Literature Resources on Superheated Steam Drying

Preface

This e- book is compiled to help potential readers from academia and industry to readily access recent literature on superheated steam drying of a wide diversity of products. Although proposed over a century ago in a German book published in 1898, this technology has seen limited market penetration despite numerous advantages it offers in terms of energy savings, safety and product quality. Few vendors offer superheated steam dryers which limits its industrial utilization.

I believe that more research and development is needed to promote this technology in the near future. I hope ease of access to the literature on this subject will facilitate future research and adoption in practice. We have included abstracts only of more recent papers.

Readers may notice that several papers/abstracts included in this compilation are not directly on steam drying of products but on closely related themes such as energy aspects or integration of steam dryers in energy savings or production schemes. Such articles are included for the benefit of readers who need to follow the systems approach when considering applications of superheated steam drying.

What is missing is complete citations to work published in books during 1978-1990 when much of the drying research work appeared in books such as the proceedings of IDS as well as book series such as Advances in Drying and Drying of Solids which were edited by Professor Mujumdar. There is also valuable information in the Handbook of Industrial Drying.

It is noteworthy that much of the publications have origin in two institutions viz. McGill University, Montreal, Canada and KMUTT, Bangkok, Thailand.

I would be pleased to receive feedback from readers.

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Foreword

I want to compliment Dr Shivanand S. Shirkole for undertaking this e-book project to facilitate further R and D in an area that is not new and yet presents unique opportunities for industrial exploitation to reduce fossil fuel consumption and enhance dried product quality.

Personally I got very interest in this area after listening to the celebrated chemical engineer of Canada, late Dr W H Gauvin who presented papers at the first IDS in 1978 on simulation of superheated steam spray drying as well as flash drying. The energetic advantages of such a dryer were obvious. No experience was available, however. I was working on research related to paper drying using high temperature impinging jets combined with through drying. Although this yielded very high drying rates, it could not be applied in practice due to significant fire hazard. This led to my proposing the use of superheated steam rather than combustion gas for drying paper. A number of graduate students and postdoctoral researchers worked with me on the new concept of combined impingement and through drying of newsprint and tissue paper using superheated steam. Much of this extensive work over some fifteen years has appeared in books and conference proceedings and hence not readily accessed using databases such as Scopus.

Over last three decades there has been sporadic activity in this area. It has covered a wide spectrum of products and industrial sectors. For the convenience of readers with limited or no access to significant library resources, abstracts are included of literature which appeared in last two decades.

It is my fervent hope that this valuable compilation by Dr. Shivanand S. Shirkole as a professional service to the global drying community will have desired impact and enhanced impact on industrial drying. Considering its potential for energy savings this technology could help with climate change and food security in the long run.

Arun S. Mujumdar

McGill University, Canada

September, 2021


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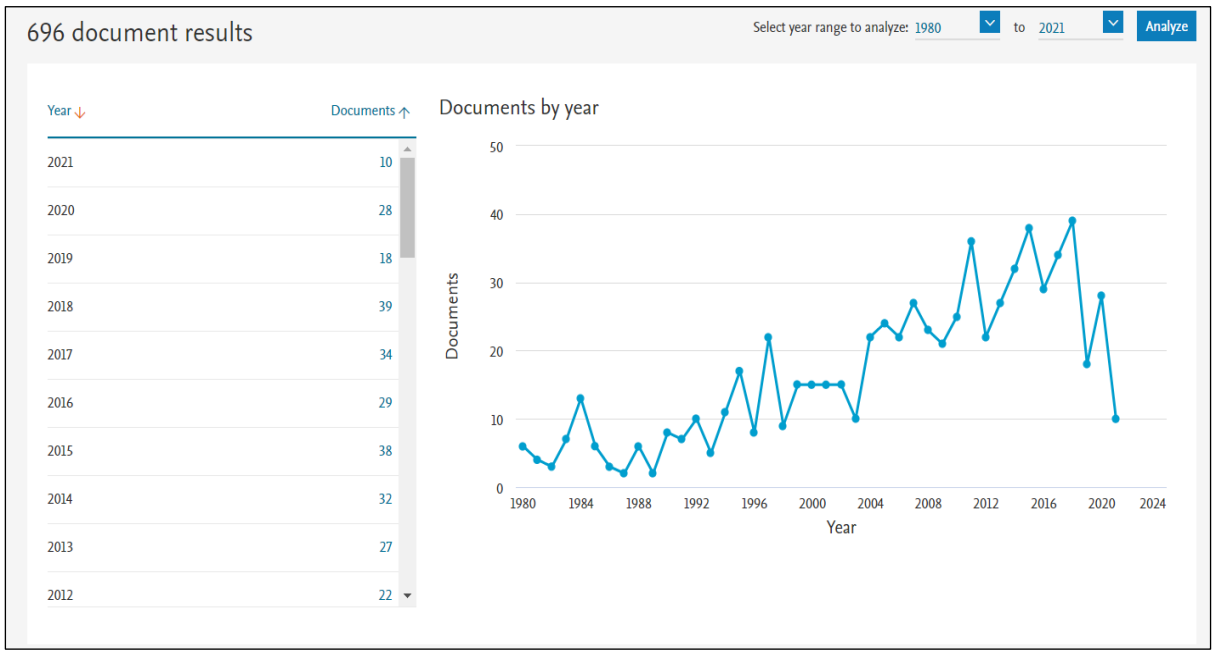
Literature Resources on Superheated Steam Drying

Source: Scopus database accessed on September 08, 2021

Search Keywords Used: Superheated Steam Drying

Publications Statistics of Articles on Superheated Steam Drying during 1980 to 2021

Documents by Year



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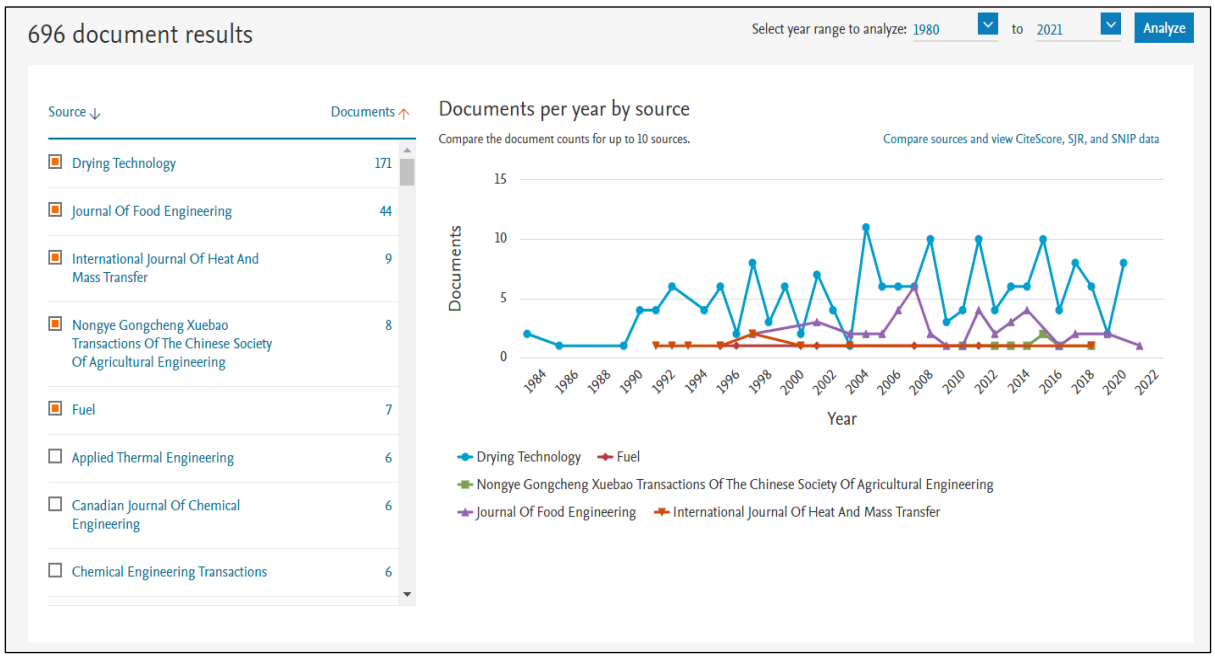
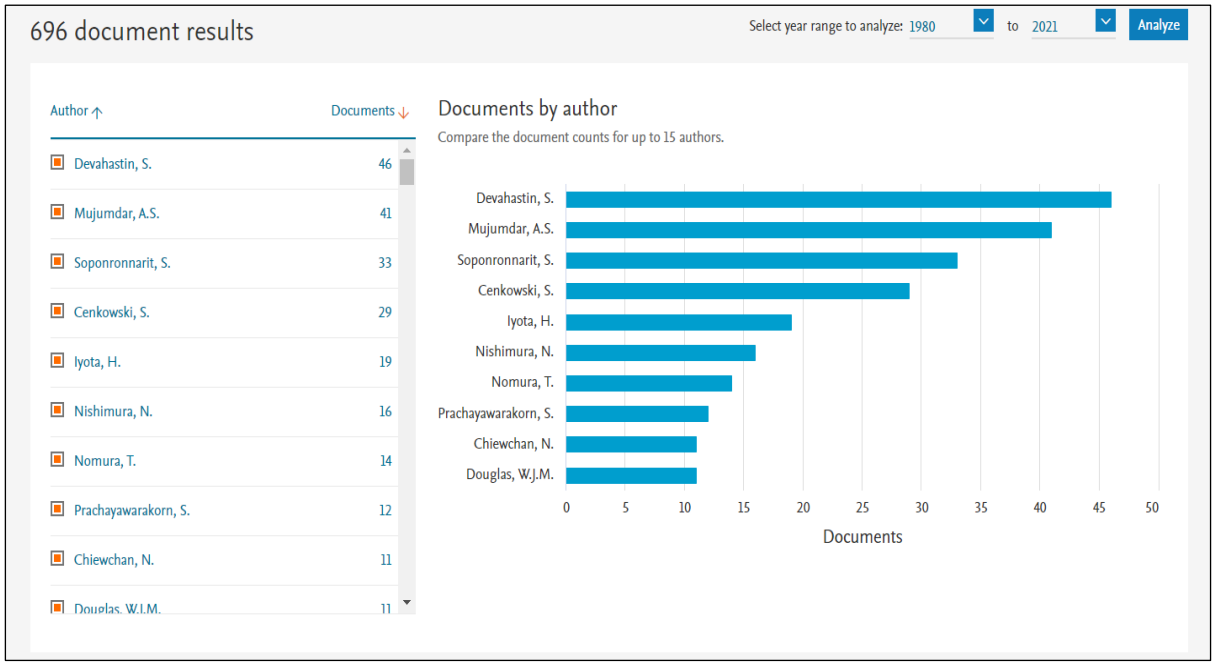
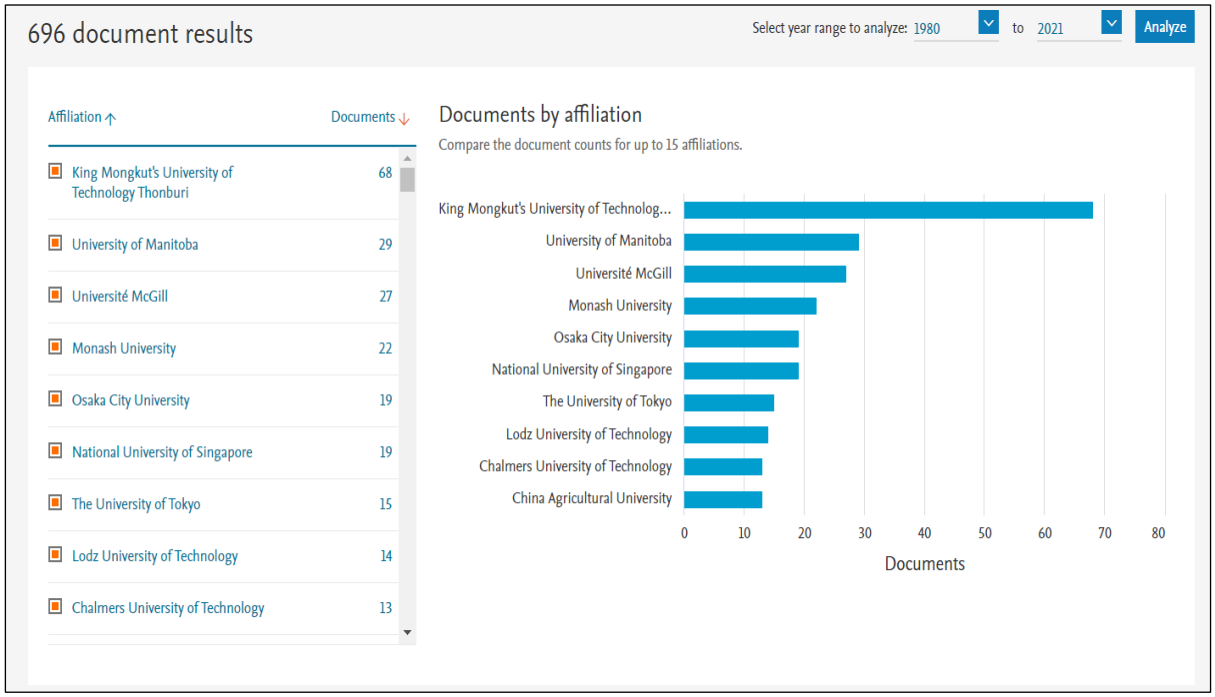


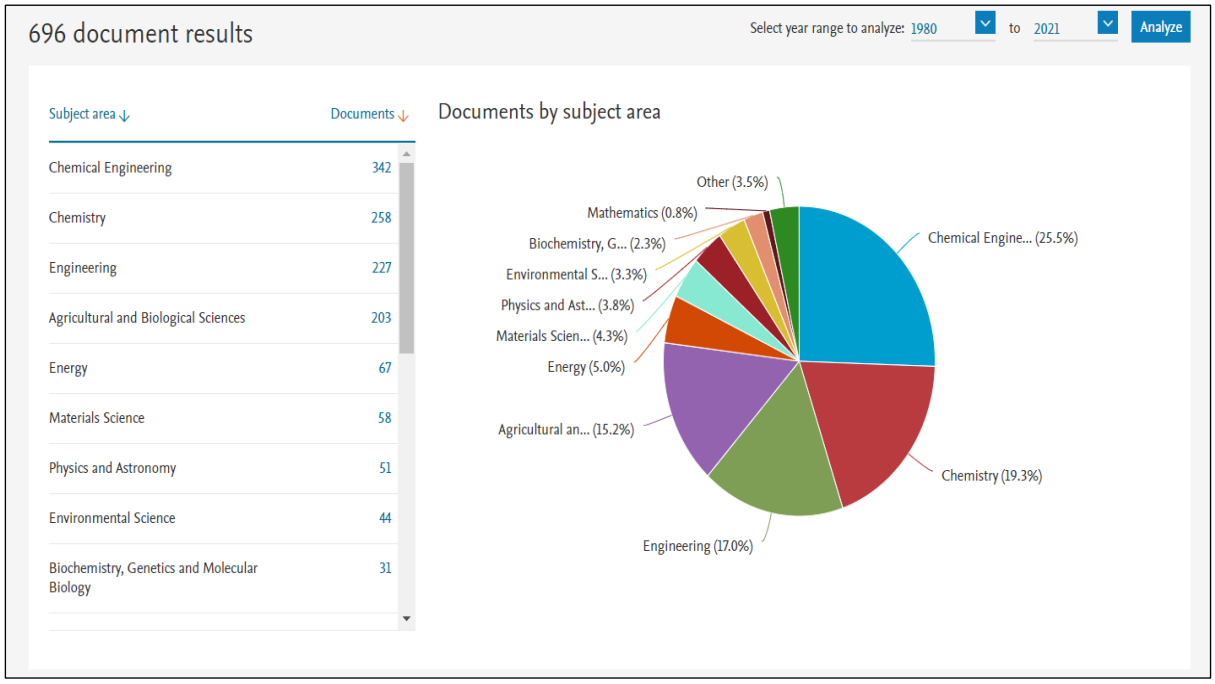
Documents by Authors



Documents by Affiliations



Documents by Subject Area



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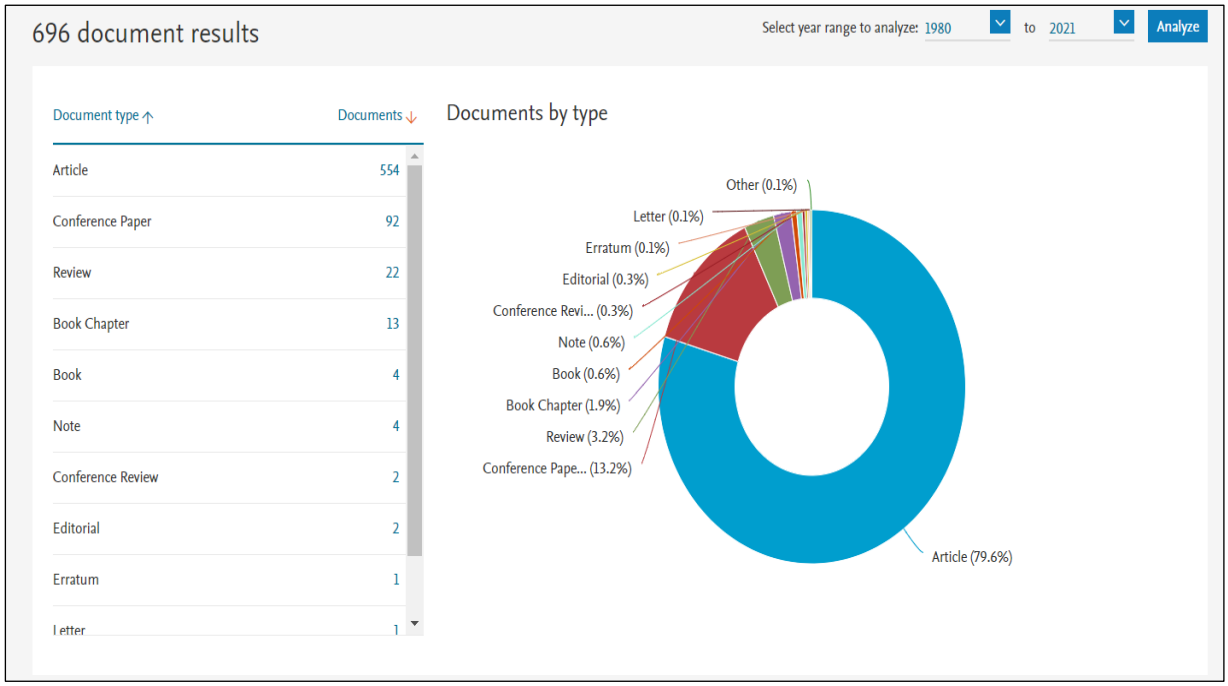


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List of articles abstracts published on superheated steam drying during 2010-2021

[1] Shaharuddin, S.; Husen, R.; Othman, A., Nutritional values of Baccaurea pubera and comparative evaluation of SHS treatment on its antioxidant properties. Journal of Food Science and Technology, 2021, 58, 2360-2367, DOI: 10.1007/s13197-020-04748-0.

