS) in the resulting powder is critical for final product quality, influencing namely key product parameters as the encapsulation efficiency (EE) of the oil, the powder flowability and particle surface properties. Commonly the ODS is set to a specific value during emulsion homogenization under the assumption, that the ODS remains unchanged throughout the drying process, which is known to not be true for most cases. The study focuses on improving the understanding of changes in ODS and structure formation during the drying step. For this purpose, model oil-in-water emulsions were spray-dried at varying air inlet and outlet temperatures and thereby at presumably different drying rates. The resulting powder particles were characterized regarding ODS and the oil EE as an exemplary key product parameter. Smaller oil droplets were observed for parameter combinations were higher drying rates are expected. We hypothesize that for a shorter drying process the ODS should be smaller as there is less time for oil coalescence. The results for the EE revealed no clear trend. A first increase of the air outlet temperature led to a small decrease in EE followed by a distinct increase of EE with a further outlet temperature increase. The first decrease may be connected to a collapse of the particle morphology but more detailed investigations are necessary for an exploration of these effects.*

Keywords*: spray drying; emulsions; encapsulation; drying rate; powder properties*

PREDICTION OF SPRAY DRIED PRODUCT PROPERTIES USING MACHINE LEARNING ALGORITHMS

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Abstract: *Spray drying is closely related to the quality of the final product, as it is usually the last operation in the processing line. Physics-based models are crucial for the analysis of drying processes. However, they have limited predictive power and are not suitable for real-time process control and optimisation of industrial drying. This paper presents a novel approach for modelling spray dryers and predicting the properties of the final product using machine learning algorithms (ML). These models are used to predict the properties of the final product. An overview of all machine learning regression methods that can be used to predict the properties of the final product and a brief comparison of these techniques is presented. Both measured data from the experiments and generated data from the CFD simulation are used to train these models. The results show that the algorithms from ML are very accurate (about 90%) in predicting spray-dried product properties.*

Keywords*: spray dryer, machine learning, CFD modelling, particle properties.*

EXPERIMENTAL STUDY OF PARTICLE AGGLOMERATION IN COUNTER-CURRENT SPRAY DRYING WITH FINES RETURN

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***Abstract**: Particle agglomeration during counter-current spray drying is complex and difficult to control. The agglomeration of particles in the drying chamber is influenced by the process conditions, the nature of the dried material, and the dynamics of phase mixing. In addition, particles separated from the exhaust air in industrial dryers are returned to the inside of the drying chamber. These particles enhance the agglomeration process. This paper presents the results of investigations to determine the agglomeration mechanism in spray drying with the recirculation of particles. The experiments were carried out in a semi-industrial scale drying plant, where a selected fraction of particles is recycled to the atomization zone. The studies presented show the change in particle diameter at different levels of the drying tower and the change in the morphological characteristics of the product depending on the parameters of the drying process used.*

***Keywords**: Spray drying, agglomeration, fines return, powder properties*

INNOVATIVE NON-CONTACT METHOD FOR TEMPERATURE MEASUREMENT OF DROPLETS AND PARTICLES IN DISPERSED SYSTEMS

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Abstract: *This paper presents a new method for measuring the temperature of particles and droplets suspended in air. Standard methods for measuring the temperature of particles during drying are subject to errors resulting from temperature changes due to drying and thermal conductivity along the measuring element. The innovative method developed is based on measuring the intensity of infrared radiation without the need to know the emission, reflection and transmission coefficients of the particles. By using a specially designed thermostatic measuring chamber, the measurement is based on a comparison of the intensity of the IR radiation of the particle and the surrounding surface. This method requires no mechanical intervention and does not interfere with the spray or fluidized bed drying process.*

Keywords*: Spray drying, temperature measurements, thermal imaging, SDD kinetics*

OPTIMIZATION OF STRAWBERRY CONCENTRATE SPRAY DRYING AT LOW AND HIGH TEMPERATURE TO OBTAIN POWDERS OF ENHANCED PROPERTIES

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Abstract: *The aim of work was to investigate the influence of variable spray drying parameters (temperature, air humidity) on drying yield and physicochemical properties of strawberry concentrate powders. Powders were obtained by conventional spray drying method (inlet air temperature 160-200°C) and low temperature, dehumidified air-assisted method (80-120°C). The response surface method (RSM) was used to test the influence of the studied factors on the dependent variables: drying yield, water activity, color, anthocyanin content and glass transition temperature. The application of dehumidified air increased the yield of the process and concentrate content (up to 80% powder solids). Moreover, obtained powders had lower water activity, lighter color and higher content of anthocyanins.*

Keywords*: spray drying, dehumidified air, RSM method, strawberry powders*

LARGE SCALE DRYING IN SUPERHEATED STEAM UNDER PRESSURE OF BEET PULP IS THE WAY TO CO_2 NEUTRAL SUGAR PRODUCTION

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***Abstract**: To save the planet we must reduce the emission of CO2 even down to nothing. The beet sugar industry is one of the industries emitting the most CO2. 67% of this comes from the fuel used in the steam boilers. 33% comes from the traditional drum driers drying the pulp.*
By drying the pulp under pressure in steam, the water from the pulp, will leave the dryer as a steam , which shall be used in the factory. Thereby 33% of the factory need for fuel is saved and the CO2 emission is reduced accordingly.
The dried beet pulp is a high value feed for cattle, but it can also be used as fuel in the steam boilers. Burning 75% f the pulp can keep the factory going. With the high prices on fuel and CO2 tax it also pays back. Thereby the factory has become CO2 neutral.

***Keywords**: drying in steam. pressurized drying. large industrial driers. large energy saving, no air pollution, CO_2 reduction*

A NEW TECHNIQUE FOR THE PHYSICAL ELIMINATION OF ASPERGILLUS FLAVUS SPORES BEFORE GRAIN DRYING

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Abstract: *In order to solve the problem of an excessive content of mould and toxin before grain drying, this paper puts forward a trial using high-energy deep ultraviolet LED and plasma technology to carry out the elimination of Aspergillus flavus spores. The results show that the high-energy deep ultraviolet LED technology had a good inactivation effect on aspergillus flavus under the time scale of seconds, and the aspergillus flavus could be completely inactivated within 120 seconds, Plasma has a certain inactivation effect on aspergillus flavus. This paper reveals the potential use of high-energy deep ultraviolet LED and plasma technology in the elimination of mould. It clarifies the research route and provides data support for the next step of mould inactivation and toxin degradation based on high water grain as the carrier.*

Keywords*: grain, cleaning and drying, toxin degradation, ultraviolet and cold plasma*

DEDERT -SPRAY DRYING IN FOOD INDUSTRY – SOLUTIONS AND APPLICATIONS.

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DEDERT CORPORATION – Who are we?

- ✓ *53 years experience in process technologies*
- ✓ *Global leader drying systems for crop-based products, incl. corn starch, pea starch, fiber/solubles, wheat gluten, rice protein*
- ✓ *Key technical personnel (engineers and designers) with >300 years combined experience in the starch industry*
- ✓ *International Presence:*
- *Dedert USA (Homewood, IL)*
- *Dedert (UK)*
- *Dedert (Copenhagen)*
- *Dedert (Canada)*
- *Dedert (Shanghai)*

Spray Dryer

DEDERT

Key Features and Advantages	
Nozzle Spray Drying	**Rotary Spray Drying**
Widely used for proteins	Potential for new product innovations
Low-solids feed with limited viscosity	Suitable for high-viscosity liquids
Nozzle atomization	Rotary atomization
Plug-flow drying	Spiral flow drying
High-pressure pump required	Low-pressure feed pump only
PSD related to nozzle pressure	PSD related to rotary disc speed
Challenges	
Tall-Form: extended head-room required	Mechanical shear on droplets

MULTI-LEVEL SIMULATION OF DRYING KINETICS DURING LYOPHILIZATION

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***Abstract**: Research concerned with numerical modelling of the process of freeze-drying has focused either on modelling the drying kinetics within the individual vial or on studying the hydrodynamic conditions within the production apparatus. In the current work, we present a multilevel model in which the drying kinetics in each individual vial (1D model) is coupled with the 3D- CFD flow model. In this way, we can study the interplay between the local hydrodynamic conditions and the drying in each vial. The current results show that the model can resolve the variation of the local chamber pressure and demonstrate that the pressure variation in the chamber affects the local drying kinetics inside the vials. Therefore, the model can serve as a potential tool for optimization of drying cycles and can be used as a tool for process transfer from laboratory scale to production scale device.*

TROUBLESHOOTING AND PROBLEM-SOLVING IN INDUSTRIAL DRYERS

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Abstract: *Dryers are designed once, but then operate for many years, and it is important to have systematic methods to solve problems when they arise. Kemp and Gardiner proposed a systematic methodology in 2001, based on categorisation of problems into five main types and a divergent-convergent algorithm to identify both root causes and potential solutions. This approach to troubleshooting has proved successful for dryers in a range of industries. This paper reviews the experience gained, some resulting improvements, overlap and synergy with other investigation methods such as Lean Six Sigma techniques, and gives examples from case studies. Appropriate theoretical models can give useful insights, often using quite simple methods such as heat and mass balances and drying times estimated with first-order kinetics. The insights can solve other drying-related problems such as caking in storage. The methods can also be used for process improvement, debottlenecking and enhanced product quality.*

Keywords*: dryer performance, heat and mass transfer, materials handling, end-use properties, moisture content, product quality, root cause analysis.*

DEVELOPMENTS IN SCALE-UP OF INDUSTRIAL DRYING PROCESSES

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Abstract: *Scale-up of drying processes is of great industrial importance, but relatively little has been published on the subject since a Drying Technology special issue in 1994. This paper reviews and updates the techniques, drawing the methods recommended for various individual dryers into a more unified overall approach. The aim is to increase batch size, or throughput of a continuous process, while maintaining final moisture content, product quality, end-use properties, safety and reliability. A key simplifying assumption is that material-dependent behaviour such as internal heat and mass transfer remains similar on scale-up at appropriately chosen conditions, allowing scaling calculations to use ratios based on heat balances and constant-rate drying. The specific drying rate (SDR) concept shows the importance of the ratio of dryer holdup to heating surface or cross-sectional area. Hence, key results such as airflow and drying time often follow a two-thirds or one-third power law on scale-up, although important exceptions can be identified.*

Keywords: *equipment design; scale-down; area-to-volume ratio; modelling; empirical methods; operating conditions; pharmaceuticals.*