Baccaurea pubera is a blood red coloured fruit found exclusively in Borneo. This study was conducted to evaluate the effect of superheated steam treatment on its antioxidant properties and mineral content as well as to determine nutritional values of the fruit. The fruits were treated with superheated steam at 170 °C for 15 min prior to extraction and freeze drying. The results showed that, in comparison to the control, superheated steam treatment enhanced the total phenolic content by 147.8% (287.16 mg GAE/100 g vs. 115.87 mg GAE/100 g) and DPPH radical scavenging activity by 23.7% (66.94% vs. 54.13%). However, there were reductions, as compared to the control treatments, in total flavonoid content by 16.5% (8.29 mg QE/100 g vs. 9.93 mg QE/100 g), lycopene content by 28.6% (0.020 μg/100 g vs. 0.028 μg/100 g) and ferric reducing antioxidant power by 22.2% (844.41 mg TE/100 g vs. 1085.15 mg TE/100 g). The superheated steam treatment was also observed to reduce the mineral content of the fruit, from as little as 3.6% to as high as 52% depending upon the specific mineral. © 2020, Association of Food Scientists & Technologists (India).

[2] Narender Singh, P., Global Advancement in Hybrid Solar Drying with Using Thermal Energy Storage System, in Lecture Notes in Mechanical Engineering. 2021. p. 191-198.

In today's vying world, the progress in technology is taking place briskly. Due to progress in technology and quick population growth, the existing energy-producing resources are depleting very fast rate. In order to recover such issues, there comes into consideration the use of hybrid solar techniques with thermal energy storage system. But the implementation of these techniques requires appropriate and efficient utilization. The present chapter focuses on the latest advance work done globally in the area of hybrid solar drying with suitable thermal energy storage system. We require large amount of continuous energy to dry the food and agriculture product. Presently, various techniques of food drying like oven drying, tray drying, hot air drying,

ultrasonic drying, vacuum drying and superheated steam drying mainly work on electricity. We know that sun is a prime source of non-conventional energy resources and freely available all round world. Sun energy along with thermal energy reserve can meet the requirement of continuous energy uses, i.e., generally available in the form of electricity. At last, the work gives a new direction in the development of hybrid solar drying system. © 2021, Springer Nature Singapore Pte Ltd.

[3] Linke, T.; Kirsch, R.; Kohlus, R., A barometric approach for high temperature water desorption isotherm determination. LWT, 2021, 140, DOI: 10.1016/j.lwt.2020.110750.

Sorption isotherms give an insight into thermodynamic behaviour of materials during drying. This is necessary for process optimization and to prevent over-processing, especially at higher temperatures, such as in drum drying or superheated steam spray drying. Aim of this study is to introduce a simple, barometric method for the determination of water desorption isotherms. As test materials, microcrystalline cellulose and potato starch are used. Both materials show specific temperatures where the trend of the determined GAB parameters and the slope of the isosteric heat of sorption are changing significantly. Thus, is the predictability of thermodynamic behaviour depending on the material. Further, it is demonstrated that the extrapolation of low temperature sorption data (<60 °C) leads to an error in prediction of 30% for microcrystalline cellulose and 15% for potato starch, compared to isothermal data determined at the respective temperature by the barometric method. Reducing the measurement time for the presented barometric pressure approach would extend its application range to temperature sensitive materials, if short residence time processes such as spray drying are of interest. © 2020 Elsevier Ltd.

[4] Le, K. H.; Tran, T. T. H.; Tsotsas, E.; Kharaghani, A., Superheated Steam Drying of Single Wood Particles: Modeling and Comparative Study with Hot Air Drying. Chemical Engineering and Technology, 2021, 44, 114-123, DOI: 10.1002/ceat.202000133.

A deterministic model is developed to describe the superheated steam drying process of single wood particles. A comparison between calculated data and experimental observations infers that the moisture-dependent effective diffusivity is suitable to be used for beechwood material drying. To reduce the computational cost of the deterministic drying model, a semi-empirical model is proposed within the framework of a reaction engineering approach (REA). The validity of the proposed model is

checked by comparing against experimental data from literature. The experimental drying behavior may fairly be reflected by the reduced model. Due to the simplicity and predictive ability of the REA model, this semi-empirical model can be implemented to describe heat and mass transfer between a population of single particles and a drying agent in dryer models. © 2020 Wiley-VCH GmbH.

[5] Konopka, A.; Barański, J.; Orłowski, K. A.; Mikielewicz, D.; Dzurenda, L., Mathematical model of the energy consumption calculation during the pine sawn wood (Pinus sylvestris L.) drying process. Wood Science and Technology, 2021, 55, 741-755, DOI: 10.1007/s00226-021-01276-8.

The article presents a modification of the existing mathematical model to calculate energy consumption during conventional drying process. Apart from energy consumption, the model permits to estimate the time of high-temperature drying process. The drying medium is air and superheated steam mixture. The obtained calculation results were compared with conducted experimental tests of drying square-edged sawn sapwood timber (Pinus sylvestris L.). The pine sawn wood samples were dried according to three different drying modes, namely mild, normal and intense. The experiments were performed in a semi-industrial scale drying chamber. On the basis of the experimental research available, existing mathematical models of drying wood have been improved. The developed model included the following changes: a different drying time for each mode and type of drying medium (moisturized air or air and superheated steam mixture). The use of an intensive drying mode significantly reduced the drying process time. The developed mathematical model revealed that the energy consumption of the drying process increases with the intensity of the mode used. © 2021, The Author(s).

[6] Kapustenko, P.; Arsenyeva, O.; Fedorenko, O.; Kusakov, S., Integration of low-grade heat from exhaust gases into energy system of the enterprise. Clean Technologies and Environmental Policy, 2021, DOI: 10.1007/s10098-021-02082-3.

The paper presents a Process Integration application for waste heat utilisation from exhaust gas streams with partial condensation. It is based on the hot composite curve construction representing the gaseous mixture cooling with accounting for the condensable vapour part's gas–liquid equilibrium. With cold composite curve for streams requiring heating, the Pinch Point is determined. On this basis, the heat exchanger network (HEN) structure for utilised heat integration into the factory's energy system is developed. It accounts for the possible splitting of two-phase flow on

gas and liquid streams and plate heat exchanger (PHE) type selection for specific positions in HEN. The method is illustrated by a case study of heat utilisation from exhaust gases after superheated steam tobacco drying and flue gases from natural gas-fired boiler. Heat transfer areas of PHEs in HEN are optimised with the total annualised cost as an objective function. The received solution's payback period is less than four months, with a substantial saving of energy, up to 10.9 TJ/y. It also leads to the reduction of CO2 emissions up to 600 t/y. About 3830 t/y of steam is not discharged to the atmosphere and as the water returned to the production process. Graphic abstract: To manuscript “Integration of Low-Grade Heat from Exhaust Gases into Energy System of the Enterprise” [Figure not available: see fulltext.]

[7] Junka, N.; Rattanamechaiskul, C.; Wongs-Aree, C.; Soponronnarit, S., Drying and mathematical modelling for the decelerated rancidity of treated jasmine brown rice using different drying media. Journal of Food Engineering, 2021, 289, DOI: 10.1016/j.jfoodeng.2020.110165.

Jasmine brown rice (JBR) attains a rancid odour because of lipid deterioration, which reduces its shelf life. This study focused on preserving JBR's stability through drying in a fluidised bed at 100–150 °C using different drying media: hot air (HA), humidified hot air (HHA), and superheated steam (SHS). The JBR and the rancid odour caused by thiobarbituric acid (TBA) were analysed. A mathematical model was developed for the drying process, and associated equations were formulated to predict the mechanism underlying changes in TBA during 180 days of storage. The dried samples became harder owing to gelatinisation of starch and decrease in 2-acetyl-1-pyrroline volatility. Changes in JBR quality were correlated to the drying temperature and drying media used. SHS drying at 150 °C decelerated TBA formation the most. The proposed mathematical model and associated equations can predict changes in TBA during storage accurately and be applied to JBR under most drying conditions.

[8] Farberova, E. A.; Maximov, A. S.; Tingaeva, E. A.; Shirkunov, A. S.; Ryabov, V. G.; Strelkov, V. A., Research Of Possibility Of Processing Petroleum Coke With Increased Volatile Substances Into Activated Carbons. ChemChemTech, 2021, 64, 92-99, DOI: 10.6060/ivkkt.20216404.6331.

In present work, study to obtain granulated active carbon based on industrial petroleum coke of the CEL grade (coke with an increased content of volatile substances) produced

in delayed coking unit have been conducted. The production of activated carbons was carried out by prelimi-nary carbonization of coke at a temperature of 500-800 °C, followed by activation in a water vapor atmosphere at a temperature of 850-900 °C. In addition, tests were carried out on the effect of impregnation of the initial coke with aqueous solutions of chemical activators (sodium hydroxide, potassium carbonate, phosphoric acid) on the efficiency of heat treatment and characteristics of the porous structure of the resulting sorbent. The use of sodium hydroxide as an activating agent increases the reactivity of the sample, but the microporous structure does not develop. Using potas-sium carbonate as the activating solution and increasing the carbonization temperature to 800 °C causes an increase in the degree of burning from 28 to 44 %. However, activation of the resulting carbonizates with superheated steam leads to a 97-98 % burn-out of the samples due to a sharp increase in reactivity. It was shown that activated carbon obtained on the base of petroleum coke with an increased content of volatile substances by preliminary impregnation with an aqueous so-lution of phosphoric acid (concentration 17 wt.%), filtration and drying, followed by carbonization at a temperature of 800 °C in an inert atmosphere and activation in water vapor medium at a tem-perature of 850-900 °C has a sufficiently high specific surface of micropores (up to 430 m2/g) and other characteristics of the porous structure. Thus, the proposed method can serve as one of the ways to expand the qualified use of petroleum coke.

[9] Alp, D. Bulantekin, Ö., The microbiological quality of various foods dried by applying different drying methods: a review. European Food Research and Technology, 2021, 247, 1333-1343, DOI: 10.1007/s00217-021-03731-z.

With the drying process, the water activity and moisture content of the foods are reduced, so the growth of microorganisms in the foods is largely prevented/postponed. But low-aw foods should not be considered sterile they can be contaminated by fungi and other contaminants during the drying process under unhygienic conditions. If drying is not done to a sufficient degree of moisture during food processing and storage, where dried foods are processed, sometimes the minimum value is reached for the growth of microorganisms. In dry foods, some pathogens, yeast and molds can continue to grow during storage, transport and transportation until the sale and they causing spoilage. They can even cause health problems if enough pathogen or spore cells remain viable. Considering this situation today, it is attempted to obtain high-quality dried foods with good microbiologically and chemically properties. For this purpose, various

drying methods have been developed. Most studies suggest that when foods are pre-treated with the ascorbic acid or sodium metabisulfite or applied with various combined methods such as UV irradiation, supercritical carbon dioxide (SCO2), low-pressure superheated steam drying (LPSSD), and infrared (IR) drying, they can be effective on inactivation of microorganisms. We have reviewed in this study how these methods made dried products efficient of microbial inactivation and microbiologically safe. © 2021, The Author(s), under exclusive licence to Springer-Verlag GmbH Germany, part of Springer Nature.

[10] Adamski, R.; Siuta, D.; Kukfisz, B.; Mitkowski, P. T.; Szaferski, W., Influence of process parameters in superheated steam drying on fire and explosion parameters of woody biomass. Fuel Processing Technology, 2021, 211, DOI: 10.1016/j.fuproc.2020.106597.

Studying of the drying kinetics and fire and explosion characteristics of biomass is a fundamental aspect in designing material drying systems based on superheated steam, and proper selection of explosion and fire protection systems. The paper presents studies on osier willow (Salix viminalis) drying kinetics under isothermal conditions (120 °C, 140 °C, 160 °C, 180 °C) and their use for process calculations of the proposed one-dimensional model of superheated steam pneumatic dryer. The model included empirical parameters in order to describe the volumetric heat transfer and specific surface of the wood particles of irregular shapes. In addition, a 20-L spherical explosion chamber, Hartmann tube apparatus, hot plate apparatus and Godbert-Greenwald furnace apparatus were used to investigate the explosion and fire characteristics of willow dusts. Based on the studies it was confirmed that the operating parameters of superheated steam drying system for woody biomass have a major impact on the explosion and fire characteristics of the formed dust. The results indicate that the lower the moisture content in the willow, the more likely the dust cloud to be ignited, the faster the explosion flame propagation, and the greater the explosion severity. Despite the fact that the superheated steam drying system for woody biomass is considered safe, the probability of occurrence of fire or explosion incidents related to the dust and air biomass mixture is high. The maximum temperature for superheated steam drying equipment covered with up to 5 mm thick layer of osier willow dust should not exceed 215 °C. © 2020 Elsevier B.V.

[11] Wu, X.; Fu, G.; Li, R.; Li, Y.; Dong, B.; Liu, C., Effect of thermal processing for rutin preservation on the properties of phenolics & starch in Tartary buckwheat

achenes. International Journal of Biological Macromolecules, 2020, 164, 1275-1283, DOI: 10.1016/j.ijbiomac.2020.07.135.

The endogenous rutin-degrading enzymes (RDEs) in Tartary buckwheat (TB) considerably limit the development of TB functional foods. In this study, three thermal treatments, including superheated steam (SS), saturated steam (ST), and far-infrared drying (FID), were used to inactivate RDEs in TB. Results showed that SS and ST could efficiently inactivate RDEs, whereas FID could not. The extractable rutin contents in TB were increased by 52.3% and 12.3% by SS and ST, respectively, with 90 s of treatment time. Furthermore, the properties of phenolics and starch were used to evaluate the influence of thermal inactivation on TB. Results showed that the soluble phenolic compounds contents in TB were significantly improved (p < 0.05) by SS. The bound phenolic compounds contents were decreased after SS and ST treatments. The change in antioxidant properties was consistent with that of phenolics and flavonoids. Besides, the starch in SS- and ST-treated TB achenes had higher relative crystallinity, setback, transition temperatures, rapidly digestible starch, and slowly digestible starch contents, but a lower ratio of 1047 cm−1/1022 cm−1, peak viscosity, breakdown, gelatinization enthalpy, and resistant starch contents, than native TB starch. In conclusion, SS was a better method for the inactivation of RDEs than ST. © 2020.

[12] Tran, T. T. H., Modelling of drying in packed bed by super heated steam. Journal of Mechanical Engineering Research and Developments, 2020, 43, 135-142.

This work presents the continuum-scale model of packed bed superheated steam drying of ceramic particles. In this model, Reaction Engineering Approach (REA) model is built to describe the mass transfer between particles and agent. In the REA model, the dehydration of porous particle is described like a reaction which needs the activation energy to overcome the energy barrier. After successful validation, the single particle drying model is combined with the continuous heat and mass conservation equations of the bed to simulate the drying process. The initiative results obtained from the bed simulations indicate that this scaling-up strategy proposed in this work can be applied to describe superheated steam dryers. © 2020 Zibeline International Publishing Sdn. Bhd.. All rights reserved.

[13] Szufa, S.; Dzikuć, M.; Adrian, L.; Piersa, P.; Romanowska-Duda, Z.; Lewandowska, W.; Marcza, M.; Błaszczuk, A.; Piwowar, A. Torrefaction of oat straw to use as solid biofuel, an additive to organic fertilizers for agriculture purposes and activated carbon-TGA analysis, kinetics. in E3S Web of Conferences. 2020.

In this paper authors present research results which are the optimum parameters of the torrefaction process using straw from oats and maize. The most important parameters for the torrefaction process are temperature and residence time. Both parameters are essential to designing and construction of industrial biomass torrefaction installations. Energy crops and waste coming from agricultural production have the most promising perspective from all kind of renewable energy sources in Poland. Currently, intensive studies on the process of biomass torrefaction are being carried out. In this experimental investigation, authors examined the torrefaction process of two types of agriculture biomass, such as: oats, maize. The main overarching objective of the experimental studies described below is the development of various biochar as an additive to agricultural fertilizers resulting from the conversion of biomass from agriculture residues-straw from oats and maize. The last of enumerated biomasses is treated through different conversion processes such as: drying, torrefaction to homogenize their physical and chemical properties. Among many of its areas, it is extremely important to optimize the production of biomass energy plants and its refinement (in the torrefaction process), which will improve the balance and profitability of energy production from RES, and reduce the logistics and storage costs of this fuel and improve the efficiency of biomass combustion process. When implementing new technologies indicated in this work and optimizing the harvesting of plant biomass, the negative impact on the environment caused by stored municipal waste can be reduced. This biomass torrefaction process temperature and residence time were necessary for the design and construction of semi-pilot scale biomass torrefaction installations with dryer and torrefaction reactor to perform a continuous biomass torrefaction process using superheated steam.

[14] Shevtsov, A. A.; Drannikov, A. V.; Lytkina, L. I.; Derkanosova, A. A.; Pribytkov, A. V. Solution of Tasks of Energy Efficiency of the Process of Drying Raw Plant Materials by Methods of Mathematical Modeling. in IOP Conference Series: Materials Science and Engineering. 2020.

Beet pulp has a high feed value, but after pressing it has a sufficiently high humidity, which leads to rapid spoilage. One of the ways to stabilize the quality of beet pulp is drying with superheated steam of reduced pressure. Mathematical modeling of heat transfer during convective drying of beet pulp is proposed. A feature of the model is the description of the drying process, which ensures its high intensity due to high heat and mass transfer ratios and preserves the quality of the finished product as a result of

the process at a reduced pressure of transfer medium. In the period of a constant drying speed, dehydration of macroscopic pores topologically related to the sample surface, which are characterized by a relatively low binding energy of water molecules with the liquid phase, is taken into account. According to experimental data, the proportion of water content in these pores is 60⋯70% of the total moisture content. In the final stage of this period, an increase in the binding energy occurs due to the removal of water from microcapillaries, which is explained by the formation of structured clusters in thin wetting films of water molecules. The change in steam temperature as a result of passing through the product layer was 8 ⋯ 10 K, and the relative temperature change was 5 ⋯ 10%. The parameters of the models were identified in the following range of parameters: superheated steam temperature 393 ⋯ 453 K; speed of superheated steam 3 ⋯ 5 m/s; the pressure inside the drying chamber is 40 ⋯ 100 kPa; the specific load of the product on the grate is 8 ⋯ 24 kg/m2. The interpretation of the simulation results is presented by the dependences of the temperature difference between beet pulp and heat carrier T on the temperature of superheated steam Ts at various pressures P: 1 - 100 kPa; 2 - 80 kPa; 3 - 60 kPa; 4 - 40 kPa; υ = 4 m/s; at various specific loads of beet pulp on the gas distribution grid qsp: 1 - 8 kg/m2; 2 - 16 kg/m2; 3 - 24 kg/m2; υ = 4 m/s; P = 60 kPa and various speeds of superheated steam υ: 1 - 5 m/s; 2 - 4 m/s; 3 - 3 m/s. A sufficient convergence of the results was ensured, in which the deviation of the calculated data from the experimental data did not exceed 12, 5% in absolute value. The obtained results of the simulation can be used in the operational control of the technological parameters of the process of drying beet pulp with superheated steam of reduced pressure with a restriction on the temperature mode due to the receipt of a high quality product. © Published under licence by IOP Publishing Ltd.

[15] Romeiko, X. X.; Lin, S.; Huang, G., Life cycle assessment of preserved plum production in Southern China. Clean Technologies and Environmental Policy, 2020, 22, 197-209, DOI: 10.1007/s10098-019-01777-y.

Abstract: The fruit preservation industry in developing countries is growing rapidly and presents unique opportunities for promoting environmental sustainability. However, very few life cycle assessment studies have evaluated the environmental performances of current production technologies in developing countries. This study represents the first life cycle assessment to compare two common production lines of the preserved plum industry in Southern China and suggested strategies for improving their

environmental performances. The first line, commonly adopted by medium-sized plants, included washing, osmotic treatment, blanching, superheated steam coupled with far-infrared radiation for drying, packaging and wastewater treatment stages. The second line, commonly utilized by small-sized plants, consisted of washing, osmotic treatment, drying by natural ventilation, packaging and wastewater treatment stages. The comparison suggested that the first production line resulted in higher fossil fuel depletion, ozone depletion, human health noncancer, respiratory and ecotoxicity impacts than the second production line. In contrast, the second production line resulted in higher photochemical formation, global warming, acidification, human health cancer and eutrophication impacts. Electricity and wastewater treatment, together, were the dominating contributors to most of the life cycle environmental impact categories. The sensitivity analyses suggested that the life cycle global warming impacts were most sensitive to electricity use, while the wastewater amount ranked as the most influential factor for the life cycle eutrophication impacts. In addition, the scenario analyses indicated that upgrading the activated sludge process to a membrane bioreactor process, for in-plant wastewater treatment, alone would increase life cycle fossil fuel depletion, photochemical formation, acidification and respiratory impacts. However, the combinational adoption of a membrane bioreactor process and electricity derived from wind or lignocellulosic biomass can significantly reduce life cycle environmental impacts of the plum preservation plants. Graphic abstract: [Figure not available: see fulltext.]. © 2019, Springer-Verlag GmbH Germany, part of Springer Nature.

[16] Pongmalai, P. Devahastin, S., Profiles of prebiotic fructooligosaccharides, inulin and sugars as well as physicochemical properties of banana and its snacks as affected by ripening stage and applied drying methods. Drying Technology, 2020, 38, 724-734, DOI: 10.1080/07373937.2019.1700517.

Contents of fructooligosaccharides and inulin along with those of selected sugars in fresh banana of different ripening stages were first determined. Banana was then processed into snacks either by hot air drying (HD) or low-pressure superheated steam drying (LPSSD). Selected physicochemical properties of both fresh banana (moisture content, water activity, flesh-to-peel ratio, total soluble solids content, pH, titratable acidity and firmness) and its snacks (microstructure, texture and color) were investigated. Fresh banana of ripening stage 5 exhibited higher fructooligosaccharides, inulin and sugar contents; its snacks also possessed maximum fructooligosaccharides and inulin contents. Drying methods did not have any significant effect on the contents

of these prebiotics. Although snacks from banana of ripening stage 5 possessed higher sugar contents, such contents, when snacks are consumed at the recommended amount, are still lower than the recommend daily intake. Stage-5 LPSSD snack exhibited better texture and color than its HD counterpart, so the former has a potential of being a prebiotic-based snack. © 2019, © 2019 Taylor & Francis Group, LLC.

[17] Patel, S. K. Bade, M. H., Superheated steam drying and its applicability for various types of the dryer: The state of art. Drying Technology, 2020, 39, 284-305, DOI: 10.1080/07373937.2020.1847139.

Superheated steam is a vital drying media due to inherently passive, nonpoisonous, no fire risk, antioxidant, and compatible with food products with superb thermophysical properties than hot air. Moreover, it will improve energy efficiency by energy-saving due to reusing the energy from exhausted steam, mainly by recirculation, and the use of partial exhaust of excess steam for other operations reduces the additional energy requirement. Additionally, the specific heat at constant pressure for superheated steam is nearly double that of the hot air, reducing the quantity required for drying. In general, superheated steam as a drying medium instead of hot air has significant potential. In this study, past, present, and prospects of the superheated steam drying (SSD) are critically analyzed and are presented systematically, such as classification, working, and recent developments. This study also focused on various areas such as analytical modeling, experimental work, and pilot-test of SSD with covering energy recovery and energy efficiency. Out of different drying systems, Fluidized bed dryers, Vacuum dryers, Rotary dryers, Flash dryers, Impingement dryers, and Spray dryers applicable for SSD are discussed in details as the current stage of development and probable potential. The SSD is having bright future for diverse applications including vegetable drying and fruit processing, chemical process industries, wood drying, chemicals, dyestuff and pigments recovery, effluent drying, etc. © 2020 Taylor & Francis Group, LLC.

[18] Park, Y.; Chung, H.; Kim, H.; Yeo, H., Applicability of continuous process using saturated and superheated steam for boxed heart square timber drying. Journal of the Korean Wood Science and Technology, 2020, 48, 121-135, DOI: 10.5658/WOOD.2020.48.2.121.

This study aims to evaluate applicability for the continuous drying process using saturated and superheated steam for large-square timber. During drying of the boxed heart square timber, changes in moisture content were examined through the slices of

the surface, inner and core layers. The results showed that there was a large moisture content difference between the surface and inner layers during saturated steam drying and between the inner and core layers during superheated steam drying. However, despite the moisture content difference between the layers, no surface check occurred, and an internal check occurred only near the pith or juvenile parts of the wood. The maximum value of the drying stress of the dried larch boxed heart square timber, calculated from the elastic strain of the slice and the tangential elastic modulus of the larch, was 1.30 MPa. The tangential tensile strength of the larch was estimated at 5.21 MPa under temperature and moisture content conditions when drying stress was at a maximum. That is, in the continuous drying process, the saturated and superheated steam did not generate a check in the surface because the drying stress of the wood did not exceed the tangential tensile strength. In further studies, the superheated steam drying conditions will need to be relaxed to suppress the occurrence of internal checks. Such studies would make the continuous drying process using saturated and superheated steam available for the drying of large-square timber.

[19] Motta, I. L.; Marchesan, A. N.; Filho, R. M.; MacIel, M. R. W., Thermodynamic analysis of superheated steam and flue gas as drying agents for biomass dryers. Chemical Engineering Transactions, 2020, 80, 187-192, DOI: 10.3303/CET2080032.

Bagasse is a sugarcane byproduct of high moisture content that usually requires drying before its use in the production of heat, power, fuels, and chemicals. This work explores the possibility of replacing flue gas, a hazardous heat source, with steam in bagasse rotary dryers using Aspen Plus v8.6 as a simulation tool. In the simulation, a bagasse-fed combined heat and power (CHP) plant generated superheated steam at 2 bar and flue gas, and both acted as drying agents in zero-dimensional biomass dryers that reduced bagasse moisture from 50 to 10 wt.%.The biomass final moisture content is inversely proportional to the drying agent temperature and flow rate. Steam dryers required a steam-to-wet-biomass ratio (S/WetBiom) of 4.0 with 2-bar steam at 260 °C to achieve a steam-to-evaporated-moisture (S/EvapMoist) ratio of 9.0, which is suggested for steam as a drying agent. For flue gas dryers, the equivalence ratio (ER) played an essential role: Higher ERs increased the O2 content in flue gas, reducing the gas higher heating value (HHV), and increasing the amount of flue gas required per unit of evaporated moisture (FG/EvapMoist). Thus, ER values of 1.1 were advised to counterbal-ance the effects of ER and still provide enough excess air to allow complete

fuel combustion in the CHP furnace. As the flue gas exiting the furnace presented extremely high temperatures (~1550 °C), this stream was cooled down to the superheated steam temperature (260 °C), and drying performances were compared. Although flue gas had an HHV lower than the steam latent heat, it presented higher production yields, resulting in lower bagasse combustion requirements in the CHP to provide enough drying agent per kg of dried biomass in flue gas dryers. Nevertheless, if the CHP system adopts steam split ratios in the range of 0-0.2 and alternative steam sources are available in the biorefinery, steam can be an attractive drying medium for biomass dryers. © 2020, AIDIC Servizi S.r.l.

[20] Malaikritsanachalee, P.; Choosri, W.; Choosri, T., Study on intermittent low-pressure superheated steam drying: Effect on drying kinetics and quality changes in ripe mangoes. Journal of Food Processing and Preservation, 2020, 44, DOI: 10.1111/jfpp.14669.

The effect of intermittent low-pressure superheated steam drying (LPSSD) at 6.0 kPa of ripe mangoes was studied and compared with hot-air drying (HAD) at 70°C and 2.0 m/s. The heating:tempering periods (10:1, 20:1, and 30:1 min) were studied. The results showed that all drying curves were suitably fitted by the Page model. The drying time of LPSSD was shorter by 58% as compared to the HAD. The LPSSD-dried products were less color changes (p '.05), shrinkage (p '.05), and rehydration time than that of the HAD-dried products. Total color differences (ΔE*) and shrinkage of LPSSD-dried products were lower than HAD-dried products approximately 12.49 and 15.10%, respectively. The intermittent LPSSD-dried products at 20:1 min provided the highest porous structure and rehydration rate. There was no significant difference in kinetic, ΔE*, and S (p '.05) in all conditions of LPSSD. The intermittent LPSSD can be utilized to improve the productivity and quality of dried fruits. Practical applications: Nowadays, the consumer demand for dried fruits is high nutritional values as well as the appearance which is most similar to fresh products. The major problem of the drying process on food products, especially HAD, is the product quality changes during the drying process due to the temperature and long drying time. The LPSSD is one of the interesting drying methods to preserve the quality of dried fruits. Therefore, the efficiency of HAD, continuous and intermittent LPSSD was demonstrated, including the quality changes in dried ripe mangoes. The results of this study provided information regarding the drying process (kinetics, drying behavior, drying rate, and Deff), including the qualitative properties (color, shrinkage, rehydration, and

microstructure) of dried ripe mangoes. For the results, the intermittent LPSSD can be utilized to improve the productivity and quality of dried fruits in the food processing industry. © 2020 Wiley Periodicals LLC.

[21] Liu, Y. Ohara, H., Lignite drying in a bench-scale pulsation-assisted fluidized bed dryer. Drying Technology, 2020, 38, 1698-1708, DOI: 10.1080/07373937.2019.1655438.

A bench-scale indirect pulsation-assisted fluidized bed dryer with a 0.24 m2 cross-section area has been built to confirm the drying performance of lignite. The fluidized bed dryer with tube bundles was utilized to investigate the scale-up effect on the drying rate of the pulsed flow using superheated steam as the drying medium. Particles agglomeration was found a serious problem when to increase the scale of the fluidized bed dryer. Agglomeration reduction could be achieved through increasing horizontal diffusion rate using the pulsation-assisted flow and then drying rate was enhanced. Drying rate enhancement effect increased with the increase of the pulsation-assisted flow velocity. The pulsation-assisted flow could enhance the drying rate by nearly 40% compared to that of the steady flow at the gas velocity of 0.29 m/s, and 20% at the gas velocity of 0.19 m/s. Frequency of pulsed flow also affected the drying rate, which 3 and 5 Hz-pulsed flow has a higher drying rate than that of 1 Hz. Highlights Drying characteristics of lignite in pulsation-assisted fluidized bed was studied. Pulsation-assisted flow enhanced the lignite drying rate. Particle horizontal dispersion rate increased by pulsation-assisted flow. 3 and 5 Hz pulsed flow increased the drying rate than 1 Hz. © 2019 Taylor & Francis Group, LLC.

[22] Linke, T.; Happe, J.; Kohlus, R., Laboratory-scale superheated steam spray drying of food and dairy products. Drying Technology, 2020, DOI: 10.1080/07373937.2020.1870127.

The major limitation of the use of superheated steam spray drying (SHS-SD) for food products is the missing proof of its applicability for heat sensitive materials. A selection of food, in particular dairy products, were spray dried under superheated steam conditions in a lab scale spray dyer with an inlet steam temperature of 250 °C and outlet steam and product temperatures between 130 and 160 °C by pressure nozzle atomization. Powder attributes show that superheated steam spray drying of heat sensitive food products is technically feasible and does not necessarily result in major quality loss such as severe browning. © 2021 Taylor & Francis Group, LLC.

[23] Lim, G. W.; Jafarzadeh, S.; Norazatul Hanim, M. R., Kinetic study, optimization and comparison of sun drying and superheated steam drying of asam gelugor (Garcinia cambogia). *Food Research*, 2020, 4, 396-406, DOI: 10.26656/fr.2017.4(2).288.

The purposes of present study are to compare the kinetic drying of the G. cambogia through sun drying and superheated steam drying (SSD) method and optimizing the quality of SSD of it through response surface methodology. G. cambogia fruit rinds were dried at temperature of 150°C, 200°C and 250°C. The drying curves were fitted into the mathematical model of Page, Lewis and Henderson-Pabis models. Page model was found to be the best in describing the drying behavior of G. cambogia. Drying rate constant (k) increased as temperature increased and SSD method had overall higher drying rates ranged from 5.929 x 10-5 to 5.861 x 10-4 min-1 than sun drying method which was 4.980 x 10-6 min-1. Total acid number showed a trend of increased followed by decreased over drying time. superheated steam drying process of G. cambogia fruit rinds was optimized by using response surface methodology employing a central composite design. Drying time and temperature were the factors in optimization while moisture content (wet basis), acid number and lightness (*L) were the response parameters. Experimental results were fitted to a second-order polynomial model and the model fitness and optimal drying condition were determined by regression analysis and analysis of variance. The optimal conditions for superheated steam drying of G. cambogia fruit rinds were identified as 46.60 mins and 150°C with the composite desirability of 0.913. Application of superheated steam drying under controlled conditions resulted in faster drying process and better quality of dried G. cambogia than conventional sun drying technique. © 2019 The Authors. Published by Rynnye Lyan Resources.

[24] Le, K. H.; Tran, T. T. H.; Nguyen, N. A.; Kharaghani, A., Multiscale Modeling of Superheated Steam Drying of Particulate Materials. Chemical Engineering and Technology, 2020, 43, 913-922, DOI: 10.1002/ceat.201900602.

A multiscale model for predicting the superheated steam drying behavior of a packed bed filled with particulate porous material is presented. By using a reaction engineering approach (REA) a semi-empirical model is developed that can describe the heat and mass transfer between a single particle and the surrounding drying agent. By analogy between superheated steam drying and hot air drying, the relative activation energy of the REA model is formulated. Next, the single-particle drying model is fed into a

continuum-scale model of a packed bed. The temperature and moisture content of the solid and the vapor temperature are successfully predicted by the bed-scale model. To endow the bed-scale model with predictive capabilities, simulation results are compared with experimental literature data. © 2020 WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim.

[25] Le, K. H.; Tran, T. T. H.; Kharaghani, A.; Tsotsas, E., Modeling of superheated steam drying of wood particles. Journal of Mechanical Engineering Research and Developments, 2020, 43, 160-170.

In this work, the superheated steam drying behavior of single wood particles at elevated temperature (i.e. 120°C, 140°C, 160°C and 180°C) are experimentally investigated by using a magnetic suspension balance system. To describe the experimental drying behavior, a coupled heat and mass transfer model of drying model is developed. The moisture diffusivity in the wood particles is determined from an inverse analysis, whereas other thermo-physical properties are measured. Two types of effective diffusivities, including moisture-dependent effective diffusivity and temperature-dependent effective diffusivity, are used to describe the moisture transport in the particles. This mathematical model is implemented and solved by using finite volume element method. Numerical results obtained with temperature-dependent effective diffusivity and moisture-dependent effective diffusivity are benchmarked by the experimental observations. It indicates that the drying behavior can accurately be described by the diffusion model using moisture-dependent effective diffusivity. Furthermore, a model-based sensitivity analysis is made to investigate the influence of drying conditions on the drying kinetics of the particles. The results obtained from the sensitivity analyses may help to optimize and customize dryer design and its operation in the future.

[26] Kallbom, S.; Lillqvist, K.; Spoljaric, S.; Seppälä, J.; Segerholm, K.; Rautkari, L.; Hughes, M.; Walinder, M., Effects of water soaking-drying cycles on thermally modified spruce wood-plastic composites. Wood and Fiber Science, 2020, 52, 2-12, DOI: 10.22382/wfs-2020-002.

The overall aim of this work was to gain more insight on the potential of modified wood (TMW) components for use in wood-thermoplastic composites (WPCs). Laboratory-scale TMWPCs were produced, and the effects of severe water soaking-drying cycles on the samples were studied. Water sorption behavior and resulting dimensional and micromorphological changes were also studied, and the results were compared with

those of unmodified wood-plastic composites (UWPCs) used as control. The TMW was prepared by cutting a spruce board into half and subjecting one-half to an atmosphere of superheated steam at atmospheric pressure with a peak temperature of 210°C, with the other unmodified wood (UW) half as a control. The TMW and UW components were then prepared by a Wiley mill and thereafter sifted into smaller (mesh 0.20-0.40 mm) and larger (mesh 0.40-0.63 mm) size fractions. A portion of the wood components were also subjected to hydrothermal extraction (HE). Composite samples with these different wood components, polypropylene (PP) matrix, and maleated PP (MAPP) as coupling agent (50/48/2 wood/PP/ MAPP ratio by weight) were then prepared by using a Brabender mixer followed by hot pressing. The matching micromorphology of the composites before and after the soaking-drying cycles was analyzed using a surface preparation technique based on ultraviolet-laser ablation combined with scanning electron microscopy. The results of the water absorption tests showed, as hypothesized, a significantly reduced water absorption and resulting thickness swelling at the end of a soaking cycle for the TMWPCs compared with the controls (UWPCs). The water absorption was reduced with about 50-70% for TMWPC and 60-75% for HETMWPC. The thickness swelling for TMWPCs was reduced with about 40-70% compared with the controls. Similarly, the WPCs with HE-UW components absorbed about 20-45% less moisture and showed a reduced thickness swelling of about 25-40% compared with the controls. These observations also were in agreement with the micromorphology analysis of the composites before and after the moisture cycling which showed a more pronounced wood-plastic interfacial cracking (de-bonding) as well as other microstructure changes in the controls compared with those prepared with TMW and HE-UW components. Based on these observations, it is suggested that these potential bio-based building materials show increased potential durability for applications in harsh outdoor environments, in particular TMWPCs with a well-defined and comparably small size fractions of TMW components.

[27] Jittanit, W. Angkaew, K., Effect of drying schemes using superheated-steam and hot-air as drying media on the quality of parboiled chalky rice compared to conventional parboiling. Drying Technology, 2020, DOI: 10.1080/07373937.2020.1761375.