MIXING OF SUB-MICRON PARTICLES IN A SPOUTED BED

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Abstract: *Mixing sub-micron particles produces Hetero agglomerates, which can exhibit innovative and superior properties over the pure components. The present study investigates the hetero- agglomerate formation of sub-micron particles in a spouted bed equipment. Sub-micron particles exist in the form of Homo-agglomerates due to interparticle forces such as van der Waals forces and electrostatic forces. In this spouted bed, the inlet air velocities are significantly higher and can be expected to exert an influence that promotes agglomerate breakage and compaction. Agglomerate morphology is ideally assessed by Scanning Electron Microscope that resolves single primary particles to identify the change of composition in different agglomerates. EDS (Energy dispersive X-ray spectroscopy) is used to quantify the mixing at sub-agglomerate level. An open issue is the dependence of compositional variance as a measure of mixedness on magnification and EDS spot size. In fact, with much smaller EDS spot than the primary particles, compositional variance will be maximal even for perfect mixtures. On the other hand, minimal variance is obtained when the EDS spot is very large, but mixedness remains unknown below this length scale. Consequently, reasonable RoIs (Region of Interest) close to the size of the intermingled structural elements will be identified and used to quantity the mixing. A method to quantify the mixing inside the agglomerate is proposed.*

Keywords: *mixing, sub-micron particles, hetero-agglomeration*

PRODUCT PROPERTIES IN A TWO-NOZZLE SPRAY DRYING SYSTEM

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Abstract: *The paper presents the influence of the parameters of the drying process on the properties of the obtained product. Drying was carried out in a counter-current spray drying system equipped with two pneumatic nozzles. The dried material was an aqueous solution of maltodextrin, which is a skin-forming material. The efficiency of the drying process and the Particle Size Distribution (PSD) were analyzed. A comparison of PSD results obtained by two measurement methods: microscopy analyzes and laser diffraction was discussed.*

Keywords*: spray drying, particle size distribution, microscopy analyzes, multi nozzle systems*

DETERMINATION OF EFFECTIVE MOISTURE DIFFUSIVITY AND DRYING KINETICS FOR LOW-TEMPERATURE DRIED ALGINATE BEADS

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Abstract: *The study presents drying curves from a low-temperature drum dryer working in a closed loop system under atmospheric pressure. Data were obtained based on drying experiments performed at five temperatures (-10, 0, 10, 20, and 30°C). Due to the time-consuming process, the obtained drying curves were described using mathematical equations in order to determine the drying time for any temperature within the range defined by the minimal and maximal temperatures for which the research was conducted. The comparative criteria for the obtained approximations are: coefficient of determination (R^2), adjusted coefficient of determination (R^2_{adj}), mean square error (SE) and significance level. In addition, the diffusion coefficient and activation energies were determined.*

Keywords*: low-temperature drying, drum drying, diffusion coefficient, drying curves*

ULTRASOUND ASSISTED DRING OF APPLES – PROCESS KINETICS, ENERGY CONSUMPTION AND PRODUCT QUALITY

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Abstract: *Convective drying is one method of fruits preservation. Due to the low energy efficiency of the dryers, it is also one of the most energy-intensive. For this reason, modern drying techniques are sought. They are required to be energy efficient, sustainable, and produce high-quality products. The aim of this work was to determine the impact of ultrasound on the kinetics and energy consumption of convective drying of apples and the quality of the products. The convective drying process and two US + convective processes differing in ultrasound power were tested. Three varieties of apples were dried. Drying kinetics, energy consumption and product quality (water activity, color change and rehydration) were compared for the tested processes. The drying kinetics was modelled mathematically. The use of ultrasound each time accelerated the process. The drying time was shortened and the speed of the process increased. This increase was mainly due to the vibration effect, causing an increase in the mass transfer coefficient. The use of ultrasound resulted in a decrease in the water activity of the product and a decrease in the color change of the dried material compared to that obtained by the convection method. From the point of view of rehydration, the dry material obtained by the US + convection method at a lower US power turned was the best.*

Keywords*: ultrasound drying; convective drying; kinetics; mathematical modelling; energy consumption; quality; apples*

Acknowledgment: *This work was supported by the Ministry of Education and Science in Poland.*

THERMAL VACUUM DEHYDRATION AND SIMULTANEOUS GRAIN PESTS EXTERMINATION

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Abstract: *Dehydration and pest control of grain are the main technological operations to remove excess moisture from the grain material, which on a national scale leads to the consumption of tens of millions of tons of standard fuel. Grain is thermolabile, so it is necessary carefully approach the issue of choosing the optimal technological mode for dehydrating grain, taking into account its thermal stability, initial moisture content and the quality of the dried product. Currently used drying plants are energy-intensive, metal-intensive. Drying of wet grain mainly carried out at atmospheric pressure and high temperatures, sometimes. The quality of dried products is low. The most common damage to grain during drying is formation of cracks on the surface of the grain or inside. The higher the heating temperature of the grain, the worse its quality, and therefore the yield of premium flour during grinding reduced. The introduction of new methods and advanced technologies in the process of dehydration and pest control of grain is the most important for improving the efficiency of grain drying equipment. A highly efficient, energy-saving, environmentally friendly technology for low-temperature drying of grain crops (and other food products) with simultaneous bactericidal treatment implemented on the newly developed thermal vacuum installation. Thermal vacuum drying technology is an alternative to traditional high-temperature methods of drying grain crops. Thermal vacuum drying quite universal and does not entail pollution of the environment and the grain itself. In this installation, the grain is dried and at the same time cleaned of light impurities and disinfected. Thermal vacuum drying allows reduce energy consumption per unit of dried products, to reduce drying time. Solves problem of grain yield safety, increases shelf life due to dehydration and suppression of vital activity of microorganisms, pathogenic microflora, and insects.*

Keywords: *efficiency; ecology; quality; drying; disinfestation*

EXPERIMENTAL STUDY ON THE DRYING AND QUALITY EFFECT OF BASILIC (OCIMUM BASILICUM L.) INCORPORATION IN MACAROONS PRODUCTION

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Abstract: *The macaroon is a small biscuit appreciated all over the globe. The food industry is increasingly interested in the products including aromatic plants.*
The aim of this work is to study the quality of macaroons flavoured with Basil (Ocimum basilicum L.) prepared and obtained inside the laboratory of research, using vacuum oven for the drying of the leaves of this culinary herb. For this case of study, it was done at 50 ± 2 °C and vacuum pressure of 0.3 ± 0.1bar. Furthermore, the characterization of these flavoured macaroons includes powdered aromatic plants, followed by a sensory analysis, precisely, colour, aroma, texture, taste and acceptability for three different Basil powder concentrations MB1, MB2 and MB3.
The results obtained showed that the increase in the rate of incorporation of plant powders leads to a slight reduction in the diameter, thickness and weight of the macaroons.
In addition, the change in colour noted well as for the case of MB3, which has a greener colour. However, adding plant powders to macaroons clearly affected its physicochemical properties (increase in pH 6.21, ash content 2.82 % and reduce water content 4.50 % compared to the basic macaroon).
The results of the sensory analysis showed that the addition of aromatic plant powders improved the sensory quality of the macaroons; the cases of MB3 and MB2 were more appreciative.

Keywords*: macaroon, basil, vacuum drying, aromatic and powders*

IMPACT OF GREENHOUSE DRYING ON NUTRIENT QUALITY AND DRYING KINETICS OF BLACK SOLDIER FLY (HERMETIA ILLUCENS) LARVAE

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Abstract: *Black soldier fly larvae (BSFL) are promising insects rich in nutrients such as protein and fat. Its exploitation is a viable solution to a circular economy and a new alternative for food and feed. The larvae drying operation is an essential step in the transformation process of the product into flour and for storage. This work aims to evaluate a basic drying technique (greenhouse), that matches better the larva-rearing method, and by considering the drying kinetics, the water content, and the quality of the dried products. By using indirect solar drying, a short time is needed while having a good nutritional quality which is manifested by a high protein and fat content. The product had a good rehydration capacity. The drying curve shows the existence only of the falling drying rate period, where Fick's second law of diffusion can be applied.*

Keywords*: BSFL; drying kinetics; solar drying; nutritional quality.*

ADVANCES IN THE SCALING UP / INDUSTRIALIZATION OF PULSE COMBUSTION DRYING TECHNOLOGY

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Abstract: *Pulse Combustion Drying (PCD) is a drying technology that uses the shockwaves or pulses that are generated by a pulsating gas burner, to atomize and dry liquids or pastes. The advantages over conventional spray drying are energy efficiency, and the capability of atomizing slurries with higher viscosity. In this work, thermal energy efficiency is been measured in two PCD dryers: a 70 kW pilot plant located in Spain and a 3.000 kW industrial plant, located in Poland. We have found that energy efficiency is better in the industrial dryer (0,71 to 0,96 kWh thermal /kg of water evaporated) that in the pilot plant (0,87 to 1,3). Both energy efficiencies are significantly better than is conventional spray dryers. Those findings are coincident with energy efficiency data about PCD provided by other authors. Next R+D activities are directed to improving more energy efficiency and the use of H2 as fuel.*

Keywords*: pulse combustion drying; scaling-up; energy efficiency; brewer´s yeast; spray drying*

PULSED ELECTRIC FIELD PRE-TREATMENT IMPROVES DIFFERENT DRYING METHODS PERFORMANCE OF CHILEAN ABALONE (*CONCHOLEPAS CONCHOLEPAS*)

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Abstract: *The Chilean abalone is a gastropod mollusk with a high commercial price, and is classified as a gourmet product. However, one of the main factors limiting export is the short shelf life thereof. In the present study, the processes of vacuum microwave drying (VMD), freeze-drying (FD), and hot air drying (HAD), along with the previous PEF application as pretreatment (2 kV/cm), were researched in terms of processing conditions, and product properties. The VMD process was carried out using an initial power intensity of 7.74 W/g for 10 min. The treatment that presented the highest diffusivity was VMD (3.28×10^{-9} m2/s), on the other hand, the treatment that presented the lowest diffusivity (7.30×10^{-10} m^2/s) was FD. In terms of energy consumption, there was a difference of 97% between FD and VMD. Therefore, it is possible to conclude that both treatments have advantages that should be used according to requirements.*

Keywords*: Chilean abalone, pulsed electric fields, drying methods, drying properties, consumption energy*

INFLUENCE OF CELL DISINTEGRATION INDEX CAUSED BY PEF IN ULTRASONICALLY ASSISTED CONVECTIVE DRYING OF TURNIP KINETICS

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Abstract: *Convective drying can be enhanced through applying alternative technologies such as pulsed electric field (PEF) pretreatment. The electroporation generated by PEF depends on process variables and can be quantified through the cell disintegration index (CDI). The aim of this work was to identify the relationship between the CDI induced by PEF and the ultrasonic (US) assisted drying kinetics of turnip. The CDI was measured in PEF pretreated turnip at different conditions. Thus, the CDI of the turnip raised when increasing both the number of pulses and the electric field strength. From these results, PEF pretretaed samples at two different CDI levels (0.25 and 0.75) were dried at 40 ºC, applying or not US (20.5 kW/m^3). Compared to conventional drying, both PEF and US application accelerated drying kinetics being the faster process found when combining US application with PEF pretreatment. Therefore, both technologies can contribute to shorten the turnip drying process.*

Keywords*: turnip; convective drying; PEF; cell disintegration index; airborne ultrasound; technology combination; effective diffusivity*

FREEZE-DRYING OF STRAWBERRIES – ANALYSIS OF CONDITIONS AND MODELING OF THE PROCESS

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Abstract: *Lyophilization is a drying method in which moisture is removed from the product under reduced pressure at a temperature below the freezing point. This method enables the drying of thermolabile products and can therefore be successfully used in food technology.*
In the present study, freeze-drying of frozen strawberries was carried out in a ALPHA 2-4 apparatus from Martin Christ GmbH. The drying process was divided into two stages: specific drying and additional drying at constant pressure. Studies on drying kinetics were also carried out. Freeze drying of strawberries was carried out in 20 different processes, varying the temperature and duration of the first drying stage. The experiments carried out allowed the optimization of the process.
The dried samples were analyzed for the moisture content of the material at different stages of freeze-drying, the bulk and true density, and the sorption isotherms. A model of drying kinetics was also developed that best reflects the process of strawberries freeze-drying.