Various drying techniques were tested on two rice cultivars (Plai Ngahm Prachin Buri and Prachin Buri 2) that typically have severe chalkiness and milling quality problems. The main aims were: (1) to apply multi-stage intermittent drying technique using

superheated-steam and hot-air as drying media to reduce the chalkiness and low head-rice yield problems of chalky rice and (2) to compare the quality of different rice products to that of single-stage drying and conventional parboiling process. The results showed that the head-rice yields improved from below the national standard (6.19% for Plai Ngahm Prachin Buri and 29.46% for Prachin Buri 2) to high milling quality levels (up to 61.38% and 68.22%, respectively) by applying hot water soaking together with multi-stage intermittent drying technique. The textural characteristics of the rice dried using multi-stage intermittent drying technique were similar to those for conventionally parboiled rice; however, the rice hardness was significantly lower by 33% and 20% for Plai Ngahm Prachin Buri and Prachin Buri 2, respectively. This study demonstrated that the hot water soaking combined with multi-stage intermittent drying method using superheated-steam drying followed by either hot-air drying at 50 °C or fluidized-bed drying at 80 °C resulted in parboiled rice products whose quality was comparable or superior to that from conventional parboiling and the commercial parboiled rice product. © 2020, © 2020 Taylor & Francis Group, LLC.

[28] Jittanit, W. Angkaew, K., Effect of superheated-steam drying compared to conventional parboiling on chalkiness, head rice yield and quality of chalky rice kernels. Journal of Stored Products Research, 2020, 87, DOI: 10.1016/j.jspr.2020.101627.

Four rice cultivars (Ayutthaya 1, Khao Bahn Nah 432, Plai Ngahm Prachin Buri, and Prachin Buri 2) that usually have a major problem with chalkiness were processed by applying superheated-steam drying and conventional parboiling methods. The main objectives were: (1) to determine the possibility of applying superheated-steam drying to solve the chalkiness and low head rice yield problems and (2) to compare the properties of rice produced using superheated-steam drying and the conventional parboiling process. Both the initial moisture content and superheated-steam drying temperature significantly affected head rice yield. The higher moisture helped to increase starch gelatinization leading to a stronger rice structure and subsequently an increased head rice yield. The rice samples dried in the superheated-steam dryer using an initial moisture content of paddy at 32% w.b. for 6 h under a steam pressure of 1.2 bar and at three drying temperatures (120, 140, 160 °C) had higher milling quality than the conventionally parboiled rice samples. The darker color of the superheated-steam-dried samples was their main drawback. Both parboiling and superheated-steam drying could clearly lessen the percentage of chalky rice kernels compared to the raw paddy.

The parboiled rice and superheated-steam-dried rice had more nutrients than normal white rice. © 2020 Elsevier Ltd.

[29] Jia, Z.; Liu, B.; Fang, T.; Chen, J.; Li, C., Comparison of mass and heat transfer properties of kelp when dried by radiation or conduction using a novel superheated steam system with built-in heat recovery unit. Drying Technology, 2020, 38, 1207-1217, DOI: 10.1080/07373937.2019.1627550.

Kelp is an aquatic product that must be dried after harvest to prevent spoilage. This study tested a novel system for drying kelp. It utilized superheated steam for heating and could recover the latent heat of the exhausted steam, for further drying of the product. The system was tested in four drying modes, including single-face radiation drying mode (SRDM), double-face radiation drying mode (DRDM), single-face conduction drying mode (SCDM), and combined conduction and radiation drying mode (CCRDM). A one-dimensional semi-empirical mathematical model was used to predict the change in the moisture content and temperature of kelp during drying in each of the four drying modes. The drying characteristics of standardized kelp samples in each drying mode were investigated and the efficiency of heat recovery was assessed and compared. The change in moisture content and surface temperature of kelp during drying in each of the four drying modes was also predicted. The results showed that the drying characteristic of the kelp differed significantly depending on the drying mode. The CCRDM was determined as the optimal drying method and exhibited the best drying characteristics, including the highest kelp surface temperature, shortest drying time, and fastest drying rate. Compared to SRDM, DRDM and SCDM, CCRDM recovered, 83.3, 79.5, and 4.5% more energy from the system, and was the most energy efficient among 4 operation modes. Compared with changes in moisture, the changes in the surface temperature of kelp were more accurately predicted during drying. © 2019, © 2019 Taylor & Francis Group, LLC.

[30] Jaszczur, M.; Dudek, M.; Rosen, M. A.; Kolenda, Z., An analysis of integration of a power plant with a lignite superheated steam drying unit. Journal of Cleaner Production, 2020, 243, DOI: 10.1016/j.jclepro.2019.118635.

Future developments of energy conversion systems are expected to be based on second and third generation technology. One of the most innovative designs involves the integration of hard coal or lignite gasification technology with a gas turbine (GT) combined cycle, which is known as an Integrated Gasification Combined Cycle. This may constitute an advantageous future energy option, especially for the use of lignite.

Gasification also provides one of the most efficient ways to produce clean fuel for the next electrical energy generating fuel cells and cars, as it permits the additional production of syngas with low levels of CO2 emissions. However, the performance of lignite (brown coal) fired IGCC is degraded by the very high content of moisture in the lignite. The most appropriate approach in order to fully utilise the potential of this type of fuel is the use of a drying system. In the present paper, an Integrated Gasification Combined Cycle for electricity production, coupled with a fuel preparation unit and a coal superheated steam drying system, is analysed. The novelty of the proposed system is its uniqueness in being equipped with a superheated coal drying system, which constitutes a potentially advantageous method of raising the calorific value of lignite and enhancing its use as a fuel. The proposed system permits lignite to become a valuable resource. The combined system is able to generate electricity with a thermal efficiency higher than for conventional systems and it decreases air pollution and fuel consumption. The system consists of seven dependent subsystems: fuel preparation (lignite drying), air separation unit (ASU), coal gasification, gas cleaning system, regeneration system heat recovery steam generator system, steam turbine and gas turbine. The present analysis demonstrates that lignite consists of more than 50 wt % (wet basis) moisture content before the drying process. In the analysed system, the process of drying coal takes place using steam at a pressure 1.2 bar and a temperature of 133.84 °C, which allows brown coal to be dried to 20 wt % (wet basis) of moisture content. The results show that with the coal drying system it is possible to increase significantly the efficiency of the system of the Integrated Gasification Combined Cycle up to 48%–56%, depending on the thermodynamic parameters of the process. The selected thermodynamic parameters are validated and compared with experimental data. © 2019 The Authors.

[31] Iannone, R.; Riemma, S.; De Marco, I., A comparative life cycle assessment study on conservation of semi-finished peaches. Chemical Engineering Transactions, 2020, 79, 187-192, DOI: 10.3303/CET2079032.

Semi-finished products are often used in the case of the high degree of perishability, like, for example, in the case of some fruits. The treatment of those fresh fruits allows the extension of foodstuffs' shelf life, maintaining low the level at which microbial spoilage and deterioration reactions can occur. These semi-finished products are frequently used as starting materials by jams' and marmalades' industries. The Southern Italy industry under study uses two different techniques to produce and preserve semi-

finished peaches: One is based on low-pressure superheated steam drying with far-infrared radiation, and one on an ohmic aseptic treatment. The aim of this work is to use a Life Cycle Assessment (LCA) approach to compare the environmental emissions of those two different production and preservation techniques on two large scale plants. The environmental impacts were evaluated using a detailed LCA analysis, normalizing all the consumptions and emissions to the functional unit (one peaches' kg on a dry basis). Data were analysed using SimaPro 8.5.2 software, whereas the Ecoinvent 3.4 database and information collected from the chosen industrial site were used for the life cycle inventory, according to the reference standard for LCA (i.e., ISO 14040 and 14044). © 2020 AIDIC Servizi S.r.l.

[32] Hoadley, A. F. A.; Qi, Y.; Nguyen, T.; Hapgood, K.; Desai, D.; Pinches, D., A field study of lignite as a drying aid in the superheated steam drying of anaerobically digested sludge. Water Research, 2020, 82, DOI: 10.1016/j.watres.2015.04.021.

Dried sludge is preferred when the sludge is either to be incinerated or used as a soil amendment. This paper focuses on superheated steam drying which has many benefits, because the system is totally enclosed, thereby minimising odours and particulate emissions. This work reports on field trials at a wastewater treatment plant where anaerobically digested sludge is dried immediately after being dewatered by belt press. The trials showed that unlike previous off-site tests, the sludge could be dried without the addition of a filter aid at a low production rate. However, the trials also confirmed that the addition of the lignite (brown coal) into the anaerobically digested sludge led to a more productive drying process, improved product quality and a greater fraction of the product being in the desired product size range. It is concluded that these results were achieved because the lignite helped to control the granule size in the dryer. Furthermore neither Salmonella spp or E coli were detected in the dried samples. Tests on spontaneous combustion show that this risk is increased in proportion to the amount of lignite used as a drying aid. © 2015.

[33] Hao, X.; Yu, C.; Zhang, G.; Li, X.; Wu, Y.; Lv, J., Modeling moisture and heat transfer during superheated steam wood drying considering potential evaporation interface migration. Drying Technology, 2020, 38, 2055-2066, DOI: 10.1080/07373937.2019.1662801.

In the present study, a mathematical model with a moving evaporation interface was constructed to quantitatively assess the mechanisms of moisture and heat transfer during superheated steam wood drying. In this model, the unsaturated Darcy flow of

free water was considered as Fick diffusion. By modeling the interface evaporation rate and volume evaporation rate, the model (1) characterized the moving water evaporation interface; (2) quantified the dynamic alterations of wet/dry regions; and (3) predicted the change regularity of real-time temperature, moisture content, interface evaporation rate, volume evaporation rate, vapor density, and relative humidity at specific locations during the wood drying. Compared with the superheated steam drying experiments using camphorwood (Cinnamomum camphora (L.) Presl) and teak (Tectona grandis L.f) specimens in different sizes, it was suggested that the developed model was able to accurately predict their drying processes, and the parameters calculated from the model contributed to the optimization of a superheated steam drying technique for teak.

[34] Dueck, C.; Cenkowski, S.; Izydorczyk, M. S., Effects of drying methods (hot air, microwave, and superheated steam) on physicochemical and nutritional properties of bulgur prepared from high-amylose and waxy hull-less barley. Cereal Chemistry, 2020, 97, 483-495, DOI: 10.1002/cche.10263.

Background and objectives: Bulgur, an ancient and traditional food extensively consumed in Turkey and the Middle East, has been gaining popularity elsewhere as a nutritious and convenient cereal product with prolonged shelf life. The cooking, drying, and comminution methods used for bulgur production may affect the color, yield, chemical composition, nutritive quality, and physical properties of bulgur. The objectives of this study were to produce bulgur from high-amylose and waxy hull-less barley (Hordeum vulgare L.) varieties and to investigate the effects of different drying methods: hot air, microwave, and superheated steam on the physicochemical and nutritional properties of barley bulgur. Findings: Different drying methods applied in this study for the preparation of barley bulgur had significant effects on the physicochemical and nutritious properties of the final products. Bulgur products from high-amylose barley (cv. CDC Hilose) contained lower amounts of proteins, but higher amounts of ash, arabinoxylans, resistant starch, total dietary fiber, and vitamin E than bulgur products from waxy barley (cv. CDC Marlina). However, bulgur products from CDC Marlina exhibited significantly higher solubility of β-glucans compared with bulgur from CDC Hilose. Conclusions: Overall, the optimal quality characteristics in terms of high bulgur yield, short cooking time, low cooking losses, high β-glucan solubility, and high retention of vitamin E were achieved for bulgur prepared from grain dried with superheated steam at 110°C. The second best results were obtained for

bulgur prepared from the microwave-dried grain. Some differences in composition and properties of bulgur prepared from waxy and high-amylose barley were related to genetic variations and differences in starch composition. The higher content of total dietary fiber in bulgur products from CDC Hilose was partly attributed to a higher content of resistant starch formed during the processing of this high-amylose barley. Significance and novelty: Barley has been long considered a wholesome and nutritious grain, and the results of this study clearly showed that it can be used for the preparation of bulgur, a convenient and functional food product. The use of superheated steam as a drying method for the preparation of barley bulgur proved to generate product with superior properties, especially when compared to conventional hot air drying.

[35] Chantasiriwan, S., Optimum Installation of Heat Recovery Devices in Biomass Boiler, in Computer Aided Chemical Engineering. 2020. p. 1537-1542.

Biomass boiler uses thermal energy from the combustion of biomass fuel and air to produce superheated steam from feed water. Biomass fuel usually has a high moisture content, which leads to low boiler efficiency. The boiler efficiency can be increased by using heat recovery devices to decrease the temperature of flue gas before it is exhausted from the boiler. Three heat recovery devices found in a typical installation of biomass boiler are economizer, air heater, and flue gas dryer. Economizer increases feed water temperature, air heater increases air temperature before combustion, and flue gas dryer decreases the moisture content of fuel. Limited available thermal energy of flue gas means that a decision must made in selecting the sizes of these devices. The main objective of this paper is to use a biomass boiler model, in which the boiler consists of as a furnace and a set of heat exchangers, to determine the optimum sizes of economizer, air heater, and flue gas dryer that minimize the total cost of installing them in biomass boiler system.

[36] Bo, H.; Shuai, C.; Hao, L.; Liu, S. Research and Design of a New Rotary Blast Dryer. in Journal of Physics: Conference Series. 2020.

The vertical shock screening and drying machine is mainly composed of a drying box located at the upper part and a screening box body located at the lower part for drying and sieving wet materials. The device designs a superheated steam recovery device to collect the superheated steam during the drying process. There are two main

applications for collecting collected hot water vapor. The first is that passing it into the heating box to heat the filling chamber in the drying box. And the second is preheating cold air to reduce the amount of heating energy. An LC shocking device is arranged in the drying box to make the wet material uniformly distributed on the material plate. And at the same time, it can promote the heat transfer area between the wet material and the hot air, thereby improving the energy utilization efficiency of the system. Using a porous grading sieve, the lower screening device can screen materials of different particle sizes at one time. The vertical shock screening and drying machine can effectively improve the utilization rate of energy and the emission of pollutants in the drying process. Thereby, it can achieve the energy saving and the emission reducing.

[37] Alyautdinov, A. R.; Antipov, A. V.; Vlasenko, G. P. Application of HP in the atmospheric freeze drying unit. in Journal of Physics: Conference Series. 2020.

Method of increasing the energy efficiency of atmospheric freeze drying due to the use of a heat pump unit (HPU) in a circuit are considered in this article. The use of HPU in the composition of the drying unit allows to more fully use the heat of superheated steam and the heat of condensation in the process of freeze-drying at atmospheric pressure. This increases the energy efficiency during operation.

[38] Acar, C.; Dincer, I.; Mujumdar, A., A comprehensive review of recent advances in renewable-based drying technologies for a sustainable future. Drying Technology, 2020, DOI: 10.1080/07373937.2020.1848858.

Conventional drying technologies generally rely on drying processes driven by using hot air, where these processes have significantly high energy consumption and greenhouse gas emissions. With our knowledge based on the limited nature of fossil fuels and the impact of climate change, it is clear that every technology has to be cleaner, cheaper, and more efficient to limit our carbon footprint while maintaining sustainable development. In this regard, the present study comprehensively reviews the recent advances in drying technologies and energy consumption and the efficiency and economic performances of several alternative drying technologies. The reviewed drying technologies include adsorption mediated, agitated thin film, electrotechnologies, hybrid systems, impingement, heat pumps, microwave, ohmic-heating, refractance window, rotating drum, superheated steam, and vacuum. The selected performance criteria are final heat use, final electricity use, primary energy

use, thermal and energy efficiencies, and operating cost. With these criteria taken into account, the results show that the refractance window has the highest sustainability ranking (8.28/10), and superheated steam has the lowest sustainability ranking (2.90/10). Besides, the sustainability of the different drying fuels and technologies is conducted, and the results show that renewables have the highest sustainability ranking. Besides, it is seen that some novel approaches in drying, such as solar-based hybrid drying systems and refractance window drying, are amongst the most promising sustainable technologies. They could be the key to clean, affordable, reliable, and efficient drying of different kinds of products in industrial processes. © 2020 Taylor & Francis Group, LLC.

[39] Singh, A. P. Ghoshdastidar, P. S. A computational heat transfer and optimization study of drying of peas and rice in a rotary dryer. in ASME-JSME-KSME 2019 8th Joint Fluids Engineering Conference, AJKFluids 2019. 2019.

The paper reports a numerical simulation study of drying of peas and rice grains in a rotary dryer with superheated steam, dry air, and humid air (20%, 40%, 60% and 80% moisture content by volume) at 1 bar as the drying media. The initial water contents in peas and rice grains are 75% and 13% (by weight), respectively. The thermal model includes turbulent convection heat transfer from the gas to the refractory wall and solids, radiation exchange among the gas, refractory wall and the solid surface, conduction in the refractory wall, and mass and energy balances of the gas and the solids. In the absence of experimental data of food drying, the present model has been satisfactorily validated with the experimental and numerical results reported in Sass (1967, Sass, A., "Simulation of Heat-Transfer Phenomena in a Rotary Kiln", Industrial & Engineering Chemistry Process Design and Development, 6(4), pp. 532-535) for iron ore and cement. It is found that for superheated steam there is an optimum kiln inner diameter at which the predicted kiln length is the highest. For dry air, the predicted kiln length monotonically decreases with a decrease in kiln inner diameter. A detailed parametric study lent a good physical insight into the drying process. An optimization study has been conducted for superheated steam as the drying medium using the Univariate Search method to minimize the length of the kiln with an upper limit on the inlet gas temperature as the constraint. Copyright © 2019 ASME.

[40] Ramachandran, R. P.; Paliwal, J.; Cenkowski, S., Computational modelling of superheated steam drying of compacted distillers' spent grain coated with solubles.

Food and Bioproducts Processing, 2019, 116, 63-77, DOI: 10.1016/j.fbp.2019.04.011.

Superheated steam (SS)could be a more effective medium than hot air for drying slurry-like materials such as distillers spent grain. As large scale drying of spent grain slurry has many challenges related to handling and transportation, a multilayered/coated product drying approach, where wet material is dried over a relatively dry core, could provide a potential solution for effective drying. The present study focuses on 3D modelling of SS drying of compacted distillers' spent grain coated with solubles. The drying experiments were conducted with cylindrical spent grain pellets with 25% moisture content coated with a thin layer of solubles (79 ± 2% moisture)at different SS temperatures (120, 150, 180 °C)and velocities (0.5, 1.0, 1.5 m/s). The effective moisture diffusivity and the thermo-physical properties of wet distillers' grain pellets with or without solubles (0, 10, 30%, 100% w/w)were determined by experimentation. A coupling model was developed by combining the Reynolds-Average Navier-Stokes and energy equations for the SS flow and the diffusion models for the coated pellet using computational fluid dynamics approach. The prediction model showed appreciable accuracy with maximum percentage error values for moisture and temperature curves of coated pellet as 9.1 and 8.0%, respectively. Sensitivity analysis for the SS operating conditions showed that the effect of SS temperatures is more prominent than that of SS velocities on drying time. Such models, capable of predicting heat and mass transfer phenomena of SS drying of multilayered products, can provide valuable information for the design or optimization of industrial-scale SS drying units. © 2019 Institution of Chemical Engineers.

[41] Peña Carrillo, J. D.; Oliveira, A. V. S.; Glantz, T.; Gradeck, M.; Labergue, A. Experimental thermal-hydraulic study of a steam-droplets flow inside a vertical pipe – Application to LOCA in PWR reactor. in 18th International Topical Meeting on Nuclear Reactor Thermal Hydraulics, NURETH 2019. 2019.

During a Loss of Coolant Accident (LOCA) in a Pressurized Water Reactor (PWR), partial or even complete drying of fuel assemblies may occur. In these conditions, the fuel temperature can increase leading to significant deformation of the fuel rod cladding and a partial blockage of the fluid domain. These zones can thus affect the cooling of the nuclear core during the reflooding phase by the emergency core cooling systems (ECCS). Investigating the cooling capacity as well as the thermal-hydraulic characteristics of the flow in these zones is a crucial point to guarantee nuclear safety.

In order to characterize the cooling capacity of these deformed zones by a two-phase flow, an experimental set-up at sub-channel scale has been developed. The experimental set-up consists of a tubular Venturi test section, a droplet supply system and a superheated steam supply system. The test section is heated up to about 700°C before starting the flow composed of superheated steam and dispersed droplets. During the cooling phase, optical measurements are carried out upstream and downstream of the test section to measure the droplets diameter, velocity and temperature, while an infrared camera records the transient of the tube temperature. This paper presents experimental results with three different test section diameters to analyze the influence of the blockage ratio on the cooling capacity. The droplets evaporation was evident with their reduction in size downstream of the heated tube.

[42] Nordin, R.; Rozalli, N. H. M.; Yang, T. A., Application of response surface methodology to optimize the drying conditions of black tea using a superheated steam dryer. International Journal of Food Studies, 2019, 8, 81-92, DOI: 10.7455/ijfs/8.2.2019.a8.

Drying conditions of black tea using superheated steam (SHS) were optimized based on a central composite design (CCD) of response surface methodology (RSM). The effects of independent variables (temperature and time) towards the total phenolic content (TPC), scavenging free radical ability, ferric-reducing antioxidant power assay and sensory attributes (infusion colour, aroma, avour and astringency) were analysed using regression polynomial equations. Analysis of variance (ANOVA) showed that a quadratic model tted the experimental design well, with a p-value less than 0.05 and a highest coefficient of 0.9474. The optimum drying conditions were achieved at 166.7°C and 21.2 minutes where the experimental values were in accordance with predicted values, with percentage errors (PE) less than 10%. Temperature (140°C-180°C) was concluded to have the most signicant effect and showed a positive direction in most responses. This effect was denitely able to support the application of a SHS dryer for the quality production (antioxidant and sensory properties) of black tea.

[43] Mujumdar, A. S. Xiao, H. W., Advanced drying technologies for foods. Advanced Drying Technologies for Foods. 2019. 1-246.

The goal of all drying research and development is to develop cost-effective innovative processes that yield high-quality dried products with less energy consumption and

reduced environmental impact. With the literature on drying widely scattered, Advanced Drying Technologies for Foods compiles under one cover concise, authoritative, up-to-date assessments of modern drying technologies applied to foods. This book assembles a number of internationally recognized experts to provide critical reviews of advanced drying technologies, their merits and limitations, application areas and research opportunities for further development. Features: Provides critical reviews of advanced drying technologies. Discusses the merits and limitations of a variety of food drying technologies. Explains drying kinetics, energy consumption and quality of food products. Reviews the principles and recent applications of superheated steam drying. The first four chapters deal with recent developments in field-assisted drying technologies. These include drying techniques with the utilization of electromagnetic fields to deliver energy required for drying, for example, microwave drying, radio frequency drying, electrohydrodynamic drying, and infrared radiation drying. The remainder of this book covers a wide assortment of recently developed technologies, which include pulse drying, swell drying, impinging stream drying, and selected advances in spray drying. The final chapter includes some innovative technologies which are gaining ground and are covered in depth in a number of review articles and handbooks, and hence covered briefly in the interest completeness. This book is a valuable reference work for researchers in academia as well as industry and will encourage further research and development and innovations in food drying technologies.

[44] Mohseni, M.; Kolomijtschuk, A.; Peters, B.; Demoulling, M., Biomass drying in a vibrating fluidized bed dryer with a Lagrangian-Eulerian approach. International Journal of Thermal Sciences, 2019, 138, 219-234, DOI: 10.1016/j.ijthermalsci.2018.12.038.

The objective of this study is drying analysis of biomass in a vibrating fluidized bed dryer with employing a DEM-CFD simulation tool as a multi-physics and multi-scale platform. In this approach, the particles are resolved as discrete elements coupled via heat, mass and momentum transfer to the surrounding gas phase leading to Lagrangian-Eulerian coupling approach. This tool predicts the motion of particles as discrete elements based on the Newtonian equations of motion; and the thermodynamic state of each particle is extended according to the related algorithms. The thermodynamic state stands for estimating the temperature and species distributions through the particle due to external heat sources and chemical reactions. The required experiments are carried

out in the industrial-scale vibrating grate dryer. The intention of experimental works is estimating the moisture content, density and size distribution of materials as well as residence time to evaluate the simulation results. The aim is optimizing the operation and efficiency of vibrating fluidized bed dryer by investigating the influence of effective parameters as temperature and velocity of inlet gas, initial dryer temperature, initial moisture content of particles and grate intensity on drying process. At the end, the effect of size distribution is shown by temperature distribution of particles during interaction with the superheated steam in the system. © 2019 Elsevier Masson SAS.

[45] Madsboll, H. Larsen, K. G. Large-scale mechanical vapor recompression drying process in superheated steam. in Refrigeration Science and Technology. 2019.

Large-scale fluid bed superheated steam drying units have been used for fibrous products such as sugarbeet pulp, and wood chips etc. as an energy efficient alternative to the standard method of heated air/flue gas in a drum dryer. The heat source is steam from nearby power plants due to the huge capacity requirements of steam at approx. 25 bar. An alternative to this method is the vapor recompression method, where steam is recompressed from approx. 3 bar to the inlet pressure of approx. 25 bar at design point operation. The benefits are significant energy savings and the use of electrical energy instead of fossil fuels. Such a unit has been modelled with a selection of centrifugal compressor designs. The model shows the energy balances, the pressure ratio, and the mass flow in the full drying unit, and it can be used to analyze part load operation, control strategy, energy consumption, preferred compressor characteristics etc. © 2019 International Institute of Refrigeration. All rights reserved.

[46] Lv, H.; Ma, J.; Lv, W.; Lv, H.; Zhao, D.; Zhao, D., Effect of Pretreatment Methods on the Moisture State and Drying Quality of Balsam Pear (Momordica charantia L.) Slices Using a Microwave Vibratory Fluidized Bed. International Journal of Food Engineering, 2019, 15, DOI: 10.1515/ijfe-2018-0327.

In order to improve the uniformity of microwave absorption and obtain good drying quality, a vibratory fluidized bed was used during the microwave drying of balsam pear slices. The temperature distribution of the materials during drying is discussed. The water state and drying quality of the balsam pear slices with blanching, ultrasonic, and superheated steam pretreatment were measured using low-field nuclear magnetic resonance and scanning electron microscopy. As a result, the drying uniformity of balsam pear slices was improved, and the drying temperature decreased more than 10°C using the microwave vibratory fluidized bed. By using an ultrasonic pretreatment step,

the activity of the water molecules was improved, and the drying time was reduced by 10min, but the product was discolored during drying. Blanching and superheated steam pretreatment did not improve the activity of water molecules, but the product color changes were minimal and drying time was reduced by 20min. The microstructure of dehydrated balsam pear slices was destructed seriously caused by this heat-moist pretreatment. Therefore, a variety of pretreatments should be integrated for the comprehensive control of the processing characteristics, such as enzyme deactivation and improving water activity, to further improve the drying efficiency and quality of balsam pear slices. © 2019 Walter de Gruyter GmbH, Berlin/Boston.

[47] Lum, A.; Cardamone, N.; Beliavski, R.; Mansouri, S.; Hapgood, K.; Woo, M. W., Unusual drying behaviour of droplets containing organic and inorganic solutes in superheated steam. Journal of Food Engineering, 2019, 244, 64-72, DOI: 10.1016/j.jfoodeng.2018.09.021.

There are currently limited studies on the effect of superheated steam (SHS) on the solidification behaviour of droplets with dissolved solids which is a core phenomenon in spray drying. In this work, the single droplet drying technique was used to investigate how SHS affects the particle formation process of organic sugar droplets (lactose and mannitol), protein droplets (whey protein isolate) and droplets containing inorganic solute (sodium chloride). Unexpected droplet drying phenomenon was observed differing from drying behaviour typically assumed in the literature. While SHS is well known to result in slower drying rates below the inversion temperature, it also exhibits a lower potential to remove moisture at the end point ‘pseudo-equilibrium’ stage of drying. This led to lactose and mannitol droplets encountering incomplete moisture removal challenges in its drying process. The higher constant rate drying temperature experienced by droplet in SHS led to the precipitation of ultrafine protein particles. This higher constant rate drying temperature also led to the production of inverted pyramidal shaped salt crystals highlighting the potential of SHS as a useful medium for spray drying crystallization control. © 2018 Elsevier Ltd.

[48] Lum, A.; Cardamone, N.; Beliavski, R.; Mansouri, S.; Hapgood, K.; Woo, M. W., Role of Steam as a Medium for Droplet Crystallization. Industrial and Engineering Chemistry Research, 2019, 58, 8517-8524, DOI: 10.1021/acs.iecr.9b00561.

Mannitol and sodium chloride (NaCl) were spray dried using a counter current superheated spray dryer. Superheated steam was found to induce relatively high nucleation during the solidification of the sprayed droplets when compared to hot air.

This allowed the production of spherical mannitol particles with very fine crystals at a lower temperature. In addition, superheated steam led to the formation of unique salt microspheres consisting of hollow hopperlike sodium chloride crystals. These unique particle morphologies were not observed in hot air spray drying. Further analysis revealed that higher droplet temperature during the constant rate drying period, under superheated steam conditions, led to the high nucleation phenomenon. Results from this work illustrate the potential of superheated steam as a useful medium for in situ crystallization control in spray dryers. © 2019 American Chemical Society.

[49] Kovbasyuk, V. I.; Buryakovskaya, O. A.; Vlaskin, M. S. Thermal utilization of wet organic waste. in Proceedings of the 2018 5th International Symposium on Environment-Friendly Energies and Applications, EFEA 2018. 2019.

In the present paper a system for thermal utilization of wet organic waste that provides its deep intensive drying is described. The scheme of the system and the estimations of its key parameters are given. The system is expected to be employed for combined generation of heat and electricity. © 2018 IEEE.

[50] Hampel, N.; Le, K. H.; Kharaghani, A.; Tsotsas, E., Continuous modeling of superheated steam drying of single rice grains. Drying Technology, 2019, 37, 1583-1596, DOI: 10.1080/07373937.2018.1518917.

In this work, a transient macroscopic model is proposed for studying the conjugated heat and mass transfer phenomena that occur inside a single rice grain during the superheated steam drying process. The governing equations of this model are derived based on the volume-averaging approach. Since rice is a highly hygroscopic material, more than 80% of water is accumulated as bound water in rice grain. Both the bound water diffusive flow in the solid matrix and the convective flow of water vapor and liquid water in the void volume are taken into account in this model. Thermophysical properties of rice which serve as model inputs are measured, except the absolute permeability and the bound-water diffusivity coefficients. These two properties are determined by minimizing the square of residuals between simulation results and experimental data, which were obtained by means of a magnetic suspension balance system at a drying temperature of 160 °C. The validity of these two estimated parameters is reflected by a good agreement between the numerical and the experimental data at drying temperatures of 120 and 140 °C. Finally, a model-based sensitivity analysis is carried out, from which quantitative guidelines for the

relationship between both the absolute permeability and the bound-water diffusivity and drying kinetics are proposed. © 2018, © 2018 Taylor & Francis Group, LLC.

[51] Erkinbaev, C.; Ramachandran, R. P.; Cenkowski, S.; Paliwal, J., A comparative study on the effect of superheated steam and hot air drying on microstructure of distillers' spent grain pellets using X-ray micro-computed tomography. Journal of Food Engineering, 2019, 241, 127-135, DOI: 10.1016/j.jfoodeng.2018.08.004.

The spatially correlated microstructure of a material during any processing operation such as drying is very important as it influences the thermo-physical properties of the material. The heterogeneity of the distillers' spent grain (DSG) pellets' microstructure was evaluated using the X-ray micro-computed tomography. The effect of two drying methods, i.e. hot air and superheated steam (SS) drying on the microstructure of this porous material was compared. The DSG pellets were prepared by mixing different amounts of distillers' solubles (10, 30, and 50% w/w) with the coarse grain fraction of the spent grains. The effect of solubles on the microstructure (total porosity, open porosity, closed porosity, and connectivity) and stability (dimensional/volumetric changes and change in density) of the pellet prior to and post drying (hot air and SS drying) was analyzed statistically. The results showed that SS drying caused an overall expansion of the pellet in the range of 90–133%. The increase in the open porosity of the pellet during SS drying enhanced the drying process resulting in a decrease in the drying time by about 81% when compared to hot air drying. Also, by increasing the concentration of solubles above 30% w/w, the dimensional stability of pellets improved by 50% for both drying methods thereby improving the mechanical strength of pellets. These results are crucial in optimizing the composition of pellets from the point of view of the pellet's dimensional stability and drying efficiency. © 2018 Elsevier Ltd.

[52] Chryat, Y.; Esteban-Decloux, M.; Labarde, C.; Romdhana, H., A concept and industrial testing of a superheated steam rotary dryer demonstrator: Cocurrent-triple pass design. Drying Technology, 2019, 37, 468-474, DOI: 10.1080/07373937.2018.1460849.

This study aims to provide a pertinent demonstration of the feasibility of superheated steam drying (SHSD) at industrial demonstrator scale. The dryer is of co-current, direct contact, and triple pass rotary type. The dryer is designed to operate under pressure (up 2 bar abs.) and at high temperatures (up 600°C). Given the operating conditions of pressure and temperature, the control and the instrumentation of the dryer were the subjects of a special study to ensure safe tests and measurements. The demonstrator

was manufactured and set-up on an industrial site. Drying experiments on pressed beet pulp are being carried out. At the end of this study, we hope to show first results to demonstrate the drying feasibility and also to provide relevant data concerning the operation of SHSD. © 2018, © 2018 Taylor & Francis.

[53] Chikashige, K.; Ogawa, T.; Nakajima, M.; sOtOme, I.; isObe, S., Effects of aqua-gas drying conditions on functional components and antioxidant activities in egoma (Perilla frutescens (L.) Bitt. Var. Frutescens) leaves. Food Science and Technology Research, 2019, 25, 39-48, DOI: 10.3136/fstr.25.39.

Aqua-gas (AQG; superheated steam containing micro-droplets of hot water) was developed as a pretreatment technology before primary processing, such as sterilization, without sacrificing the material yield and maintaining qualities such as functionality. Its application to drying treatment, however, had yet to be studied. In this study, we examined its applicability to drying treatment of egoma (Perilla frutescens (L.) Bitt. var. frutescens) leaves. Results revealed that when egoma leaves were treated with AQG, they underwent a drying process that progressed with time, as was the case for treatment with superheated steam (SHS). AQG treatment produced dried leaves with a final wet weight-based water content of <10 %. We then investigated the effects of different drying methods on functional components in egoma leaves, and found that such components (e.g., α-linolenic and rosmarinic acids) were preserved during treatment with AQG, or AQG followed by SHS, at levels comparable to those by freeze drying (FD). In contrast, rosmarinic acid content was reduced after drying with SHS alone or hot air drying (HAD). In addition, egoma leaves were successfully sterilized by treatment with AQG, SHS, or AQG followed by SHS, or by steaming followed by HAD. Common bacteria remained viable after HAD treatment. Moreover, egoma leaves dried with AQG, AQG followed by SHS, or steaming followed by HAD had significantly higher DPPH radical-scavenging activity than the FD-treated product. In contrast, such activity was reduced after HAD. In addition, radical-scavenging activity correlated well with total soluble polyphenol content and polyphenol oxidase activity. These results suggest that AQG treatment shows promise as an efficient approach to completing the multiple steps generally required for drying leafy vegetables (blanching, drying, and sterilization) in one step, while preserving functional components. Copyright © 2019, Japanese Society for Food Science and Technology.

[54] Chantasiriwan, S. Charoenvai, S., Bagasse saving and water recovery in cogeneration system using superheated steam dryer. Chemical Engineering Communications, 2019, 206, 919-926, DOI: 10.1080/00986445.2018.1538974.

The cogeneration system in sugar factory uses bagasse with high moisture content as the fuel for the boiler, which results in low boiler efficiency. The system also produces superheated steam, which is extracted from the turbine, and mixed with cooling water to produce saturated steam required by the evaporation system. The potential use superheated steam to reduce bagasse moisture content is ignored in the standard practice of the sugar factory. In this article, an investigation is made into the improvement of the cogeneration system by using superheated steam dryer to reduce the moisture content of bagasse. Mathematical models are developed for the typical system without superheated steam dryer and the improved system with superheated steam dryer. They are then used to compare the performances of both systems. It is found that, under the condition that the required steam flow rate for the evaporation process and the power output are the same, the improved system requires less bagasse consumption, and has larger energy utilization factor. In addition, water that would be lost with flue gases in the typical system is recovered in the improved system. © 2018, © 2018 Taylor & Francis Group, LLC.

[55] Chan, E. W. C.; Ong, A. C. L.; Lim, K. L.; Chong, W. Y.; Chia, P. X.; Foo, J. P. Y., Effects of superheated steam drying on the antioxidant and anti-tyrosinase properties of selected Labiatae herbs. Carpathian Journal of Food Science and Technology, 2019, 11, 166-177.

In this study, the antioxidant and anti-tyrosinase properties of fresh, commercial dried (CD) and superheated steam-dried (SS-D) Labiatae herbs were analysed and evaluated. Superheated steam drying (SSD) was performed at 150°C and 200°C for 5, 10 and 20 min. Fresh and CD rosemary had the highest phenolic contents and the strongest primary antioxidant activities of free radical scavenging and ferric reducing power. Fresh spearmint, CD peppermint and CD oregano displayed the strongest secondary antioxidant activity of ferrous ion chelating ability. Based on total phenolic content and free radical scavenging, three broad categories of SS-D herbs were recognized i.e. herbs that showed declines for all the drying regimes (thyme and peppermint); those that showed declines or remained unchanged (marjoram and oregano); and those that showed all three traits of increment, declines or unchanged (rosemary, sage and spearmint). Tyrosinase inhibition was strongest in fresh sage, fresh rosemary, CD

thyme and CD rosemary. Reported for the first time, SS-D rosemary, SS-D thyme and SS-D marjoram showed enhanced anti-tyrosinase properties for all the drying regimes. SS-D marjoram was the most exciting as tyrosinase inhibition was not detected in fresh samples. This study on the antioxidant and anti-tyrosinase properties of selected Labiatae herbs has provided some useful insights on the effects of SSD. The drying technique can be used for the production of tyrosinase inhibitors, which are increasingly used in medicines for treating pigmentation disorders, in cosmetics for skin whitening, and in food products for inhibiting browning. © 2019, North University of Baia Mare.

[56] Bantle, M.; Schlemminger, C.; Gabrielii, C.; Ahrens, M. Turbo-compressors for R-718: Experimental evaluation of a two-stage steam compression cycle. in Refrigeration Science and Technology. 2019.