Keywords: *freeze-drying; lyophilized strawberries; moisture; drying kinetics, modeling*

ELECTROHYDRODYNAMIC-ASSISTED DRYING TECHNOLOGIES

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Abstract: *Electrohydrodynamic (EHD) drying refers to the removal of water from a wet material exposed to a strong electric field due to the aerodynamic action of so-called "ionic", "electric, or "corona" wind. This wind originates from electrically charged sharp electroconductive pin(s) in the direction of a flat electroconductive collecting electrode.*
The corona wind impinges the surface of wet material, placed on the collecting electrode. This action disturbs the gas boundary layer, decreasing convective mass transfer resistance and promoting convective mass transfer from the drying material. Due to the depression of material temperature below the ambient temperature, EHD drying is regarded as a non-thermal technology particularly suitable for dewatering heat-sensitive materials such as high-value bioactive components of fruits and medicinal plants, living cells (bacteria, yeasts, and viruses), nonliving substances of biological origin such as blood plasma, serum, hormones, enzymes, antibiotics, probiotics, nutraceuticals, and the like organic materials.
Energy consumption in EHD drying is much lower than that in hot air drying because of the targeted energy supply and practically no heat lost with the exhaust air. The product quality includes lesser shrinkage, higher rehydration ratio, retained color, and preserved valuable components such as vitamin C.
The EHD drying is usually accompanied by a convective low-temperature air stream which takes away the evaporated moisture. Moreover, it was found that the EHD can be used in conjunction with other drying technologies such as solar drying or heat-pump drying thus providing better energy efficiency and product quality.

Keywords*: EHD; corona wind; energy; thermal drying; hybrid technology; quality*

THE POTENTIAL OF ARTIFICIAL INTELLIGENCE (AI) IN INDUSTRIAL DRYING

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Abstract: *Currently used convective drying technologies assume constant temperature during the entire drying, which results in energy and quality losses. As an alternative, we propose intelligent control and optimization strategy, which provides the best product quality with the least energy expenses. In addition to machine vision and soft sensors, this drying strategy employs multiple AI tools, such as artificial neural networks, fuzzy logic, and evolutional algorithms. This strategy is based on the combination of supervised and unsupervised machine learning. Supervised learning helps to link drying factors to specific quality attributes to establish criteria for optimization. This knowledge will be used in the design of an adaptive control system, which will allow fine-tuning of drying conditions. The benefit of adaptive intelligent control is unsupervised learning. The integration of machine vision and machine learning with an AI decision-making framework has significant potential to improve the performance of industrial drying systems.*

Keywords*: quality, efficiency, machine learning, adaptive control, optimization*

PHYSICO-CHEMICAL AND TEXTURAL PROPERTIES OF SELECTED PLANT MATERIALS DEHYDRATED USING HYBRID FREEZE-DRYING

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Abstract: *The research was carried out using a prototype of a hybrid freeze-dryer (HFD), in which frozen samples of strawberries, beetroots or parsley weighing 100 g were subjected to drying with the use of hybrid energy sources delivered by a heating plate and magnetrons. Control samples were obtained in the traditional way of freeze-drying (FD) using energy supplied only by the heating plate. The results revealed that hybrid heating system improved the quality of the freeze-dried product by increasing antioxidant activity as well as the content of polyphenolic and volatile compounds. The tests of the mechanical properties of strawberries showed that the shear stresses of HFD samples and the cutting work were greater than those of FD samples. This means that the HFD samples have the properties of crispy products, in which the values of these parameters are higher compared to the dried materials obtained during traditional FD.*

Keywords*: freeze-drying, hybrid heating, strawberries, beetroots, parsley, quality*

ELECTROSTATIC SPRAY DRYING: A SUSTAINABLE TECHNOLOGY FOR THERMOSENSIBLE POWDER

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Abstract: *There has been substantial growth in demand across the industry for the dried form product especially for thermosensitive products. An innovative technology entitled as "electrostatic spray drying" is a promising approach to answer the current challenges in drying technologies which are: scalability and energy consumption. The methodology of the scale-up is explained based on mass balance calculation and is shown to be a solid base to obtain the same powder quality in case of bacteria and oil encapsulations. This product quality is also compared to the conventional and industrial processes: spray drying and freeze drying. The viability and the stability of bacteria presented higher values for the electrostatic spray drying: 80% after 55 days compared to 55% for freeze drying. The oil encapsulation efficiency was also calculated for electrostatic spray drying and spray drying, and it was demonstrated that it was possible to reach 96% using this novel process. The last section presents the environment impacts of electrostatic spray drying. Working at lower temperature than spray drying, using less electricity than freeze drying and with a higher product quality, electrostatic spray drying is presented as more sustainable process.*

Keywords*: electrostatic spray drying, scale-up, life cycle assessment, thermosensitivity*

MODELLING THE DRYING OF HYDRATED AND SOLVATED ORGANIC CRYSTALS

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Abstract: *While numerous small scale experimental studies exploring the kinetics of API dehydration/desolvation exist, transfer of this information into drying models useful to industry is scarce in literature. To address this, a one-dimensional model of an agitated filter dryer that encompasses both vacuum and convective drying modes and is capable of describing the drying of hydrates/solvates has been developed. The model is based on equilibrium thermodynamics and a mass transfer resistance network that couples the transport processes within the crystal lattice (molecular scale) to axial transport in the gas phase of the bed (macro scale). Current work involves evaluating key transfer resistances (namely those internal to the crystals), as a function of solvent content and drying conditions (temperature, vacuum level, relative humidity/pressure) using literature data, and later on, our own experiments on model systems. The hope is that this work enables optimisation of drying operations on hydrate/solvate systems with greater confidence.*

MATHEMATICAL MODELLING OF CONVECTIVE DRYING OF A HETEROGENEOUS PARTICLE BED

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Abstract: *A dynamic distributed parameter model at the continuum scale for convective drying of a static particle bed has been formulated from a set differential mass and heat balances. The effect of preferential channelling of gas flow due to cracking/shrinkage of the cake is described by adjustable parameters for the channel width and distribution of gas between channel and bulk regions; these are capable of converting the cake from a homogenous to an increasingly heterogeneous entity. With increasing gas fraction residing in channels, the drying time lengthens due to relative reduction in flow through the bulk of the cake to that of the channels, causing an additional transport resistance for radial gas phase diffusion to arise. Similarly, greater channel widths also increase drying time as smaller portions of the bed are contacted by the fast moving flow.*

Keywords*: drying, mathematical modelling, heat transfer, mass transfer*

RAPID DRYING OF BIOLOGICALS AT ROOM TEMPERATURE

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Abstract: *In this study we developed a prototype of Room Temperature Aerosol Dehydration (RTAD), a scalable system for continuous rapid room-temperature dehydration of liquid pharmaceutical formulations, which provides thermal stabilization of biological drugs and eliminates the need for a cold chain. The RTAD system is based on the patented technology of ultra-fine liquid atomization into submicron (~0.2 μm for water) droplets that are 10-1,000x smaller than those generated by commercial nozzles and nebulizers. We constructed a small-scale setup (<1 g of powder) and demonstrated applicability of the technology for drying of various biologicals and small molecules, including albumin, bevacizumab, insulin, green fluorescent protein and others. The results showed no change in the secondary structure of proteins and improvement in powder dispersity compared to conventional systems. Future research will focus on scale up the production rate and establishing efficacy and reliability of RTAD as a commercially promising drying approach for various biopharmaceuticals.*

Keywords*: biologicals, droplet, drying, room temperature*

INFLUENCE OF ETHANOL PRETREATMENT ON CONVECTIVE DRYING KINETICS AND QUALITY OF PEAR (*Pyrus communis*)

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Abstract: *Nowadays, in times of energetic crisis, it is crucial to limit energy consumption. Drying is one of the most energy-consuming operations as it is a long-lasting process. Pre-treatment in alcohol enhances dehydration causing drying time reduction, and energy savings as a result. This study aimed at the pre-treatment of pear fruit in ethanol using various process variants: at atmospheric pressure (E), at vacuum (EV), and with ultrasound (EU) before convective drying (CV). The reference sample was dried only convectively. It was shown that pre-treatment in ethanol considerably reduced the drying time and energy consumption. In addition, several qualitative parameters were assessed such as total polyphenol content and antioxidant capacity, vitamin C content, and colour. It was shown that regardless of the pre-treatment process carried out, there was no meaningful loss of quality compared to fresh or convectively dried fruit.*

Keywords: *ultrasound; alcohol; vacuum; vitamin C; polyphenols; specific energy consumption*

MODELLING THE DRYING BEHAVIOUR OF SINGLE DROPLET MALTODEXTRIN IN AQUEOUS SOLUTION

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Abstract: *A diffusion based single droplet drying model in the solute-fixed coordinate system was numerically solved using a fully implicit backward finite difference scheme to predict the moisture distribution and the average temperature of the droplet during the drying process. The approach allowed for predicting the concentration gradient within the droplet and tracking the shrinkage and temperature of the droplet during the drying process. The model was applied to investigate the drying behaviour of maltodextrin droplets in an aqueous solution. The model was validated by comparing the prediction with experimental measurement and prediction from the literature, and it was found that the model predictions followed the literature data reasonably well for the moisture and average temperature profile with 4% deviation. A significant increase in solute concentration from the centre to the surface of the droplet occurs throughout the drying process, potentially resulting in non-uniformities in the final dried product. The numerical method used in this study was found to be more robust than that used previously because the model equations were resolved at each time increment (Δt = 0.01 s), resulting in more accurate and stable solutions. Therefore, this numerical method can be relied upon for providing more accurate predictions. The improved model has potential applications in industrial spray drying processes, such as in the food and pharmaceutical industry, to improve the understanding of drying behaviour and the quality of the final product while reducing the need for physical experimentation.*