Water (R-718) is a safe and energy-efficient refrigerant. Mechanical vapour recompression (MVR), an open-loop heat pump using R718, can significantly reduce the energy consumption for steam-heated processes like drying, pasteurization, evaporation or distillation. However, the existing compression technology is not cost-efficient, especially in the capacity range from 500 kW to 4 MW. Therefore, a novel two-stage turbo-compressor system, developed for application in industrial superheated steam drying and based on mass-produced automotive turbocharger technology, was developed. Its performance was evaluated in a test facility, showing that it is possible to compress superheated steam from atmospheric pressure up to 3 bar, delivering 300 kW at 133°C, with a COP of 5.9, an isentropic efficiency of 74% and a Carnot efficiency of 48%. With an estimated investment cost of 150 €/kW installed heating capacity, the system clearly has the potential of being a cost-effective solution for heat recovery in steam-heated industrial processes. © 2019 International Institute of Refrigeration. All rights reserved.

[57] Zhang, M. Chen, H., Steam jet mill—a prospective solution to industrial exhaust steam and solid waste. Environmental Science and Pollution Research, 2018, 25, 17842-17854, DOI: 10.1007/s11356-018-1722-y.

Bulk industrial solid wastes occupy a lot of our resources and release large amounts of toxic and hazardous substances to the surrounding environment, demanding innovative strategies for grinding, classification, collection, and recycling for economically ultrafine powder. A new technology for grinding, classification, collection, and recycling solid waste is proposed, using the superheated steam produced from the industrial exhaust steam to disperse, grind, classify, and collect the industrial solid

waste. A large-scale steam jet mill was designed to operate at an inlet steam temperature 230–300 °C and an inlet pressure of 0.2–0.6 MPa. A kind of industrial solid waste fluidized-bed combustion ashes was used to grinding tests at different steam temperatures and inlet pressures. The total process for grinding, classification, and collection is drying. Two kinds of particle sizes are obtained. One particle size is d50 = 4.785 μm, and another particle size is d50 = 8.999 μm. For particle size d50 = 8.999 μm, the inlet temperature is 296 °C and an inlet pressure is 0.54 MPa for the grinding chamber. The steam flow is 21.7 t/h. The yield of superfine powder is 73 t/h. The power consumption is 3.76 kW h/t. The obtained superfine powder meets the national standard S95 slag. On the basis of these results, a reproducible and sustainable industrial ecological protocol using steam produced by industrial exhaust heat coupled to solid waste recycling is proposed, providing an efficient, large-scale, low-cost, promising, and green method for both solid waste recovery and industrial exhaust heat reutilization.

[58] Zakrzewski, M.; Sciazko, A.; Komatsu, Y.; Akiyama, T.; Hashimoto, A.; Kaneko, S.; Kimijima, S.; Szmyd, J. S.; Kobayashi, Y., Numerical analysis of single and multiple particles of Belchatow lignite dried in superheated steam. Heat and Mass Transfer/Waerme- und Stoffuebertragung, 2018, 54, 2215-2230, DOI: 10.1007/s00231-018-2314-6.

Low production costs have contributed to the important role of lignite in the energy mixes of numerous countries worldwide. High moisture content, though, diminishes the applicability of lignite in power generation. Superheated steam drying is a prospective method of raising the calorific value of this fuel. This study describes the numerical model of superheated steam drying of lignite from the Belchatow mine in Poland in two aspects: single and multi-particle. The experimental investigation preceded the numerical analysis and provided the necessary data for the preparation and verification of the model. Spheres of 2.5 to 30 mm in diameter were exposed to the drying medium at the temperature range of 110 to 170 °C. The drying kinetics were described in the form of moisture content, drying rate and temperature profile curves against time. Basic coal properties, such as density or specific heat, as well as the mechanisms of heat and mass transfer in the particular stages of the process laid the foundations for the model construction. The model illustrated the drying behavior of a single particle in the entire range of steam temperature as well as the sample diameter. Furthermore, the numerical analyses of coal batches containing particles of various sizes were conducted to reflect

the operating conditions of the dryer. They were followed by deliberation on the calorific value improvement achieved by drying, in terms of coal ingredients, power plant efficiency and dryer input composition. The initial period of drying was found crucial for upgrading the quality of coal. The accuracy of the model is capable of further improvement regarding the process parameters. © 2018, The Author(s).

[59] Vlaskin, M. S.; Kovbasyuk, V. I.; Miroshnichenko, V. I.; Grigorenko, A. V. Opportunities for energy efficient solution of anthropogenic waste problem. in Journal of Physics: Conference Series. 2018.

Present paper is devoted to the solution of the problem of drying wet organic waste by superheated steam under pressure. In this case, the vapor of the evaporated moisture is removed to the drive of the heat machine for the production of useful work, which compensates the heat consumption for the evaporation of moisture. Steam, as a heat carrier with high heat capacity, allows to intensify drying, and increased pressure-to reduce the size of the flow elements. It should be noted that, perhaps, the main purpose of the new drying can be considered the possibility of subsequent effective gasification of biofuels. © 2018 IOP Publishing Ltd.

[60] Singh, A. P. Ghoshdastidar, P. S. A numerical study of drying and preheating of food in a rotary dryer with superheated steam and air as the drying media. in International Heat Transfer Conference. 2018.

This paper presents a numerical study of drying and preheating of apple and carrot pieces in a rotary dryer with superheated steam (Case I), dry air (Case II), and humid air with 20% moisture and 80% dry air by volume (Case III) at 1 bar as the drying media. The initial water content is 19% with respect to dry solids (by weight). The solids inlet and exit temperatures are 288.6 K and 413 K, respectively. The gas exit temperature is 416 K. The thermal model includes turbulent convection heat transfer from the gas to the refractory wall and solids, and radiation exchange among the gas, refractory wall and the solid surface, conduction in the refractory wall, and mass and energy balances of the gas and the solids. Finite-difference techniques are used and steady state conditions are assumed. False Transient Method is used to solve the wall conduction equation. The solution is initiated at the inlet of the kiln and proceeds to the exit. The direction of gas flow is opposite to that of the solids. The inlet temperature of the superheated steam (Case I) predicted by the present model is 512.8 K for apple, as compared to 460 K, calculated by Sinhal et al. (2012). The deviation may be attributed to the curvature effect of the kiln considered in the present model in contrast with Sinhal

et al. (2012) which used Cartesian coordinate system. The predicted kiln length for both the models is 93.6 m for apple drying. Interestingly, it is found that for apple drying with superheated steam there is an optimum kiln inner diameter at which the kiln length is highest. It is also observed from the model predictions that, out of the three media, that is, superheated steam, dry air and humid air, dry air is the most effective drying medium from the point of view of economy as it gives rise to requirement of least kiln length and lowest gas inlet temperature.

[61] Sehrawat, R.; Nema, P. K.; Kaur, B. P., Quality evaluation and drying characteristics of mango cubes dried using low-pressure superheated steam, vacuum and hot air drying methods. LWT, 2018, 92, 548-555, DOI: 10.1016/j.lwt.2018.03.012.

Ripe mango cubes were dried using different methods to process shelf-stable, nutrient-rich and convenient snack. To develop nutritive dried mango cubes as snack (MCS) low-pressure superheated drying (LPSSD) was carried out at 60–80 °C at ∼10 kPa and its effect on quality parameters and on drying behavior were compared to vacuum drying (VD) and hot air drying (HAD). In MCS higher retention of ascorbic acid, β-carotene, total phenol content and antioxidant activity followed the order of LPSSD, VD and HAD. Differences in color parameters, rehydration ratio and activation energy were not significant in MCS dried using LPSSD and VD as compared to HAD. Page model was found to fit best to the experimental data. Higher moisture diffusivity and lower activation energy was obtained in MCS dried by VD, followed by LPSSD and HAD. But, the differences were not significant in the activation energy in between VD and LPSSD process. The appropriate drying conditions for retaining the quality of MCS were found to be at 70 °C using LPSSD and at 60 °C using VD and HAD.

[62] Sehrawat, R. Nema, P. K., Low pressure superheated steam drying of onion slices: kinetics and quality comparison with vacuum and hot air drying in an advanced drying unit. Journal of Food Science and Technology, 2018, 55, 4311-4320, DOI: 10.1007/s13197-018-3379-4.

Pungency is important characteristics of onion and during processing it is generally reduces. Low pressure superheated steam drying (LPSSD) is gaining importance due to energy and product benefits. It results in better retentions of bioactive components. So, in current study onion slices were dried using low pressure superheated steam, and compared with vacuum and hot air drying at different temperature in NIFTEM advance

drying unit. Among the selected models, Page's model gave a better prediction and satisfactorily described drying characteristics of onion slices. The Activation energy was found to be 41.87 kJ/mol in LPSSD. Quality of product, i.e. retention of color, rehydration ratio, thiosulphinate content, total phenol content and antioxidant activity, were better at 70 °C using LPSSD, at 60 °C using VD and HAD, as compared to other drying temperature in respective drying technologies used. Significant differences in quality of the dried product were also observed due to drying temperature in different drying techniques. © 2018, Association of Food Scientists & Technologists (India).

[63] Salinas-Lira, C.; Acuña-Alegría, L.; Sepúlveda-Villarroel, V.; Ananías, R. A.; Salvo-Sepúlveda, L.; Torres-Mella, J.; Cancino-Mundaca, F.; Vasco, D. A., Warp Recovery in Radiata Pine Lumber Using Steam Treatment. BioResources, 2018, 13, 8421-8431, DOI: 10.15376/BIORES.13.4.8421-8431.

Steam treatment was used in this work to correct the observed warp in dried core-wood radiata pine (Pinus radiata) lumber that appears during the industrial drying process at high temperatures. The experimental design considered seven tests and three process variables: temperature, overload, and treatment time. The warp and moisture content before and after the treatment were measured, which allowed for assessing the efficiency of the cup recovery process of the studied thermal treatment programs. Of the analyzed types of warp (twist, bow, crook and cup), only twist was observed to be relevant to the effects of the permissible wood quality classification. The results showed that the twist recovery depends on the temperature, treatment time and overload magnitude. The best treatment results were with a steaming temperature of 100 (°C) and an overload of 3 (ton/m3) applied for 6 (h), which allowed an average recovery value of approximately 43.1%. Moreover, there was an increase in the moisture content and wood density of 10% and 3%, respectively. Finally, the post-treatment of wood with superheated steam did not show a significant improvement to the warp recovery. © 2018.

[64] Rumaisa, N.; Hanim, M. R. N.; Hii, C. L., Superheated Steam Drying of Black Tea and Quality Improvement. International Journal of Food Engineering, 2018, 14, DOI: 10.1515/ijfe-2018-0185.

The effects of drying temperature (120°C to 200°C) on drying characteristics of black tea leaves using superheated steam dryer (SHS) were investigated. It was observed that increased drying temperature caused higher drying rate that helped to shorten drying times. The effective diffusivities of moisture transfer in SHS ranged between 2.30 ×

10-10 and 3.90 × 10-10 m2/s within the temperature range tested. The effective diffusivities were correlated by Arrhenius relationship with Arrhenius constant and activation energy estimated at 1.07 × 10-8 m2/s and activation energy 12.34 kJ/mol, respectively. Increased in drying temperature and time significantly decreased the brightness (∗L) of tea leaves from 26.34 to 22.66 and TPC from 87.93 to 42.39 mg/g. However, comparison to commercial black tea showed that SHS dried-tea leaves exhibited better colour attribute and 91.4% higher in phenolic content. © 2018 Walter de Gruyter GmbH, Berlin/Boston.

[65] Ramachandran, R. P.; Paliwal, J.; Cenkowski, S., Modeling of effective moisture diffusivity and activation energy of distillers' spent grain pellets with solubles during superheated steam drying. Biomass and Bioenergy, 2018, 116, 39-48, DOI: 10.1016/j.biombioe.2018.06.004.

Drying is an essential unit operation needed for safe storage and handling of the wet Distillers' spent grain (DSG), a major by-product of the ethanol industry. For the simulation and modeling of the drying process, a detailed study on different pre-requisite parameters such as the thermo-physical properties and effective moisture diffusivity of the material to be dried is required. The present study reports the effective moisture diffusivity and activation energy of the DSG pellets during superheated steam (SS) drying. Cylindrical DSG pellets at two moisture mass fractions (25 and 35%) and three mass fractions of distillers' solubles (0, 10, and 30%) were dried at three SS temperatures (120, 135, 150, 165, and 180 °C) and three SS velocities (0.5, 1.0, and 1.5 m/s), respectively. The experiment-based moisture diffusivity of the DSG pellet with and without solubles was determined by using the drying characteristic and the analytical solution of Fick's law of diffusion. The results showed that the effective diffusivity increased with an increase in SS temperature and velocity and its value was in the range of 2.49 × 10−9 to 17.9 × 10−9 m2/s. The dependency of the moisture diffusivity on temperature and moisture mass fraction was established by using Arrhenius equation and Levenberg-Marquardt optimization algorithm. The model coefficient and constants were compared with the calculated values of instantaneous effective moisture diffusivity with the mean relative percentage deviation ≤10%. These findings could serve as a fundamental input for the numerical modeling of SS drying of DSG. © 2018.

[66] Piyawanitpong, C.; Therdthai, N.; Ratphitagsanti, W., Effect of precooking and superheated steam treatment on quality of black glutinous rice. Journal of Food Quality, 2018, 2018, DOI: 10.1155/2018/8496723.

Consumption of glutinous rice has been increasing. Leum Pua rice (Oryza sativa Linn.) is black glutinous rice containing high nutrition, but its cooking process is time-consuming. This study aimed at decreasing cooking time by changing rice properties using superheated steam treatment. The black glutinous rice was subjected to pretreatment: Uncooking and precooking before superheated steam treatment at 250°C and 300°C. Drying rate constant (k) of uncooked rice was 0.0301-0.0744 s-1. Precooking rice prior to superheated steam treatment at 300°C reduced the kinetic rate constant to 0.0596 s-1. From SEM, porosity of the treated rice was observed. However, superheated steam treatment reduced ferric reducing antioxidant power and total phenolic content, compared with control. From X-ray diffraction, A-type crystalline structure of the treated rice was disappeared. Cooking time of the superheated steam-treated rice was reduced to 1-5 min. Their hardness and overall liking scores were comparable to control. © 2018 Chinnatat Piyawanitpong et al.

[67] Park, Y.; Yang, S. Y.; Chung, H.; Kim, H.; Yeo, H. Square timber drying by saturated steam and superheated steam based on the drying stress analysis. in WCTE 2018 - World Conference on Timber Engineering. 2018.

Saturated steam and superheated steam were used to dry larch square timber without occurrence of surface checks. The moisture contents (MC) of the square timber, which was dried by saturated steam, became similar with a small difference between the surface and the inner of the timber. Then, the timber was immediately quickly dried in superheated steam. No check occurred during the saturated steam drying process; however, some internal checks were observed during the superheated steam drying process. In addition, the drying stress in the square timber was quantitatively measured using the slice method. The maximum tensile stress in the tangential direction during the drying process was 1.30 MPa, and the tangential tensile strength of the larch wood was 5.21 MPa. Because the maximum tensile stress in the tangential direction of the square timber did not exceed the tensile strength, surface check did not occur. Based on the time of occurrence of the checks and the drying stress measurements, it is expected that larch square timber can be dried without occurrence of checks by changing the superheated steam drying conditions. © WCTE 2018 Committee.

[68] Palmer, G.; Millard, J.; Cobos, J.; Williams, H. An engineered approach to drying refractory concrete for the ammonia and petrochemical industries. in Ammonia Plant Safety and Related Facilities. 2018.

The drying or rapid heating of refractory and ceramics used in the ammonia and methanol industry can be problematic for industry. Despite many advances, the industry still has little choice but to follow supplier "rules of thumb" or "trial and error" when drying or heating refractory. Using advanced engineering simulation techniques and testing installed refractory samples means drying schedules can be optimized and the most economical and safest schedule can be achieved. Accurate measurement of permeability is important. The addition of polymer fiber could reduce explosive spalling risk but cannot eliminate it. Data show that maximum pore pressure is highly dependent on heating rate. Explosive spalling results when the peak pore vapor pressure initiates a crack and the sudden release of the superheated liquid water into steam acts as a propellant.

[69] Orikasa, T.; Ono, N.; Watanabe, T.; Ando, Y.; Shiina, T.; Koide, S., Impact of blanching pretreatment on the drying rate and energy consumption during far-infrared drying of Paprika (Capsicum annuum L.). Food Quality and Safety, 2018, 2, 97-103, DOI: 10.1093/fqsafe/fyy006.

We incorporated a superheated steam blanching pretreatment step into a paprika drying process and compared the far-infrared (FIR) drying rates, hardness of the sample surfaces, cell membrane stabilities, and energy consumption of blanched and non-blanched paprika. The average drying rate of blanched paprika samples during FIR drying was higher than that of non-blanched samples. The hardness and cell membrane stability of dried blanched samples were lower than those of non-blanched samples. We estimated that the softening of the sample surfaces and injury to the cell membranes caused the drying rate to increase. The total energy consumption of the FIR drying of paprika was reduced by approximately 30% by introducing the blanching pretreatment. These findings contribute to the development of environmentally friendly FIR drying techniques for paprika. © 2018 The Author(s). Published by Oxford University Press on behalf of Zhejiang University Press.

[70] Oladejo, A. O.; Ma, H.; Qu, W.; Zhou, C.; Wu, B.; Uzoejinwa, B. B.; Onwude, D. I.; Yang, X., Application of pretreatment methods on agricultural products prior to frying: a review. Journal of the Science of Food and Agriculture, 2018, 98, 456-466, DOI: 10.1002/jsfa.8502.

Frying is one of the methods of processing foods, which imparts flavour, taste, colour and crispness in the fried foods. In spite of an increase in the demand for fried foods by consumers all over the world, the danger posed by consuming too much fat is still a challenge. Many researchers have put forward many ideas on how to reduce the oil uptake and improve the nutritional and organoleptic qualities of foods during frying. Several pretreatment techniques applied to food materials prior to frying have been investigated by researchers in a bid to reduce the oil uptake and improve the quality parameters of fried foods. Therefore, this review focuses on the various pretreatment methods and the recent novel methods like ultrasound, infrared, superheated steam drying, microwave technique and pulsed electric field applied to foods prior to frying and its effects on the qualities of fried foods. © 2017 Society of Chemical Industry. © 2017 Society of Chemical Industry.

[71] Malekjani, N. Jafari, S. M., Simulation of food drying processes by Computational Fluid Dynamics (CFD); recent advances and approaches. Trends in Food Science and Technology, 2018, 78, 206-223, DOI: 10.1016/j.tifs.2018.06.006.