Keywords*: single droplet drying, numerical simulation, spray drying*

ON THE NUMERICAL SIMULATION OF PARTICLE DEPOSITION IN SPRAY DRYERS

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Abstract: *This study involves the numerical simulation of a deposition model on a spray dryer chamber using the Eulerian-Lagrangian approach. A sticky point curve is implemented as a user-defined function in a commercial software to simulate the deposition of dried particles on the chamber walls. The steady-transient strategy with the k-ω SST turbulence model is applied to solve governing equations. The model is used to predict the deposition of skim milk powders with 8.8 wt% solid content in a pilot scale spray dryer with co-current air flow and a pressure nozzle. Particle kinetic drying is calculated using the Characteristic Drying Curve (CDC) model, and a two-way coupling algorithm is used between continuous and discrete phases. The model has been validated with an available experimental study in the cone section of the dryer, and the error analysis shows that it is able to predict the deposition model within an acceptable range.*

Keywords*: Spray drying, deposition model, numerical simulation.*

NON-DESTRUCTIVE MONITORING OF FREEZE-DRYING PROCESS OF MICROPARTICLES USING MICROWAVE RESONANCE SPECTROSCOPY

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Abstract: *We have developed a nondestructive monitoring technique for freeze-drying process using microwave resonance spectroscopy. In this presentation, we report on our attempt to apply this technique to the freeze-drying of micro-particles. Monitoring by temperature sensors is practically impossible for freeze-drying of fine particles due to the difficulty in insertion of temperature sensors, and this technique has the potential to solve this problem. We measured microwave resonance spectra during the drying of frozen micro-particles prepared by dropping them into liquid nitrogen, and found a strong correlation between the degree of drying and changes in microwave resonance spectra. It was found that the degree of drying can be predicted from the acquired spectral data.*

Keywords*: freeze-drying; microwave resonance spectroscopy; process analytical technology*

EFFECT OF SOLAR RADIATION AND FULL SPECTRUM ARTIFICIAL SUN LIGHT ON TEXTURAL PROPERTIES OF ASIAN WHITE RADISH (*RAPHANUS SATIVUS* L.)

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Abstract: *The aim of this study was to deals with the effects of a solar radiation and full spectrum artificial sun light on the ultra-structural and textural characteristics of Asian white radish (*Raphanus sativus *L.). The effect of drying was observed by the drying kinetics and drying characteristics. The independent parameters such as Moisture content, color L*, a* and b*, and water activity was observed during the drying process. The final moisture content of radish sample reduced from 94.5 % to 65.0 % wb. The textural parameters such as hardness and fracturability of radish sample was analyzed by using textural profile analyzer (TPA). The results were then compared with a commercial sample. According to the results, textural changes during dehydration were associated with light-induced ultra-structural changes. The significant importance of temperature, drying time, and solar radiation has affected on textural properties.*

Keywords*: sun drying, hardness, fracturability, texture analysis, drying improvement*

DRYING CHARACTERISTICS OF FORTIFIED CARROT POMACE BLENDED DEHYDRATED SWEET CORN PORRIDGE

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Abstract: *Maize (Zea mays L.) is popularly known as "Corn" and is one of the most popular cereals crops. The proportion of ingredients, cooking time and temperature are key factors for designing any new product based on retention of vitamins and nutrients. The different physico-chemical characteristics and sensory evaluation of different drying temperature were performed. The optimum conditions observed for development of carrot blended sweet corn halwa were 35 g of carrot pomace, 100 ml milk, 16.00 g sugar and 13 min cooking time. The final moisture content for dehydrated halwa were 6.02 to 11.58% wet basis for selected temperature range 60 to 75 °C. It can be concluded that sample dehydrated at 60°C performed better for physico-chemical parameter and sensory characteristics. The optimized dehydrated product can be stored for longer time and used after reconstitution by using water or milk.*

EVALUATION OF BIO-ACTIVE COMPOUNDS AND COLOR RETENTION IN SOLAR DRIED MEXICAN FIG: MERIT OF UV-BLUE BLOCKING FILTERS

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Abstract: *Solar drying of figs has been practiced long ago for nutritional benefits during post-harvest periods. Dried fig contains dietary fiber (9.8 g), protein (3.3 g), sugars, vitamins, minerals, and antioxidants, per 100 g; and this makes it an ideal nutritional supplement. Solar drying improves the shelf life by preventing microbial growth but may degrade some bioactive compounds, which are sensitive to sunlight. We used cellular polycarbonate carrying a UV-Blue blocking semiconductor coating of copper chalcogenide (sulphide/selenide) to investigate the drying kinetics of Mexican fig, compared with direct solar and other drying conditions to see the preservation of anthocyanin content and color as a function of the duration of drying. Differences were observed in the drying rate, color, and anthocyanins. The experimental data were fitted to 12 models to elucidate the drying kinetics. The cellular polycarbonate + UV-Blue block coating retained better the anthocyanins and the color.*

Keywords*: anthocyanin, antioxidant activity, colour, UV-blue light solar filter, secondary metabolites*

H2020 PREMIUM PROJECT: PRESERVING BACTERIA WITH OLIGOSACCHARIDES AND ECO-FRIENDLY PROCESSES

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Abstract: *The European project PREMIUM (GA n°777657) is a four-year multidisciplinary project, involving academic and industrial partners from France, Argentina, Portugal, Spain and the United Kingdom. PREMIUM aims at developing new and innovative strategies to preserve lactic acid bacteria from laboratory to industrial scale taking into account product quality, process efficiency and environmental impact.*
Innovations are developed in the field of i) protective molecules by using oligosaccharides (fructo-oligosaccharides and galacto-oligosaccharides) produced either by enzymatic synthesis or biomass hydrolysis, and ii) processes with the association of the layer-by-layer encapsulation method with different stabilization processes (freeze-drying, spray-drying).
Furthermore, the PREMIUM project generates fundamental knowledge on the understanding of the degradation and protective mechanisms following drying processes, the main focus of this presentation, and on the development of a reliable methodology to compare process alternatives based on the approach of multi-criteria analysis.

Keywords: *lactic acid bacteria, freeze-drying, spray-drying, FTIR spectroscopy, glass transition*

MECHANISTIC MODELING OF THE DRYING OF SOLIDS: STATE-OF-THE-ART AND PERSPECTIVES

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Abstract: *This keynote presentation gives an overview of a recent paper written on the occasion of the 40th anniversary of the Drying Technology Journal (Perré et al. 2023). We will discuss the historical context of the macroscopic set of coupled equations used to model drying processes, present the state-of-the-art of drying, and provide insights into its future trajectory. All aspects will be deliberately presented in a pedagogical manner with many illustrations to make the presentation accessible to young scientists. The main points addressed include:*
- The description of the comprehensive macroscopic formulation,
- An historical perspective of the progress made in computational simulation,
- The contribution of modelling in parameter characterization,
- The mechanical aspects of drying: strain and stress induced by drying, including the case of large deformations,
- The impact of non-local equilibrium,
- The promising domain of the digital twin in parameter tuning and control/command.

Keywords: *applied mathematics; machine learning; mechanics; multiphysics; multiscale; heat and mass transfer.*

USING CFD-TFM APPROACH FOR MODELLING THE PULSED FLUIDIZED BED OF REFINED STANDARD SUGAR

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Abstract: *The flow behavior of gas and particles with a horizontal pulsed gas jets in a gas-particles bubbling fluidized bed was simulated by 2D Two Fluid Model (TFM). Fluidizating processes of refined standard sugar with continuous flow, single and multiple pulsed jet flow on cross-section of the particles layer were simulated. The effect of pulse frequency on the hydrodynamics of the gas and particles was also analyzed. The results showed that the porosity of the bed and the size of the bubbles caused by the pulsed gas jets were greater than that of the continuous fluidization. For fluidizating with 1, 2 and 6 pulsed jet gas, the porosity of the bed reaches the maximum value at 0.25s, 0.5s and 1.0s, respectively. The granular material fluidizating system with pulsed gas enhances the mixing of gas-particles while reducing gas flow compared to conventional continuous fluidizating system.*

Keywords: *fluidizating, pulsed gas jets, simulation, refined standard sugar, Two Fluid Model, porosity, pulse frequency*

DIMENSIONLESS EQUATION FOR THE VOLUMETRIC HEAT TRANSFER COEFFICIENT IN FLUIDIZED BED DRYING

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Abstract: *The knowledge of the volumetric heat transfer coefficient is essential for the application of the heat and mass transfer model of fluidized bed drying. From the experimental results, a relationship between the dimensionless numbers was created in* $Nu' = f(Re, Pr, Ar, \frac{L}{d_P})$ *form by using statistical evaluation. The volumetric heat transfer coefficient for a fluidized bed dryer can be calculated by using the equation within its scope.*

Keywords*: fluidized bed drying, volumetric heat transfer coefficient, modified Nusselt number, dimensionless relationship*

SPRAY DRYING OF SLURRY DROPLETS: EFFECT OF ACOUSTIC FIELD AND GAS ABSORPTION

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Abstract: *In the present study, we developed a transient model for drying an acoustically levitated slurry droplet at the stage when solid particles have formed a wet porous agglomerate. The comprehensive model accounts for the effects of acoustic streaming, forced convection, soluble gas absorption/desorption, filtration, and compressibility of the gas-vapor mixture inside the porous crust on the intensity of the drying of the wet porous agglomerate. The model is described by a system of transient conjugate nonlinear energy and mass conservation equations using an anelastic approximation. It is shown that the presence of the active gas increases the drying rate. Also, we found that the drying time decreases with the increase of sound pressure amplitude and increases with the increase in frequency. As shown by numerical calculations, a gas mixture containing air with ammonia desorption allows the residual moisture to be reached during the drying process in a much shorter time than that in a gas mixture not having an active gas. The predictions of the developed model are in good agreement with the experimental results available in the literature. The suggested model can be considered as a basis for alternative drying technologies.*

Keywords*: slurry droplet; acoustic levitation; porous shell; heat and mass transfer*