Background: Understanding the mechanisms underlying the drying processes has a critical role in dehydration of food and agricultural products. Advanced computer modeling and simulation techniques can help in developing new dryers, modification of current systems, energy saving and process optimization. Also the most important parameter during the drying food products is food quality (moisture content, crack formation, case hardening, etc.) which can be enhanced through using appropriate modeling. Computational Fluid Dynamics (CFD) is a well-known modeling technique which has received more attention in the food industry in the recent years. Hydrodynamics of fluid flow, heat and mass transfer during drying can be predicted using CFD. Scope and Approach: This article reviews fundamentals, merits and shortcomings of CFD in the drying process modeling with a special focus on dehydration of food products. Since the drying is a growing unit operation, there is an emphasis on investigation of CFD utilization in modeling emerging drying processes of food products such as microwave assisted drying, infrared and superheated steam drying besides conventional convective drying systems notably in recent 5 years. Key Findings and Conclusions: CFD has been considered as a promising method which could help developing the design of new dryers, enhancing current dryers and the most important aspect of utilization of this method in the food industry research and development is “food quality” improvement. © 2018 Elsevier Ltd.

[72] Lum, A.; Mansouri, S.; Hapgood, K.; Woo, M. W., Single droplet drying of milk in air and superheated steam: Particle formation and wettability. Drying Technology, 2018, 36, 1802-1813, DOI: 10.1080/07373937.2017.1416626.

Superheated steam drying has been receiving research attention in recent years due to its increasing industry prevalence in the food and agricultural sector. There is however a gap of knowledge in superheated steam spray drying involving the drying of droplets with dissolved solids as most application to date are solely on solid materials. With this constraint, it is vital to understand and study the effect of superheated steam on the particle formation process as well as on the final particle. The aim of this work is to explore the potential of superheated steam in the spray drying of milk. Specifically, this report examines how superheated steam influences the migration of fats, protein, and lactose in milk during the particle formation process. Studies were conducted by drying fresh milk, using a single droplet drying technique in a superheated steam environment and a hot air environment at a fixed temperature of 110°C. The wettability of the dried single particle was examined using contact angle measurements. The surface of superheated steam-dried milk particles revealed a relatively higher wettability when compared to air-dried milk particles. This suggests that superheated steam promoted the presence of hydrophilic components such as lactose on the exterior surface of the particle. These results have therefore shown the possibility of using superheated steam to control component relocation in multicomponent solutions based on the component hydrophilicity. By recognizing the potential of application of superheated steam in spray drying, engineered multicomponent particles with specific features can be produced. © 2018, © 2018 Taylor & Francis.

[73] Liu, J.; Xu, Q.; Shi, Y.; Wang, R.; Li, Z., Influence of steam condensation on vitamin C retention in green turnip undergoing low pressure superheated steam drying. Journal of Food Process Engineering, 2018, 41, DOI: 10.1111/jfpe.12898.

In this article, green turnip discs were dried in low pressure superheated steam for high vitamin C retention. Drying kinetics and vitamin C variation in green turnip was studied at 95 mbar in superheated steam from 75 to 90 °C, considering the influence of steam condensation on the retention of vitamin C. It was found that an amount of vitamin C was transferred in the condensate water during drying process, especially in the constant evaporation period. Due to steam condensation and assistant electrical heating, the material surface temperature was higher than the water boiling point temperature at corresponding environment pressure when superheated steam stopped condensing. The

condensate occurred in material surface could enhance the loss of vitamin C in green turnip. Vacuum preheating could reduce the amount of steam condensation and material temperature rise, and hence the vitamin C retention in green turnip was higher than that in continuous superheated steam drying. Practical applications: Green turnip is a nutritional, economical and healthy plant, which contains various nutrients such as carotene, ascorbic acid, protein, etc. Dried green turnip has been used as a resource of food seasoning and pickled foods. Fresh green turnip having relatively high moisture contents is very sensitive to microbial spoilage. Drying is one of the most common methods used for green turnip preservation. LPSSD is an innovative technology and which has been applied for dehydration of biological materials due to high nutrients retention, better product appearance, and energy efficiency. Low pressure superheated steam drying process has an initial steam condensation period, transferring an amount of latent heat to the material. It has been demonstrated that steam condensation on sample surface have some influence on material quality. Understanding the effect of condensation on vitamin C retention in green turnip is helpful for improving the quality of dried green turnip slices. © 2018 Wiley Periodicals, Inc.

[74] Li, Z.; Liu, J.; Xu, Q.; Shi, Y., Study on inversion temperature in low pressure superheated steam drying of green turnip slice. Nongye Gongcheng Xuebao/Transactions of the Chinese Society of Agricultural Engineering, 2018, 34, 279-286, DOI: 10.11975/j.issn.1002-6819.2018.01.038.

Low pressure superheated steam drying is an innovative drying technology by utilizing steam beyond its boiling point as a drying medium in a dryer to remove excess water from the material. Low pressure superheated steam drying is commonly used for drying of heat sensitive products or to prevent degradation of volatile components and micronutrients (such as ascorbic acid and β-carotene). Compared with traditional drying methods, low pressure superheated steam drying can preserve the nutrients in food material better during the drying process. However, only when drying temperature is above the inversion temperature, superheated steam drying has an advantage in drying efficiency. There is no constant rate drying period for food material drying in low pressure superheated steam and whether there is an inversion temperature has not been reported in the literatures. Green turnip slice is rich in nutrients and has medicinal value, which is popular with consumers. Dried green turnip slice has been used as a resource of food seasoning and pickled food. In this paper, green turnip slice was selected as experimental material to study the inversion temperature based on the

average drying rate of the first falling rate drying period and the whole drying period. Because the inversion temperature is usually higher, which may cause more loss of nutrients in the material during the drying process, the retention rates of vitamin C in the dried green turnip slices dried by the low pressure superheated steam and vacuum drying below and above the inversion temperature were investigated. Through analyzing the factors influencing the inversion temperature of green turnip slices, lower inversion temperature could be obtained and lower drying temperature for green turnip slice by low pressure superheated steam drying could be selected to reduce the damage of nutrients at high drying temperature. The results showed that there were 2 inversion temperatures based on the 2 drying rates, and the inversion temperature calculated by the whole drying stage was higher than that by the first falling rate drying period. The reason was that with the rise of drying temperature, the temperature difference changes between the material surface and the drying medium by low pressure superheated steam drying were larger than that by vacuum drying. Hence more heat was transferred to the material, and the drying rate was changed more significantly. According to the rehydration characteristics of the product, changes in the internal structure of the material affected moisture diffusion in the late drying period. Thus, the inversion temperature calculated by the whole drying stage was higher than that calculated by the first falling rate drying period. The inversion temperature calculated by the first falling rate drying period increased with the raise of drying pressure, and the influence of material diameter and thickness could be ignored. The inversion temperature calculated by the whole drying period increased with the raise of drying pressure and material thickness, while the influence of material diameter could be ignored. A lower inversion temperature could be obtained by reducing the drying pressure and the thickness of the material within the allowable range of the equipment and material. When the drying temperature was above the inversion temperature, low pressure superheated steam drying had not only a higher drying efficiency than vacuum drying, but also a higher vitamin C retention rate.

[75] Li, Y.; Li, X.; Quan, P.; Cheng, X.; He, X.; Mou, Q., Investigation of drying characteristics in superheated steam drying of UF-impregnated Chinese fir. European Journal of Wood and Wood Products, 2018, 76, 583-589, DOI: 10.1007/s00107-017-1245-0.

Urea formaldehyde (UF) resin-impregnated Chinese fir (Cunninghamia lanceolata (Lamb.)Hook.) was dried at different temperatures in an atmospheric pressure superheated steam dryer. Drying characteristics, moisture content, drying rate, temperature profile, drying defects, and color change were investigated. The moisture content was reduced from 66.21 to 11.79% within 30 h without causing severe drying defects; in contrast, the conventional hot air process required 7–8 days. After 25 h of drying, the temperatures at both the center and the surface of wood remained stable. After 34.5 h, the surface temperature gradually approached the steam temperature. The color of the superheated steam dried Chinese fir appeared slightly more intense yellow and red than the control. Investigation of the UF-impregnated Chinese fir wood by scanning electron microscopy (SEM) revealed that the majority of the lumens and voids, including the microvoids in wood structure, was filled with urea formaldehyde resin. © 2017, The Author(s).

[76] Li, B.; Zhu, W.; Wang, P.; Lu, D.; Wang, L.; Wang, B., Fast drying of cut tobacco in drop tube reactor and its effect on petroleum ether tobacco extracts. Drying Technology, 2018, 36, 1304-1312, DOI: 10.1080/07373937.2017.1402022.

Entrained flow drying is an important fast drying tool in tobacco industry. This study used a drop tube reactor (DTR) as an entrained flow dryer to investigate drying process of flue-cured cut tobacco. Lab-scale cold and hot DTRs were set up to obtain drying kinetics for three types of cut tobacco using different drying gases and temperatures. The effective diffusion coefficients of cut tobacco in DTRs were compared with those in a general cylinder dryer. Moreover, the effects of different drying gases and temperatures on petroleum ether extract content were investigated. The results showed that the effective diffusion coefficients of cut tobacco in the DTRs were between 2.296 × 10−8 and 8–6.244 × 10−8 m2/s, which are two orders of magnitude higher than those in the cylinder dryer. Compared to hot air as a drying medium, superheated steam improved the effective diffusion coefficient of cut tobacco. The petroleum ether tobacco extract had a higher retention ratio when the superheated steam was used in the DTRs. An increase in the drying temperature resulted in a lower retention of the petroleum ether tobacco extract. © 2017, Published with license by Taylor & Francis. © 2017, © Bin Li, Wenkui Zhu, Pengfei Wang, Duanfeng Lu, Le Wang, and Bing Wang.

[77] Le, K. H.; Tsotsas, E.; Kharaghani, A., Continuum-scale modeling of superheated steam drying of cellular plant porous media. International Journal of Heat and Mass Transfer, 2018, 124, 1033-1044, DOI: 10.1016/j.ijheatmasstransfer.2018.04.032.

In this work, a continuous model is developed to describe the dynamics of heat and mass transfer in cellular plant porous media during the superheated steam drying process at atmospheric pressure. This model accounts for the advective liquid and vapor flows in the intercellular void space as well as for the diffusive liquid flow across the solid cell membranes of the porous medium. The numerical results are verified against drying experiments for potato samples, which were carried out by a magnetic suspension balance at three different superheated steam temperatures (160 °C, 180 °C, 200 °C). A comparison between the simulation results and the measured data shows that the drying characteristics of a plant porous medium can fairly be predicted by using the continuous model developed herein. The influence of the cell membrane water conductivity on the spatio-temporal distribution of the moisture content and of the temperature within the porous medium is studied by numerical simulations. It is observed that the water diffusion across the cell membranes controls the dynamics of the heat and mass transfer in the porous medium, and thus the drying kinetics. © 2018 Elsevier Ltd.

[78] Le, K. H.; Hampel, N.; Kharaghani, A.; Bück, A.; Tsotsas, E., Superheated steam drying of single wood particles: A characteristic drying curve model deduced from continuum model simulations and assessed by experiments. Drying Technology, 2018, 36, 1866-1881, DOI: 10.1080/07373937.2018.1444633.

Computational fluid dynamics (CFD) and CFD coupled with discrete element method (DEM) are powerful approaches to describe the drying behavior of real drying towers. In these approaches, the heat and mass interaction between fluid phase and the wet solid is required as an essential input. In this work, a new methodology for establishing simple drying model of single wood particles is presented. First, a spatially resolved continuum-scale model that describes the coupled heat and mass transfer within a single porous wood particle during superheated steam drying under atmospheric pressure is developed. The thermophysical properties of wood particle required as input data for the continuum model are determined experimentally. Then sophisticated continuum model is reduced to a simpler lumped model, which is referred to as the characteristic drying curve (CDC) model. The continuum model simulations are performed in a board range of operating drying conditions and the associated results are used to establish

correlations for the CDC model parameters. The results of both sophisticated and reduced models are validated against the experimental observations made using a magnetic suspension balance. The sensitivity analysis performed with the continuum model indicates a strong dependency of the critical moisture content on particle size and drying condition. The established CDC model can be implemented in the CFD or CFD-DEM model of superheated steam dryers. © 2018, © 2018 Taylor & Francis.

[79] Kovbasyuk, V. I., The Efficiency of Different Technologies for the Preparation and Use of Wet Fuel in Power Engineering. High Temperature, 2018, 56, 581-586, DOI: 10.1134/S0018151X18040107.

We consider the possible technical solutions for the treatment moisture fuel from the standpoint of such general problems as a reduction in greenhouse gas emissions and lowering fuel costs with increased energy generation. The use of the biofuels, which is almost always highly wet, does solve these problems in perspective, but it results in an urgent problem regarding an increase of the energy efficiency of the suitable technologies. The practice shows that a reduction in the costs of fuel and energy production currently takes place with generation based on the cheap brown coal (lignite); however, it is necessary to increase qualitatively the efficiency of power plants in order to reduce fuel consumption, as well as atmospheric emissions. We consider the use of complex technologies of moisture fuel preparation for its efficient application via intensive drying with subsequent gasification in order to pass to the combined cycles with the gas turbines. A new technology for intensive energy-saving drying using superheated pressurized steam is presented. We present an analysis and comparison of the means of such approach to implementation and substantiate the selection of the optimal solutions, which are applicable not only to power engineering but also elsewhere in the utilization of moisture combustible materials and waste products. © 2018, Pleiades Publishing, Ltd.

[80] Kang, E. J.; Park, Y. J.; Park, S. S.; Lee, J. K., Comparative study on physicochemical properties of cherry tomato (Solanum lycopersicum var. cerasiforme) prepared using hot-air and combined drying. Korean Journal of Food Science and Technology, 2018, 50, 339-343, DOI: 10.9721/KJFST.2018.50.3.339.

Effects of different drying processes, such as hot air drying (HA), superheated steam with hot air drying (SHS/ HA), and superheated steam with far infrared radiation (SHS/FIR), on the properties of cherry tomatoes (Solanum lycopersicum var. cerasiforme) were studied. Characteristics of dried cherry tomatoes were determined

by examining the water content, internal microstructure, and rehydration capacity under different drying processes. Moreover, ascorbic acid (AA) and lycopene levels were also measured to evaluate thermal damage caused by drying. Cherry tomatoes dried using both SHS/HA and SHS/FIR had water content and water activity similar to those of intermediate moisture food, indicating partial dehydration after combined drying processes. Although AA and lycopene levels decreased drastically after drying, tomatoes dried using SHS/FIR showed the lowest losses of AA and lycopene among samples. Cherry tomatoes dried using SHS/FIR showed a less compact internal cell structure than that of cherry tomatoes dried using HA and SHS/HA, resulting in the highest rehydration capacity. These results suggest that a combined drying process such as SHS/FIR is more effective than conventional hot air drying for the production of partially dried cherry tomatoes with improved quality attributes. ©The Korean Society of Food Science and Technology.

[81] Jia, Z.; Liu, B.; Li, C.; Fang, T.; Chen, J., Newly designed superheated steam dryer bearing heat recovery unit: Analysis of energy efficiency and kinetics of Kelp drying. Drying Technology, 2018, 36, 1619-1630, DOI: 10.1080/07373937.2017.1420080.

In this work, a newly designed superheated steam dryer (SSD) bearing exhaust heat recovery unit (RD) was fabricated. The dryer was designed for the superheated steam (SS) to be generated by foodstuff being dried, and the latent heat of the exhaust SS was recovered by microtube radiators and exploited to heat the RD unit. The system was then applied in Kelp drying, in which the drying kinetics was analyzed and fitted with mathematical models. The energy efficiency by the system was further evaluated and compared with hot air (HA)-drying. The results showed that the Kelp drying process in SSD could be described by two stages: heat-upstage (stage I) and superheated steam stage (stage II). While in stage I, different heat-up times of 10, 15, and 20 min were required to generate superheated steam at temperatures of 110–150°C, in stage II, the moisture content in Kelp was decreased to approximately 50 ± 5% (wet basis) within 60, 50, and 30 min at 110, 130, and 150°C, respectively. Moreover, the Midilli and Kucuk model best described Kelp drying curve in both stages, whereas the logarithmic model best fitted with that in stage II. Finally, the energy efficiency for SSD-RD was in the range of 1.127–1.425 kWh/kgwater compared with 2.406–2.508 kWh/kgwater for HA operating under the same conditions, demonstrating that the SSD-RD was able to reduce the energy input by at least 46.14%. © 2018, © 2018 Taylor & Francis.

[82] Hou, J.; Yi, S.; Zhou, Y.; Pan, B.; Zhou, F., Effects of platen temperature on moisture state in poplar lumber during hot-press drying. Beijing Linye Daxue Xuebao/Journal of Beijing Forestry University, 2018, 40, 111-116, DOI: 10.13332/j.1000-1522.20180097. [Objective]

In order to provide basis for analyzing hot-press drying mechanism, the temperature and pressure in poplar lumber (Populus tomentosa) were monitored during hot-press drying, and the effects of platen temperature on temperature, pressure and moisture state in the core layer of poplar lumber were further investigated. [Method] Temperature and pressure in the core layer of poplar lumber were measured with the integrated probe and real-time recorded with a data logger at the same time in hot-press drying, and the effects of platen temperature on moisture state were further analyzed in accordance with the comparison of measured pressure and saturated pressure (theoretical pressure) of vapor calculated with measured temperature in poplar lumber. [Result] With the increase of platen temperature from 120 to 140 ℃, the peak value of pressure increased from 146.4 to 213.1 kPa, whereas that of temperature increased from 102.8 to 123.7 ℃. The temperature and pressure reached peak values at the same time, and the time to peak values decreased from 17.5 to 11.6 min. The moisture in the core layer of poplar lumber with moisture content (MC) beyond fiber saturation point (FSP) was unsaturated water under overpressure condition with the platen temperatures of 120 ℃ and 130 ℃, the final MC (48.55% and 49.88%) of core layer was greater than FSP. The heat was transferred from platens to the core layer and resulted in the vaporization of free water in poplar lumber when the platen temperature increased to 140 ℃. State of the steam in core layer of poplar lumber changed from the saturation state to superheated state with the further increase of steam temperature, and the final core MC (27.70%) was lower than FSP. [Conclusion] It was concluded that the higher the platen temperature was, the higher the peak temperature and pressure reached, and the shorter the duration time for keeping peak pressure was in hot-press drying. When the poplar lumber's MC was greater than FSP, the moisture state in poplar lumber may be liquid state (unsaturated water under overpressure condition), saturated steam or superheated steam states depends on different platen temperature levels in hot-press drying.

[83] Hou, J.; Bao, Y.; Zhou, Y., Effects of Superheated Steam Pretreatment on Conventional Drying of 50 mm-Thickness Poplar Lumber. Linye Kexue/Scientia Silvae Sinicae, 2018, 54, 131-136, DOI: 10.11707/j.1001-7488.20180215.