DESIGN AND BUILT OF A SUPERHEATED STEAM DRYER WITH HEAT PUMP

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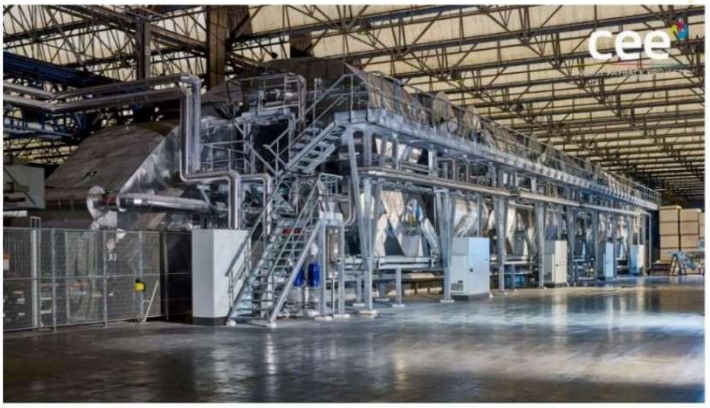
Abstract: *CEE Engineering designed and built a superheated steam dryer for manufacturing fire protection boards. The installation has a capacity of 3 t/h water evaporation over 8 processing zones, with a total thermal capacity of 3 MW . The boards are dried from 66% water down to 10%. The residual moisture content is crucial in order to achieve the fire protection characteristics. Energy efficiency and product quality were the main drivers to select superheated steam as a drying medium. The absence of air avoids unnecessary stack losses. On top of this, a 600 kW heat pump increases the efficiency by condensing the steam in the exhaust stack and upgrade and re-use the heat in the dryer. The required process conditions were developed in a custom built, board size, laboratory installation. Lab results were input to the engineering phase where the layout of the dryer and components where translated in a PFD/PID/3D model. All construction was done by CEE, including mechanicals, electricals, automation, commissioning and startup, followed by maintenance and support.*



ORGANIC ACIDS RETENTION DURING CONTINUOUS AND INTERMITTENT DRYING OF COCOA BEANS

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Abstract: *The cocoa drying operation is of great importance in the post-harvest processes. In this stage, the product is microbiologically stabilized by reducing its water activit.In addition the quality of the final product can be altered during processing, especially through the retention of organic acids that affect on the flavor. This research aimed to evaluate the drying conditions for cocoa beans, variety TCS01, under controlled operating conditions (type of drying and temperature), which allow for enhancing the quality of the beans. For this, continuous and intermittent drying experiments were considered. For both types of drying, hot air at three temperatures was used: 50°C, 60°C, 70°C, and a constant air rate of 1 m/s. Using chromatographic method the concentration of organic acids (lactic, citric, and acetic) were determined. In general terms, the intermittent drying process showed lower content of organic acids, particulary the treatment at 60°C, with better results.. The intermittent drying process the drying, time was reduced in comparison with the continuous drying process, which can be to reduce energy costs during the drying process.*

Keywords*: convective drying, flavor, organics acids, temperature effect*

DRYING WOOD BASED WASTE IN A FOUNTAIN DRYER OF OWN DESIGN AND MATHEMATICAL MODELING

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Abstract: *For drying biomass, sawdust drum and belt dryers are most often used. On the market, there are no other solutions available for industrial production. An article describes a fountain dryer adapted for drying sawdust in continuous operation. It enables a cheap and environmentally friendly way to dry sawdust intended for the production of fuel pellets. Based on the collected data, an equation describing the drying of biomass in such a device was proposed. The paper presents a mathematical model of biomass drying kinetics in a fountain dryer of its own design. The description and principle of operation of the device for drying wood-based waste intended for the production of fuel pellets are also presented. The proposed model was derived based on the collected results at the test stand. The work also compares selected mathematical models based on the proposed one. Selected equations were compared based on the previously determined Mean Absolute Percentage Error. The analysis shows that the proposed model describes the kinetics of drying with 18.53% accuracy, where in the case of equation II of Fick's law the error was 38.27%. The tests were carried out for the drying temperature ranges of 100, 125, 150, and 175°C.*

Keywords*: fountain bed dryer, sawdust drying, pellet, biomass, mathematical model*

THIN LAYER DRYING KINETICS OF CARROT (DAUCUS CAROTA) IN A NATURAL CONVECTION UV FILTER GREENHOUSE SOLAR DRYER

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Abstract: *A natural convection greenhouse solar dryer was used for drying agricultural products. The thin layer drying kinetics and dryer wall temperature with UV filter were evaluated with 5, 15, 30 and 35 kg of carrots (Daucus carota) at ambient conditions in Temixco, Morelos, Mexico. The key advantage of the UV filter is the use of solar radiation. The carrot with an average initial moisture content of 93% was dried up to 17% in the greenhouse solar dryer, under natural convection. The maximum solar irradiance was 915 W/m^2 corresponding to an ambient temperature of 30.2 °C. The roof of the drying chamber reached a maximum temperature of 90 °C and a minimum of 55 °C at 11:00 a.m. for a 5kg load. Using a greenhouse solar dryer, the average drying time of the carrot was 300 min, reducing color deterioration caused by solar irradiance.*

Keywords: *greenhouse, UV filter, solar energy, drying kinetics, natural convection*

SIMULATION OF FOOD DRYING IN A CAPE-OPEN SOFTWARE

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***Abstract**: In this study, a mathematical model of fixed-bed drying was developed and solved by the finite volume method. The model predicts micro- and macro-transfer phenomena at both the product and drying-process scales (pypi.org/project/pydrying). A user-made drying operation is integrated into DWSIM software (dwsim.org), a flowsheet environment for modeling, simulation, and optimization of steady-state and dynamic chemical processes, conforming to CAPE-OPEN standards. Our model simulates the drying of arbitrary solids, such as most solid food products. We can highlight four original contributions related to this work: (1) combining the drying process with other unit operations at the scale of a production workshop or industrial plant, (2) better estimation of streams (drying-product and drying gas) from a multiphysics modeling approach, (3) development of an accessible and open-source CAPE-OPEN drying module, and (4) simulation of the drying process with nonconventional solids.*

***Keywords**: fixed bed drying, finite-volume, flowsheeting, solid food product, DWSIM, CAPE-OPEN*

PROPERTIES OF INNOVATIVE SUGAR BEET POWDER OBTAINED BY DRYING METHOD

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Abstract: *Sugar beet is commonly used for the extraction and purification of sucrose. The resulting side stream contains the fibrous portion of the root, commonly known as sugar beet pulp, and it is mostly used for animal feed and, in some cases, it is purified further for food applications. However, most of the sugar beet derived food products available on the market have a somewhat dark colour, earthy flavour notes, and a gritty mouthfeel, which limits their use in many food products. Within the current research, a sugar beet powder that contains the same sugar/fiber ratio as the raw material and with improved colour, flavour, and mouthfeel properties can be produced. Through a well-controlled heat treatment, a product that maintains the neutral colour of the sugar beet can be obtained, due to the inactivation of the enzyme responsible of browning oxidation. Furthermore, the heat treatment significantly decreases the earthly notes of the sugar beet. Due to the high-water holding capacity of the present fibers, roller drying technology is used to efficiently evaporate the water bond to the fibrous matrix without caramelizing the present sugar and while preserving the well integration of the fibers and the sugars, which provides higher stability against caking. The produced ingredient therefore can be used as a more nutritious sweetener compared to refined sucrose. Furthermore, the soluble fibers of the ingredient build up the viscosity of the liquid solution when dissolved, also enabling its use as a bulking agent.*

Keywords*: sugar beet, sugar beet pulp, enzyme deactivation, pulp drying*

ULTRASOUND-ASSISTED ATMOSPHERIC FREEZE DRYING FOR LOW TEMPERATURE DRYING APPLICATIONS

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Abstract: *A new ultrasonic design based on the indirect transmission of ultrasonic energy from the ultrasound emitter through to the material to be dried was developed and investigated to assist in atmospheric freeze drying of materials. The application of the improved ultrasonic design tested in this work was found to significantly reduce the energy consumption by up to 40% with similar retention of key product quality attributes compared to the standard vacuum freeze drying. This offers a promising approach towards a better applicability of ultrasound in industrial drying operation, since no direct contact between the sample and the ultrasonic emitter is needed. This presentation will discuss the development and evaluation of the new patented ultrasonic design for application to intensify atmospheric freeze drying of materials.*

Keywords*: ultrasound-assisted; atmospheric freeze drying; freeze drying; energy consumption; product quality*

NON-DESTRUCTIVE MONITORING OF DRY-SALTING OF BEEF LOINS USING ULTRASONIC TECHNIQUES

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Abstract: *Salting is a traditional preservation process for meat and meat products. During salting, water activity depletion is dually linked to both salt gain and dehydration. However, most of the current conventional methods for industrial control of salt and moisture content on meat products are time-consuming and destructive. Thus, the aim of this work was to evaluate the feasibility of non-contact ultrasound technique (0.3 MHz) to monitor the moisture content of beef steaks during dry-salting compared with the conventional contact ultrasound technique (1 MHz). For that purpose, beef steaks were dry-salting at different salting times (0, 1, 4, 8 and 24 hours) to reach different salt and moisture content. At each salting time, ultrasonic measurements were carried out by both techniques followed by physicochemical analysis: moisture and salt content and texture (stress-relaxation test). Experimental results showed that the moisture content of beef steaks was reduced from 73.5 % (w.b.) to 56.1 % (w.b.). As salting progressed, beef steaks became more elastic and increased their stiffness. The moisture content of beef steaks was satisfactorily described by both ultrasound techniques: non-contact ultrasound (R^2=0.95) and contact ultrasound (R^2=0.93). Experimental results showed the feasibility of non-contact ultrasound as a non-destructive technique for real-time moisture control at the industrial level.*

Keywords*: ultrasound, dry-salting, beef, non-destructive, moisture content*

THERMAL EFFECT OF AIRBORNE ULTRASOUND APPLICATION DURING PORK LIVER DRYING

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Abstract: *Efficient utilization of animal by-products, such as pork liver, may require a prior stage of dehydration, which demands a large amount of energy and time. In this sense, the aim of this study was to analyze the thermal effect due to airborne ultrasound application on hot air drying of pork liver. For that purpose, drying experiments were carried out at 40 and 60 °C on pork liver cylinders at 2 $m \cdot s^{-1}$ without (AIR) and with (US) ultrasonic application. Thus, the application of ultrasound shortened the drying time by up to 30 % at 40 °C, while at 60 °C its effect was of lesser magnitude. When ultrasound was applied, an increase in both the sample and air flow temperature of approximately 4.5 and 2.5 °C respectively, was found. This fact partially contributes to explain the increase in the drying rate.*

Keywords*: meat by-products; dehydration; meat protein; novel technologies; airborne ultrasound transmission*

MATHEMATICAL MODELLING OF COMBINED MICROWAVE-VACUUM DRYING OF BLACK PEPPER (*PIPER NIGRUM*) PRETREATED WITH STEAM

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Abstract: *Black Pepper (Piper nigrum) is often dried using conventional drying methods that have low drying rates and takes a long time which affects its organoleptic properties. Microwave vacuum drying is advantageous over traditional methods as it enables faster drying rates along with better preservation of physicochemical and sensory properties. The present study evaluates a rapid drying method using microwave and vacuum and its effect on the quality characteristics of pepper. Samples were dried using different microwave power densities (1-5 W/g), and steam time (0-15 s) for different times (70-150 s). Different models such as Page model, Newton, Henderson and Pabis, wang and Singh etc. were also developed and compared for their best fit. Quality and physico-chemical analysis were carried out and correlation with independent variables was studied. Optimization was carried out to find out the best combination with the best quality and physicochemical properties.*

Keywords*: drying kinetics and models, piperine content, antioxidant activity, moisture diffusivity, Biot number*

DIGITALISED STRATEGIES FOR PRODUCT DEVELOPMENT AND OPTIMISATION OF COMMERCIAL SCALE SPRAY DRYING

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Abstract: *Digitalization is a term we hear often, in many contexts and in many industries. That's not surprising when we consider that digitalization is a process – the process of using digital technologies to transform the tools and practices we use.*

In Process development and commercial spray drying, the tools and philosophies have (in general) changed little. These are centered on the use of DoE, scale-up, commercial scale trials and the use of single loop PID control of key process parameters.

In this paper we look at some of the tools and the application of more advanced strategies. Some of these are "borrowed" from other process industries, where they have been around for many years and in that time have proven transformational in delivering improved process performance. In particular, we look at optimized experimental design, machine learning and application of data driven models for optimization.

ANALYSIS OF MALTODEXTRIN AND COFFEE POWDER PROPERTIES PRODUCED BY FLAME SPRAY DRYING PROCESS

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Abstract: *In the last years energy security issues connected with the threat of fossil fuels supply disruption became at the high concerns in Europe. Additional challenges faced by energy sector such as increasing energy prices, scarcity of conventional non-renewable energy sources as well as obstacles generated by climate change open the possibility for development and introduction of new technologies. Since drying processes consumes large amounts of energy in the industrial sector, the elaboration of novel energy efficient drying processes is at high priority.*

To meet this demand our research group at Lodz University of Technology developed new Flame Spray Drying (FSD) method, where energy is generated in spray atomization zone via combustion of liquid fuel coming from renewable energy sources.

The paper presents the experimental analysis of the reconstitution properties of powders: maltodextrin and instant coffee. Before the analysis the substances were dried by standard spray drying (SSD) method or FSD. Drying test were performed in co-current pilot-plant spray drying tower which may operate at both modes, FSD and SSD. In standard spray drying method drying air is heated up by the electric heater, whereas for FSD process, air heaters are shut off, air is supplied at the ambient temperature, sprayed stream is igniter by electrodes.

During FSD and SSD tests following process parameters were applied: atomization pressure from 0.3 to 6.2 bars, feed flow rate 5.5, 7 and 10 kg/h, feed temperature 30 and 70°C, air flow rate from 250 to 480 Nm3/h. During the analyses, the influence of the applied drying parameters on the analysed properties was also estimated.

Analysis of the results showed that the applied drying method affects the final powder properties. For FSD wettability of maltodextrin particles was 380 ± 68 s, whereas after SSD wettability time of powders was lower 149 ± 24 s. There were significant differences (p=0.05) observed between drying methods for both, wettability, and solubility. Longer time in wettability test for powder obtained after FSD comparing to SSD may be explained by significantly lower bulk density of maltodextrin powders after FSD. On the

other hand, the solubility of maltodextrin particles obtained via FSD were enhanced (124 ± 14 s) comparing to particles after SSD (195 ± 21 s) due to specific particles morphology, i.e., agglomerated and puffed particles. After FSD maltodextrin powders were difficult to wet, however once particles fall below the water surface, they dissolve quickly.
Analysing maltodextrin powders dried with the flame method, a significant influence of the atomization pressure and particle size on the wettability parameter was found. In the case of solubility, these relationships were not observed.
For instant coffee powder no significant differences were observed between initial product – granulated instant coffee and powder produced by FSD method in terms of powder reconstitution.

***Keywords**: flame spray drying, instant coffee, wettability, solubility*

ULTRASOUND ASSISTED DRYING OF FERMENTED BEETROOT CHIPS: DRYING KINETICS AND QUALITY OF DRIED CHIPS

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Abstract: *Ultrasound is an interesting technique which can be used for supporting hot air convective drying (HACD) and low-temperature drying (LTD) to shorten drying time or/and improve the quality of dried material. The aim of this study was to investigate the effect of ultrasound (US) on HACD and LTD drying kinetics, bioactive compounds, antioxidant activity, color and surface structure of dried fermented beetroot chips. HACD and LTD of fermented beetroot slices were conducted at temperatures of 80 and −10°C, respectively. Both drying methods were studied with and without ultrasound application. During HACD+US and LTD+US the US were applicated constantly and the US power was set at 200W. The results of the study are very promising and fill the gap of knowledge related to the influence of US on the HACD and LTD drying kinetics and physicochemical properties of fermented beetroot chips.*
Acknowledgements:
This study was supported by the Polish National Science Center (grant No. 2020/37/B/NZ9/00687, title: The effect of ultrasound, microwaves, infrared radiation and reduced pressure on the dehydration and drying kinetics of beetroots and the University of Warmia and Mazury in Olsztyn (grant No. 16.610.001-110)."

Keywords*: low-temperature drying, hot air convective drying, bioactive compounds, color*

PROBABILISTIC OPTIMIZATION OF INDUSTRIAL WOOD DRING CONSIDERING ENERGY CONSUMPTION, PROCESS DURATION AND QUALITY

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Abstract: *Drying is the most energy consuming process in the industrial transformation of wood. The current energy and climate crisis makes it imperative to improve wood drying schedules in order to reduce energy consumption and adapt to energy availability/cost, in terms of quantity and temperature level. The drying schedules, however, have been developed from practice in an attempt to achieve good drying quality in a short time, under the assumption of cheap and abundant energy. The drying conditions have been adapted to the specific characteristics of the species, the board dimensions and the kiln specifications. The present work proposes the use of a mechanistic drying model as a predictive tool to adapt conditions to specific situations. A multiscale computational model, Multi_Wood_DryS, which simulates the drying of an entire stack of boards and computes the energy consumption was combined with a probabilistic optimization code. This combination of computer tools is able to propose tailor-made drying schedules that meet operators' expectations in terms of energy consumption, quality, cost, and drying time. An example of optimization of drying schedule of oak and beech wood is proposed. The optimized schedule would allow energy savings of the order of 3 to 8 %, which is unfortunately limited. However, the resulting metamodel is a first step towards an intelligent controller, which will be more efficient, if not the only way, in the case of intermittent energy.*

Keywords*: probabilistic optimization; wood drying; numerical simulation; energy consumption; drying quality*

MODELLING OF A FOUNTAIN BED DRYER FOR MAXIMISING ITS DRYING EFFICIENCY

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Abstract: *The drying efficiency of current industrial dryers is low due to the poor heat and mass transfer rates. Therefore, fountain bed dryers have been recently proposed as an alternative to the current technologies for the drying of sawdust of various morphologies. Previous studies have approached the optimization of the operating conditions in fountain bed dryers. Thus, bright colour sawdust with low moisture content was obtained when air inlet temperatures of 150 – 175 ºC were used. However, the effect of the geometry of fountain bed dryers on the drying efficiency has not been approached to date. Accordingly, a model based on unsteady state heat and mass balances is proposed in this paper. It has been validated by comparing the simulated values and those obtained experimentally. The results show that the angle of the cone is an influential parameter, as it may modify the gas-solid contact in the dryer.*

Keywords*: fountain bed dryer, sawdust drying, cone angle effect, simulation, heat and mass transfer*

ULTRASOUND-ASSISTED VACUUM IMPREGNATION OF FRUIT WITH VITAMIN C FOLLOWED BY DRYING PROCESS

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Abstract: *One of the most emerging pre-treatments in food technology is vacuum impregnation (VI). This technique allows for enriching any product with additional, valuable ingredients such as vitamins and minerals, improving the quality, stability, and sensory properties. Intensification of VI by ultrasound (US) is based on the phenomenon of cavitation, which allows more efficient mass exchange, altering the structure, aimed at increasing the pore-space capacity in which the impregnation takes place. The efficiency of VI in different stages was evaluated based on ascorbic acid content introduced into the apple tissue from the solution. The aim was also to find the optimal drying method for the impregnated product. VI combined with US increased vitamin C content and allowed the ingredient to be well retained in dry fruit. However, the final product quality depended on the stage of VI enhanced with US as well as the drying method used.*

Keywords*: ascorbic acid content; food preservation; apple; water activity; colour change, browning index*

CONVECTIVE DRYING OF POTATO PRE-TREATED WITH ULTRASOUND-ASSISTED VACUUM IMPREGNATION: PROCESS KINETICS AND PRODUCTS QUALITY

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Abstract: *Vacuum impregnation (VI) allows an introduction of the water-soluble compound (e.g., vitamins) into the porous matrix of the food material. In this way, the properties of raw materials may be changed and the value of food may be increased – the production of functional foods. Unfortunately, impregnated samples are prone to spoilage because of very high-water activity, thus requiring preservation, e.g., by drying. During the preservation procedure, some of the introduced compounds may be lost. The aim of this research was to assess how drying influences the content of the marker bioactive compound - ascorbic acid. The material was impregnated under different conditions (regular and optimal according to response surface methodology) and dried convectively. In addition to the ascorbic acid content, other quality parameters such as colour, water activity, and rehydration ratio were evaluated. The drying kinetics was also assessed. Obtained results revealed that drying affects the amount of introduced during VI marker compound. Deep impregnation of the material tissue at low pressure (5 kPa) allows high preservation of the active component in the dried samples (loss c.a. 15%). Superficial impregnation at higher pressure (30 or 55 kPa) leads to a significant loss of the marker during drying (loss, c.a. 50-70%). The negative effect of impregnation on other quality parameters of dried products or drying kinetics was not stated. The application of ultrasound during impregnation visibly affects the effectiveness of VI, but regrettably did not notably influence the drying kinetics. However, some changes induced by ultrasounds in the quality parameters of dried products were observed.*

Keywords*: Solanum tuberosum, colour, vitamin C, water activity, rehydration ratio, ion leakage*

DRYING WOODY BIOMASS IN AIR ATMOSPHERE USING "ROLLING-BED" PILOT SCALE DRYER AS PRE-PROCESS FOR SUPERHEATED STEAM TORREFACTION PROCESS – KINETICS AND EFFICIENCY

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Abstract: *In this work a kinetics of biomass drying process and efficiency of biomass dryer "rolling-bed" type of woody biomass drying process were conducted. In pilot scale dryer with 50 kg/h capacity an wood chips have beend dryed in order to get 10% of moisture content as a entrance conditions for main process – superheated steam torrefaction process in counter-flow horizontal reactor. In order to conduct an energy effective thermo-chemical process which is torrefaction a pre-process which is drying process need to be apply. In our research we have design a "rolling-bed" biomass dryer working in air atmosphere which was heated additionally from waste heat from superheated steam torrefaction process recovered in special designed scrubber. In addition a optimal working conditions for dryer were established in order to obtain the most economical process.*

Keywords*: rolling-bed dryer, woody biomass; biocarbon; kinetics, efficiency*

MONITORING THE HOT AIR-DRYING PROCESS OF TURNIP SLICES USING COMPUTER VISION TECHNOLOGY

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Abstract: *In this study, we investigated the drying of turnip slices through the use of computer vision as a tool in drying monitoring. Samples were subjected to several temperatures (40, 45 and 50 °C) up to a moisture content (dry basis) of 0.19 g/g. Prediction models for changes in moisture content were created and encouraging results were achieved. Based on the results, it is possible to assist hot-air-drying by a computer vision, which allows to precisely measure the area of shrinkage of product slices, and then to predict changes in moisture content of turnip slices. The practical implication of this study is that modelling the data acquired during drying through computer vision can provide useful information concerning the drying kinetics of product. In overall, the proposed method aims to develop a smart dryer to provide high final product quality.*

Keywords: *turnip drying, drying kinetics, computer vision, hot air-drying, moisture content*

THE EFFECT OF PEF TREATMENT AND ULTRASOUND ASSITED DRYING ON THE CHOSEN PHISICAL PROPERTIES OF APPLE TISSUE

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Abstract: *Recently, non-thermal techniques aimed at the enhancement of the drying process are investigated. Some of them can be applied only before drying (e.g. pulsed electric field – PEF) whereas the others can be applied both before and during drying (e.g. ultrasound - US). The aim of this study was to determine the impact of PEF pretreatment combined with US-convective drying on the drying kinetics, the chosen physical properties and the microstructure of apples.*
The specific energy input of PEF was 1, 3.5 and 6 kJ/kg, whereas the US power was 120, 160, 200 W. Water activity below 0.6 was achieved for all dried samples. PEF at 3.5 kJ/kg contributed significantly to shortening of the drying time, reducing the loss of soluble solids during rehydration and minimising the total color difference in comparison to the fresh apple. The photos taken with scanning electron microscopy have shown the differences in the tissue microstructure.

Keywords*: apples, PEF treatment, ultrasound assisted drying, physical properties*

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EFFECT OF THE SPRAY DRYING CONDITIONS IN THE MICROENCAPSULATION OF OIL USING ORANGE BY-PRODUCTS

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Abstract: *This research evaluates the effects of the spray drying conditions (air inlet temperature and emulsion flow rate) on the yield powder, microencapsulation efficiency and oxidative stability of the oil encapsulated from an o/w emulsion enriched with orange by-product flour (OBF). Emulsions, prepared with 2.4% w/w OBF, soy proteins (0.3%), maltodextrin (33.3%) and 4% sunflower oil, were spray-dried (Buchi B-290) at two air inlet temperatures (135 and 155 ºC) and emulsion flow rates (0.32 and 0.48 kg/h) with fixed aspiration and atomization air flow (31.5 and 0.83 m^3/h, respectively). When drying at 135 ºC, the collector and total yields (including chamber) decreased from 34 to 28% and from 84 to 56%, respectively, as the emulsion flow rate increased ($p<0.05$), although the powder's water activity was lower at the highest emulsion flow rate. This suggests that at the highest emulsion flow rate, only very dry powder got to the collector and the humid one stuck to the chamber walls. Collector and total yields were not affected by the emulsion flow rate when drying at 155 ºC (average 30 ± 1 and 73 ± 3%, respectively). Oil oxidation (as measured by specific UV-vis absorbance at 234 nm) before drying (2.3) did not increase after drying at the lowest emulsion flow rate but increased by 47-24% at the highest one. These parameters did not affect the encapsulation efficiency (average 73 ± 2%). These results indicate that orange by-products could be useful in the microencapsulation of lipophilic compounds, but both the yield and the oxidative stability of the oil depend on the drying conditions.*

Keywords*: spray drying; microencapsulation; by-products; emulsions*

INVESTIGATION ON NOZZLE ZONE AGGLOMERATION DURING SPRAY DRYING USING RESPONSE SURFACE METHODOLOGY

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Abstract: *Spray drying (SD) is a popular method for transforming liquids into shelf-stable powders. The functional properties of these powders are largely affected by the agglomeration during SD. However, optimization of agglomeration is currently done through trial and error, resulting in material losses and high energy consumption. To promote more sustainable drying processes, a better understanding of how to steer nozzle zone agglomeration during SD is necessary. In this paper, we present a systematic investigation of how SD processing conditions affect the onset of nozzle zone agglomeration using response surface methodology. A central composite trial design was used to vary the drying air temperature, mass flowrate of the dry fines, and mass flowrate of the drying air on a pilot-scale spray dryer with maltodextrin DE 21 while dosing dry fine particles in the nozzle zone. The size enlargement in the resulting powders was quantified using the Agglomeration Index (AI). Results showed that the mass flowrate of the dry particles had the most significant effect on the AI, with higher flowrates increasing the AI by increasing the collision probability. Additionally, lower drying air temperature and flowrate led to higher AI values due to their effects on the sticking probability, which could be combined by calculating the supplied thermal power. A lower drying air flowrate also increased the collision probability. The gained insights into the effects of processing conditions on agglomeration can be used for steering agglomeration to move away from the current trial-and-error approach and optimize energy efficiency.*

Keywords*: spray drying; agglomeration; response surface methodology; pilot-scale*

EXPERIMENTAL SETUP FOR MEASURING DRYING OF MOLDED FIBER UNDER NEAR AIRLESS CONDITIONS

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Abstract: *In order to apply heat pumps effectively in the drying of molded fiber and thereby greatly reducing its carbon footprint, a significant increase in absolute humidity levels is required. This allows to remove the latent heat at higher temperature levels which reduces both CAPEX and OPEX of the heat pump. This paper shows the impact of high humidity levels on the drying of molded fiber by conducting drying experiments over a range of air conditions such as flowrate, temperature and humidity. The results indicate humidity has a limited effect on the drying rate whilst the conditions do favour the application of heat pump-based drying of molded fiber.*

Keywords*: molded fiber, airless drying, energy efficiency*

HEAT TRANSFER COEFFICIENT FOR WATER EVAPORATION

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Abstract: *In the case of air flowing over an evaporating surface, the heat transfer coefficient will be greater than for pure heat transfer. The aim of our research was to investigate the heat fluxes generated by the evaporation of water in a heated vessel and to determine the heat transfer coefficients for the evaporation process. The phenomenon of evaporation was grouped according to the occurring heat flows. Measurements were carried out for water evaporation at the same air velocity, at different liquid and air temperatures, so three different cases were examined. It can be established that, for the same air temperature, as the water temperature is increased, the heating increases. If the air temperature is increased while maintaining the same water temperature, the heating demand decreases. The higher the temperature difference between the fluid and the environment, the higher the heat loss. The heat flux removed by evaporation increases as the air and liquid temperatures increase. It can be observed that the heat transfer coefficient between air and water surface takes a higher value than the heat transfer coefficient determined for the flat solid plate, so the simultaneous heat and mass transfer is more intense than the heat transfer alone.*

Keywords*: evaporation, heat transfer coefficient, evaporation rate, cases of evaporation*

UNRAVELLING THE INFLUENCE OF CONVECTIVE DRYING ON THE QUALITY OF CABBAGE SEEDS

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Abstract: *Drying seeds is a common step during processing of high-quality seeds. It enables storage by stopping germination after wet treatments such as priming and by reducing moisture content, so that microbial growth is prevented and deterioration is slowed. At present, only limited knowledge is available on how drying affects seed quality, and mostly slow and mild drying processes are applied. This study provides further data on how drying affects seed quality to improve seed drying efficiency in the future without compromising on quality. Therefore, a drying set-up was developed and modified to dry seeds under highly controlled conditions and to measure weight and temperature of seeds in-line. The temperature and relative humidity of the drying air was varied in each trial, while the air velocity and drying time were kept constant. After drying, germination quality and speed were determined via germination tests on paper. Little or no effect of drying conditions on overall germination quality was detected probably because drying damage is detectable only after a certain time of storage. However, we observed that higher temperatures reduced germination speed by up to 0.5 days, which is a relevant difference for seed germination. Temperature explained 88% of the variation in germination speed ($p = 0.0002$). Based on these results, drying at a temperature below 35 °C and above 20% relative humidity is recommended. To substantiate the findings, germination tests after storage as well as more replicates for trials with an exceptionally high standard deviation are required. Promising follow-up research would be developing a pre-indication test and a model to more easily predict the effect of drying.*

Keywords*: Brassica seeds; seed drying; drying conditions; seed quality; germination; germination speed*

LATENT HEAT RECOVERY IN CONVECTIVE DRYERS BY A SEMI-CLOSED LOOP ZEOLITE ADSORPTION/DESORPTION CYCLE

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Abstract: *In the Dairy Industry, spray drying is a core technology used to produce a wide variety of powdered ingredients and consumer products. Convective water evaporation is a high energy demanding process, and as such one of the largest contributors to the carbon footprint in Dairy production facilities.*
A breakthrough innovation is necessary to enable a step change in the energy use of spray dryers. Here we propose a heat pump that can recover both the sensible and latent heat from the dryer outlet air.
The solution to a latent heat pump on spray dryers is not evident due to the large temperature difference between ingoing and outgoing air. We present a zeolite adsorption/desorption based heat pump that has potential to save ca. 50% energy in our dairy spray drying processes. The crux of this solution lies in optimization of outlet air bleed to inlet air feed ratio.

Keywords*: heat pump, latent heat, heat recovery, spray drying, dairy, zeolite, adsorption, desorption, steam*

PORE NETWORK SIMULATION OF HEAT AND MASS TRANSFER DURING FREEZE-DRYING OF POROUS MEDIA

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Abstract: *Freeze-drying is investigated based on a pore network (PN) model that incorporates transient heat transfer with coupled mass transfer in the transient regime between molecular diffusion and viscous flow. Simulations were carried out using two idealized 3D square lattices of size 150 x 150 x 135 (length x width x height) μm^3 with periodic boundary conditions and similar porosity. The major difference between the two PNs concerns their pore size distributions (PSD), which are realized so as to compare two situations: i) a narrow PSD and ii) a broad PSD. The boundary conditions of the simulations are P = 10 Pa and T = -42°C at the open top side of the PNs as well as T = - 18°C at the contact interface of the PN with the shelf (bottom side). The simulation results indicate that the overall drying behaviour is very similar in both cases. But, due to the variation of the PSD, the PN with overall larger pores shows a significant widening of the sublimation front, which is much less pronounced in the PN with the narrow PSD. This is an important finding which highlights the capability of the discrete approach to study local, i.e. pore scale, effects.*

Keywords*: pore network simulation, heat and mass transfer, freeze drying, X-ray tomography*

EFFECT OF PHASE CHANGE CAPSULE AS CARRIER PARTICLES ON SPRAY-FREEZING DRYING PROCESS

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Abstract: *Spray freeze drying is a new and advanced particle preparation technology, the powder produced by spray freeze-drying has rich pore structure, good fluidity, and can retain biological activity. However, due to the need to maintain vacuum and low temperature environment during the drying process, spray freeze drying technology leads to limited heat and mass transfer driving force of materials, affecting drying efficiency, high energy consumption and high cost. In order to improve the drying efficiency of the spray freeze drying device to shorten the drying time and achieve the purpose of saving electricity consumption, paraffin/polymethyl methacrylate (PMMA) phase change microcapsules were prepared by suspension polymerization with paraffin wax as the core material and methyl methacrylate (MMA) as the wall material. This study aims to prepare phase change microcapsules with high encapsulation efficiency, good heat storage performance and can be used as inert particles for spray-freeze drying device by suspension polymerization. The functional groups were qualitatively analysed by Fourier infrared spectroscopy absorber, the thermal conductivity of phase change microcapsules was determined by laser thermal conductivity, and the latent heat of phase change microcapsules was determined by DSC, and the thermal conductivity and differential scanning calorimetry showed that the heat storage performance of microcapsules was good, and the latent heat of phase change was as high as 179.7J/g. In addition, the characterization thermal stability and reusability of phase change microcapsules were determined using thermogravimetric analysis and leak testing. The above studies show that paraffin/PMMA phase change microcapsules can be used as inert particles in spray freeze drying equipment, and the drying efficiency can be increased by 36.6% after being put into spray freeze drying equipment as inert carrier particles.*

Keywords*: inert particles; phase change microcapsules; phase change materials; spray freeze drying*

EHD AUGMENTED INFRARED DRYING OF COURGETTE

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Abstract: *The purpose of the present study was to evaluate the EHD drying as a potential method for dehydration of courgette, to investigate the effects of temperature and electric field strength on process kinetics, color, water activity and rehydration ratio, and to select the most suitable drying conditions. Dehydration of courgette was carried out with different combinations of temperature (40°C, 56°C, 70°C) and electric field strength (5 μA, 10 μA and 15 μA). Effects of EHD method were studied and compared to results of infrared drying. Application of EHD drying resulted in improved process kinetics. Rate of drying increased with rising the electric field strength in dehydration at 56°C, opposed to processing at 40°C, where 15 μA slowed down the drying rate comparing to 10 μA, and at 70°C, where differences in process kinetics between processing with 5 μA and 10 μA were insignificant. EHD augmented drying contributed to reduced color degradation observed as higher brightness of product. After processing at 56°C, samples were the brighter the stronger electric field was used, indicating its positive effect. Dehydration at 56°C, 10 μA contributed to the least changed color with reference to raw material, while process conditions of 70°C, 10 μA led to its greatest alteration.*

Water activity of EHD-dried product was in most cases higher and increased with elevating the electric field strength in drying at 40°C. Average aw of samples dehydrated at lower temperatures was much higher comparing to samples processed at 70°C, however, all products had aw below 0.6 which is acceptable for dried fruits and vegetables.

Application of EHD drying improved rehydration ratio of dehydrated courgette. Enhanced electric field caused gradual increase of RR in material dried at 56°C and decrease when it was dried at 70°C. EHD augmentation of infrared drying was proved to enhance process kinetics and improve some properties of dried courgette. The best results were obtained for process conditions of 56°C, 10-15 μA. EHD drying is a promising method which should be further investigated for industrial use.

Keywords*: electrohydrodynamic (EHD) drying; infrared drying; courgette; drying rate; color; water activity; rehydration ratio*

STRUCTURAL EFFECTS OF PHASE TRANSITIONS IN THE DRYING OF ACOUSTICALLY LEVITATED SURFACTANTS DROPLETS

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Abstract: *The drying of surfactants has been examined to show the structural development of liquid crystal phases within the process. Initial phase diagrams were created with relation to temperature and concentration, using cross polarized microscopy and small angle x-ray scattering, for both sodium dodecyl sulfate and a commercial surfactant system. Acoustically levitated droplets of these surfactants were prepared at varying concentrations, then studied using cross polarized microscopy to see the development of phase changes. The impact of changes in surface concentration were observed as the development of a crust formation takes place. The drying curves were then created using image processing software and compared to show the effect of this structure on the drying rate. The morphology of the dried droplets was studied and compared to note any effect of changes in concentrations and temperatures in the drying process.*

Keywords*: surfactant, drying, phase transformations, cross polarized microscopy, small angle x-ray scattering*

SENSORY QUALITY OF AN OSMO-DEHYDRATED ORANGE SUBJECTED TO DIFFERENT OSMOTIC SOLUTIONS

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Abstract: *The growing interest in high-quality food leads to looking for new solutions in the production of natural fruit snacks. The aim of the study was to evaluate the sensory quality of oranges slices subjected to osmotic dehydration and convective drying. The different solutions (xylitol solution, rosehip juice with the addition of trehalose, molasses, and sucrose as standard solution) for the osmotic dehydration process were used. The sensory characteristics, color, and visual appearance of the snack were assessed.*

The xylitol solution was the best in terms of organoleptic evaluation from among the unconventional solutions used in the study. The overall quality of the orange dehydrated in this solution was rated the highest in relation to other solutions, it was also higher than the evaluation of the orange dehydrated using a sucrose solution. Moreover, the results obtained by this orange were the closest to those of the fresh orange.

Keywords*: orange, osmotic dehydration, convective drying, organoleptic assessment, color*

Acknowledgment: *This project has received funding from transnational funding bodies, partners of the H2020 ERA-NETs SUSFOOD2 and CORE Organic Cofunds, under the Joint SUSFOOD2/CORE Organic Call 2019 (MILDSUSFRUIT) as well as National Centre for Research and Development (POLAND, decision DWM/SF-CO/31/2021).*

EXPERIMENTAL STUDY ON PULSE COMBUSTION SPRAY DRYING OF VARIOUS LIQUID MATERIALS

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Abstract: *Compared with traditional spray drying, pulse combustion(PC) offers merits such as short drying time, high energy efficiency and high product quality, low pollution emssions, etc. White due to the difficulty on design of pulse combustor, PC spray drying is not widely applied in indutry. This paper aims to develop a laboratory scale PC spray drying unit, which consisted of a 16 KW Helholtz type pulse combustor, a horizontal drying room, a cyclone. After trial-error testing, the unit works steadily and its operation parameters such as pulse frequency and amplitude, flue gas temperature, were measured. Selected liquid materials such as milk, soybean, NaCl, LiH2PO4 solutions, etc were dried using this unit and the product quality was reported. The drying performance were based on the obtained experimental results.*

Keywords: *pulse cobmustion, spray drying, energy efficiency, product quality*

FREEZE-DRYING PROCESS OF Ni/Y_2O_3 NANOCOMPOSITE PROCESSED BY ULTRASONIC SPRAY PYROLYSIS

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Abstract: *The research work includes the synthesis process of Ni/Y_2O_3 nano-composite by ultrasonic spray pyrolysis and freeze-drying, a study of the influence of technological parameters on the composition of nano-composite particles and the influence of the stabiliser on the drying process. The effect of the concentration of the starting materials yttrium and nickel nitrate under unchanged process conditions on the chemical composition and particle size of the nano-composite was investigated. It was found that the increased concentration of stabiliser in ultrasonic spray pyrolysis resulted in a more homogeneous distribution of nano-composite particles in the final dried material. The increase of stabiliser concentration affects longer drying time in the freeze-drying process, as experiments confirmed that the suspension of nano-composite particles dries much faster at a lower stabiliser concentration. The lowest stabiliser concentration was chosen so that the material would not be lost during the freeze-drying process.*

SPRAY DRYING OF BIOPOLYMER SINGLE DROPLET

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Abstract: *The spray drying technique is suitable for different kinds of liquid dispersions and can be easily optimized to produce solid particles with tailored properties. The spray drying technique is a complex process. To better understand the effect of drying process variables on the dried particle formation, it is essential to observe the drying of single droplets. Fundamental processes such as mass and heat transfer can then be easily monitored and compared with theoretical models. Acoustic levitation enables droplet/particle suspension in the air without any mechanical contact. Experiments in the acoustic levitator can be used to mimic the drying process in the spray dryer. The size evolution of the droplet/particle, and moisture content during the drying were modeled using the Reaction Engineering Approach (REA). This model can be implemented in the large-scale modeling of spray drying using Computational Fluid Dynamics (CFD).*

SPRAY FREEZE DRYING ; DYNAMIC DRYING SILO ; DISCRETE ELEMENT METHOD ; ANALOGUE SIMULATION

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Abstract: *In order to improve the drying efficiency of materials in the spray freeze drying process, and to design large-scale industrialization spray freeze drying equipment. A dynamic drying silo suitable for spray freeze drying was proposed, and a dynamic drying silo and material simulation model were constructed in this study. Discrete Element Method (DEM) was used to simulate the dynamic drying process of materials in different size drying bins. Small size (130 Φ75mm) drying silo are compared with the experimental results, the dispersion state of material obtained from simulation and experiment is basically consistent, and the relative error of discharge rate is 0.31%.The structure and process parameters of large size drying silo (2600Φ1500mm) were simulated, the simulation results indicate that when the rake angle of the board in the drying bin is 5 °, the number is 18, and the rotation speed is 33 r/min, the material dispersion uniformity in the drying bin is the highest, 94%; When the bending radian of the discharge blade is 7 π/36 and the rotation speed is 25 r/min, the discharge rate reaches the maximum, which is 2.25 kg/s.*

Keywords: *spray freeze drying, dynamic drying silo, discrete element method, analogue simulation*

DRYING KINETICS OF MOLDED PULP PRODUCT WITH MICROWAVE DRYING TECHNOLOGY

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Abstract: *With the purpose of improving molded pulp product (MPP) drying process, the present work investigated the microwave drying performance of MPP under the power level of 500 W and compared that with the convective drying method. The drying kinetics, effective moisture diffusivity, and energy consumption of the two drying methods were evaluated respectively. It was found that the drying time was shortened from 22.0 min for convective drying to 16.0 min for microwave drying due to 27% of drying rate enhancement, the effective moisture diffusivity was increased from* 3.01×10^{-10} *to* 4.49×10^{-10} m^2/s, *and 88% of energy consumption could be saved by microwave drying technology. Artificial neural network (ANN) was employed to predict the moisture removing kinetics of MPP. Results revealed that the ANN modeling could be used to predict the drying kinetics of MPP effectively and then determine the moisture content in the drying process.*

Keywords*: molded pulp product, drying kinetics, microwave drying, energy consumption*