Objective: In order to provide basis for improving drying rate, reducing energy consumption and the high value-added utilization of poplar lumber, the effects of pretreatment with superheated steam (SHS)on conventional drying rate, drying quality and drying time of poplar lumber (Populus tomentosa) were studied in this paper. Method: The SHS pretreatment conditions were following: the temperature was 110, 120 and 125℃ respectively, and the duration was 5 h. The sample dimension was 900 mm × 120 mm × 50 mm(longitudinal × radial × tangential), and the initial moisture content(MC) was ranged between 100% and 150%. The effects of SHS pretreatment on the MC, stress, appearance quality and drying rate during the conventional drying of poplar lumber were analyzed. Furthermore, the drying quality of poplar lumbers with SHS pretreated and untreated was evaluated respectively according to the Chinese national standard. Result: 1) The results of SHS pretreatment showed that the MC decline ratio was increased from 59.26% to 77.11% as the SHS pretreatment temperature increasing from 110℃ to 125℃, and MC of lumber was remarkably decreased and close to fiber saturation point (FSP) in a short time by SHS pretreatment. Residual stress in the SHS pretreated lumbers was ranged from 2.71% to 7.75%. Appearance quality index of the SHS pretreated specimens met the requirements of the 1st drying grade. However, the collapse ratio of SHS pretreated lumbers was ranged from 25.00% to 36.96%. 2)Experimental result of conventional drying revealed that the average drying rate of lumber pretreated by SHS under the temperature of 110, 120 and 125℃ was increased by 7.97%, 16.52% and 78.42% in comparison with conventional drying index of the untreated lumbers. The drying quality index of drying uniformity among different boards and MC deviation in thickness met the requirements of the 1st grade in accordance with national standard of lumber drying quality. However, the final MC met the 2nd grade requirements. Additionally, residual drying stress generated in SHS pretreatment was released in the following conventional drying process, and met the 2nd grade requirements. Appearance quality index of the SHS pretreated lumbers after conventional drying met the requirements of the 1st drying grade. The collapse occurred in SHS pretreatment was partly recovered during the following conventional drying process. Compared with SHS pretreated lumbers, collapse ratio of the conventional dried lumbers was decreased to 28.60%, 9.09% and 15.00%, respectively.

3)Results of total drying time analysis showed that the total drying time of the lumbers pretreated by SHS under 110, 120 and 125℃ was decreased by 24.96%, 44.22% and 67.24% as compared with the conventional dried lumbers. Conclusion: The MC of poplar lumbers was decreased significantly by SHS pretreatment. The drying rate was improved, and the drying time was shortened in the following conventional drying process. In overall consideration of the drying quality and drying efficiency, the optimized SHS pretreatment temperature of 50 mm-thick poplar lumber is 120℃.

[84] Eang, R. Tippayawong, N., Optimization of process variables for drying of cashew nuts by superheated steam. Cogent Engineering, 2018, 5, 1-13, DOI: 10.1080/23311916.2018.1531457.

Cashew is an important economic crop in international market. Thermal processing of cashew nut is essentially an optimization problem. In this work, influence of drying of cashew kernels with testa using superheated steam on product color change and process energy consumption was simultaneously investigated and optimized using response surface methodology. Three independent process variables: temperature (120–140°C), velocity (1–3 m/s), and drying duration (5–30 min) were considered. Box–Behnken design of experiments was employed to obtain the optimum process conditions. It was shown that the second-order polynomials were adequate for the regression model. The coefficient of determination (R2) for the color difference and energy consumption were found to be 0.964 and 0.864, respectively. The color difference and energy consumption were also observed to be a linear function of steam temperature, velocity, and drying duration. For superposition of maximum yield of kernel and other quality indices, optimum thermal processing condition of superheated steam drying was found at 30 min of drying duration, 4 m/s velocity and 115°C temperature of steam.

[85] Darmawan, A.; Fitrianto, A. C.; Aziz, M.; Tokimatsu, K., Integrated system of rice production and electricity generation. Applied Energy, 2018, 220, 672-680, DOI: 10.1016/j.apenergy.2018.03.098.

Research and development of approaches to improve energy efficiency in the rice industry can help stakeholders to make informed decisions. In this study, an enhanced integrated system of both rice production and power generation was proposed. The integrated system mainly consisted of superheated steam drying, husking, polishing,

torrefaction, steam gasification, and power generation. In addition, suitable technology options for power generation and rice production processes for increasing the energy efficiency were also investigated. Furthermore, to contribute to minimization of the exergy loss, recovery was performed by combining the concept of heat circulation and process integration. Results show a considerably higher energy efficiency of the proposed integrated system. In a single rice production system, processing of 200 t rice grain d−1 can generate surplus electricity of about 3.4 MW with an electricity production efficiency of about 32%. A high economic benefit could be achieved by synergetic integration in the rice industry. © 2018 Elsevier Ltd.

[86] Darmawan, A.; Biddinika, M. K.; Huda, M.; Tokimatsu, K.; Aziz, M., Toward sustainable agricultural: Integrated system of rice processing and electricity generation. Chemical Engineering Transactions, 2018, 70, 1669-1674, DOI: 10.3303/CET1870279.

Research and development of approaches to improve the energy efficiency in the rice industry can help stakeholders to make informed decisions. In this study, an enhanced integrated system of both rice production and power generation was proposed. The integrated system mainly consisted of superheated steam drying, husking, polishing, torrefaction, steam gasification, and power generation. In addition, suitable technology options for power generation and rice production processes for increasing the energy efficiency were also investigated. Furthermore, to contribute to minimization of the exergy loss, recovery was performed by combining the concept of heat circulation and process integration. Results show a considerably higher energy efficiency of the proposed integrated system. In a single rice production system, processing of 200 t rice grain d-1 can generate surplus electricity of about 3.4 MW with an electricity production efficiency of about 32 %. A high economic benefit could be achieved by synergetic integration in the rice industry. Copyright © 2018, AIDIC Servizi S.r.l.

[87] Celen, P. Erdem, H. H., An experimental investigation of single lignite particle dried in superheated steam and hot air. International Journal of Coal Preparation and Utilization, 2018, DOI: 10.1080/19392699.2018.1536047.

In lignite (low-rank coal)-fired thermal power plants, thermal efficiency can be improved by decreasing the lignite moisture. The lignite moisture can be removed by using superheated steam and hot air as drying fluids. In this study, Turkish (Afşin-Elbistan) lignite having a diameter of 30 mm was dried with superheated steam and hot air at temperatures of 117°C under atmospheric pressure. The changes in its weight and

temperature with time were observed, and the drying characteristics were obtained during the drying process. In the first period of drying, which is called heating period, the drying rate of superheated steam is higher than hot air in contrary to during constant-rate period. Moreover, the experiments revealed that less time is required to heat lignite sample with superheated steam compared to hot air. © 2018, © 2018 Taylor & Francis Group, LLC.

[88] Behera, G. Sutar, P. P., A comprehensive review of mathematical modeling of paddy parboiling and drying: Effects of modern techniques on process kinetics and rice quality. Trends in Food Science and Technology, 2018, 75, 206-230, DOI: 10.1016/j.tifs.2018.03.015.

Background: Paddy is one of the most important food crops in the world. The major operations of paddy processing are soaking, parboiling/steaming, drying and milling. The paddy processing is an energy-intensive process with the substantial wastewater generation. Scope and approach: The knowledge of mathematical modeling in different stages of paddy processing helps to improve the final rice quality and reduce the energy consumption. The present article analyzes the results of the recently published research work on different models used in paddy soaking, parboiling and drying operations. In addition, the article discusses the effects of modern methods of parboiling and drying operations on the process kinetics, microstructural changes and rice quality. Key findings and conclusions: Hot water soaking (40–80 °C), single steaming, double steaming, pressure cooking and microwave heating are used to parboil or gelatinize the starch in rice. Also, acids/alkaline solutions can gelatinize the rice starch. The open sun (2–4 days), hot air (50–80 °C), superheated steam, vacuum, infrared (0·167-0·625 W cm−2), and microwave drying (2.45 GHz) are employed to dry the parboiled paddy up to 12–14% moisture content (db). Modelling and simulation tools have been used to study these complex processes during paddy hydration, starch gelatinization and drying. Fick's law of diffusion, Peleg model, and exponential equation are used to describe the water sorption in paddy. Arrhenius equation, Ozawa Model and Kissinger equation are useful in understanding the starch gelatinization kinetics. Several empirical and semi-empirical models are used to study the drying kinetics of gelatinized paddy. In drying, the models given by Page, Henderson and Pabis and Newton describe the drying kinetics better than other models. The effects of modern methods of the parboiling and drying can be understood from the kinetics and other constants of the models as well as from the change in the microstructure of starch that takes place in the

process of gelatinization. The recent developments on the effects of modern methods of hydration, parboiling and drying with limitations have also been focussed in the manuscript. Because of the concerns of wastewater generation during paddy hydration and parboiling, new techniques need to be developed for reducing wastewater generation and its treatment. © 2018 Elsevier Ltd.

[89] Batenin, V. M. Kovbasyuk, V. I., On the Technology of Sediment Sewage Utilization. Thermal Engineering, 2018, 65, 935-937, DOI: 10.1134/S0040601518130037.

The solution of the problem of disposing of human waste, including sewage sludge, is an important task of environmental technologies, which today use modern energy achievements, safe combustion, and energy utilization. The specific goal of the present work was the qualitative improvement of technologies of this kind, not so much for the sake of obtaining a large energy output but for the creation of an efficient, affordable, and ecologically perfect equipment based on advanced developments in the field of power generation on wet fuels. The possibility for successful implementation of new technologies is oriented towards the drying of moisture in organic materials and gasification of dried mass. The examples of new equipment are not yet experimentally tested. © 2018, Pleiades Publishing, Inc.

[90] Baranski, J., Moisture content during and after high- and normal-temperature drying processes of wood. Drying Technology, 2018, 36, 751-761, DOI: 10.1080/07373937.2017.1355319.

The aim of the article is to present the results of moisture content of wood during and after the high-temperature steam and air–steam mixture drying processes and after an open air-drying process. The knowledge of moisture content changes of wood in the process of its drying is one of the important parameters to economy drying process and to keep the quality of dried wood. Wood samples, namely, spruce (Picea abies K.) and beech (Fagus silvatica L.) from the northern part of Poland, were subject to steam, air–steam mixture and, air-drying, respectively, with a temperatures about 105, 80, and 25°C. The samples of thickness 70 mm and length about 1,050 of spruce, and about 1,500 mm of beech were used. They were machined by the modern narrow kerf frame sawing machine. Temperature of the cross section of dried wood was measured by thermocouples, wood moisture content was determined during process using moisture sensors. Measurements of moisture content for steam-dried and air-dried samples, as reference, allowed to reveal the effect of drying process on moisture content of wood.

It has been recognized that steam wood drying causes almost constant amount of moisture in treated material in comparison to air-drying one. © 2017 Taylor & Francis.

[91] Barannikov, M. V. Bazarov, Y. M., Influence of methods of preparing polyamide-6 to processes of treatment on properties of finished product. ChemChemTech, 2018, 61, 72-75, DOI: 10.6060/tcct.20186104-05.5669.

When preparing the polyamide-6 granulate for treatment proceses, its properties such as the content of low-molecular compounds (caprolactam and oligomers, LMC) and relative viscosity are normalized. Two alternative methods of preparing the polyamide-6 granulate for proceesing are used: 1) currently, the industry uses a method consisting of stages of aqueous extraction of lowmolecular compounds from PA-6 granules, followed by drying of the latter and separation of LMC from extraction solutions by evaporation; 2) an alternative process is being developed, which consists in simultaneously carrying out the drying and demonomerization of polyamide-6 granulate. Through of these methods samples of granulate of polyamide-6 of 2 kinds were prepared: 1) equilibrium matted granulate of industrial production; 2) granules after solid-phase dopolyamination in a superheated steam environment. These samples were conversed by the re-melting method, which consists in melting the polyamide-6 granulate at T = 270 °C. The properties of these samples were determined before and after the conversion using the following methods: the content of low molecular weight compounds is determined by their extraction from granules. The content of caprolactam is determined by its sublimation from granules; the value of the relative viscosity is determined by viscometry. It is shown that during the process of conversion of the polyamide-6 granulate, the polymer acquires practically the same properties, regardless of the preparation method. Thus, it is proved that the process of combined drying-demonomerization is more advantageous in terms of energy and material costs than the process of extraction of low-molecular compounds from the polyamide-6 granulate. © 2018 Ivanovo State University of Chemistry and Technology.

[92] Bantle, M.; Schlemminger, C.; Tolstorebrov, I.; Ahrens, M.; Evenmo, K. Performance evaluation of two stage mechanical vapour recompression with turbo-compressors. in Refrigeration Science and Technology. 2018.

Mechanical Vapour Recompression (MVR) is an open loop heat pump system using water (R718) as working fluid, one of the most abundant and safest refrigerant on the planet. The concept can significantly reduce the energy consumption for steam based processes like drying, pasteurization, evaporation or distillation but also for steam

production itself. However, the compression technology is commonly not cost efficient especially for small scale productions in the capacity range from 500 kW to 4 MW. A two stage turbo-compression system was developed and tested based on mass produced automotive turbocharger technology. The turbo-compressor of the first stage reached a pressure ratio of 1.69 and is designed for a mass flow of 400-600 kg/h superheated steam. The second stage turbo-compressor had an identical design and achieved the same pressure ratio. Between compression stage one and two de-superheating is applied by water injection. With the developed system it is possible to compress superheated steam from atmospheric pressure to above 2.8 bar, where it can be condensed at a temperature of 131°C. The COP of the performed investigation was 7.8, when the achievable condensation energy is compared to the total amount of energy supplied to the system. The compressor efficiency is around 70% of the Carnot efficiency.

[93] Arima, K.; Tsuchiyama, Y.; Sawatsubashi, T.; Kinoshita, M.; Ishii, H., Drying of wet brown coal particles by a steam-fluidized bed dryer. Drying Technology, 2018, 36, 664-672, DOI: 10.1080/07373937.2017.1323337.

Although the world has abundant resources of brown coal, its moisture content is often high. Thus, a fluidized bed drying system using superheated steam for fluidizing gas has been developed as large-capacity and low-energy-consumption drying technology. Since brown coal particles have wide particle size distribution and cohesiveness due to high moisture content, it is important to know their fluidization characteristics as well as handling characteristics in storage and transportation facilities. However, their drying characteristics are complicated because brown coal contains water in various forms, namely, free water on a surface, bound water in small pores, and non-freezable water chemically bound to hydrophilic functional groups. In this work, basic experiments were carried out to evaluate drying characteristics of brown coal particles. Drying rate, critical, and equilibrium moisture content were formulated and their relevance to the forms of water was discussed. Also the influence of moisture content on flow properties of pulverized coal was evaluated in relation with forms of water.

[94] Alves-Filho, O., Energy effective and green drying technologies with industrial applications. Chemical Engineering Transactions, 2018, 70, 145-150, DOI: 10.3303/CET1870025.

Heat pump drying is a green technology with zero global warming potential and zero ozone depletion potential when operating with natural fluids. A well designed heat pump dryer can be several times more energy efficient and less costly than conventional dryers. This dryer beneficially contributes to a sustainable society while providing superior products at competitive cost. It is an advanced engineered drying technology ready for implementation by modern industries wishing a return of investment while contributing to a sustainable society. This paper covers the advances in heat pump and superheated steam drying technologies. These drying processes are in the category of green technologies because they are highly effective and advantageous for the environment and climate change. Descriptions and layouts are given covering design of heat pump and steam dryers. Details are provided in their beneficial operation in single and multistage with vapor compression and drying chambers placed in series. The drying modes covered are atmospheric sublimation and evaporation for improved capacity and superior characteristics of dried materials. The future trend is heat pump drying with natural fluids and superheated steam drying complying with proper industrial practice and with regulations reducing damage to sea, soil and water as well as zeroing contribution to global warming and to climate change. These technologies have been built and extensive R&D has been done at Norwegian University of Science and Technology in Trondheim. The technology has progressed to pilot scale and industrial applications indicating a small but real contribution to a better society today and tomorrow. Lastly, this is an advanced engineered drying technology ready for implementation by modern industries wishing a return of investment while preserving the environment. Copyright © 2018, AIDIC Servizi S.r.l.

[95] Altgen, M.; Willems, W.; Hosseinpourpia, R.; Rautkari, L., Hydroxyl accessibility and dimensional changes of Scots pine sapwood affected by alterations in the cell wall ultrastructure during heat-treatment. Polymer Degradation and Stability, 2018, 152, 244-252, DOI: 10.1016/j.polymdegradstab.2018.05.005.

There is a complex link between the water sorption behavior and the presence of accessible hydroxyl groups in the wood cell wall, which can be altered by heat-treatment (HT). This study analyses the effect of changes in the cell wall ultrastructure caused by two HT techniques on the hydroxyl accessibility, water vapor sorption and dimensional changes of Scots pine (Pinus sylvestris L.) sapwood. HT of wood in pressurized hot water at 120–170 °C was applied to cause the preferential bond cleavage, whereas HT of wood in oven-dry state in superheated steam at 180–240 °C

was performed to create additional covalent cross-links within the cell wall matrix. Removal of cell wall polymers by HT and water leaching reduced the oven-dry dimensions of wood and enhanced the cellulose aggregation during drying. Cellulose aggregation restricted the cell wall shrinkage in circumferential direction, resulting in inhomogeneous shrinkage of the cell wall with only little changes in lumen volume by HT. Cellulose aggregation also reduced the water-saturated dimensions, but a decrease in swelling was only achieved when additional cross-links were formed by HT in dry state. Additional cross-links in the cell wall matrix also resulted in an additional reduction in water sorption at 25 °C and 93% RH. However, this was not caused by a further reduction in the hydroxyl accessibility. Instead, cross-linking was shown to reduce the amount of accessible OH groups that are simultaneously active in sorption, which was explained based on the concept of sorption of water dimers at hydroxyl group pairs at high RH levels. © 2018 Elsevier Ltd.

[96] Zhifeng, X.; Fan, Z.; Lei, X.; Jianhong, W.; Nanxing, W., Numerical Simulation on Superheated Steam Fluidized Bed Drying at Different Operating Pressures. International Journal of Food Engineering, 2017, 13, DOI: 10.1515/ijfe-2017-0093.

During superheated steam fluidized bed drying process, the operating pressure has an important influence on heat and mass transfer characteristics and the vapor-solid two-phase flow characteristics. Based on the two-dimensional unsteady model of rapeseeds drying process, the influence of operating pressure on the superheated steam fluidized bed drying kinetics was revealed by computer numerical simulation. The quantitative analysis of relationship between operating pressure and maximum drying rate was conducted under negative pressure, near atmospheric pressure and high pressure environment, respectively. The optimum operating pressure values for superheated steam fluidized bed drying were obtained with the imported superheated steam temperature and superficial velocity. The simulation results provide a theoretical reference for superheated steam fluidized bed drying technology applying to agro-processing projects. © 2017 Walter de Gruyter GmbH, Berlin/Boston.

[97] Zhan, J. F. Avramidis, S., Impact of conventional drying and thermal post-treatment on the residual stresses and shape deformations of larch lumber. Drying Technology, 2017, 35, 15-24, DOI: 10.1080/07373937.2016.1156123.

Quality evaluation and grading of thermally treated wood products are of fundamental importance to their commercial utilization. The combined impacts of conventional drying, thermal post-treatment, and transverse dimensions of lumber over the residual

stresses and shape deformations of larch (Larix gmelinii) wood were examined. Larch specimens with two different thicknesses (25 and 40 mm) and three different widths (100, 150, and 200 mm) were dried using conventional technology and thereafter thermally treated at 200°C for 1 h at atmospheric superheated steam conditions. Drying and residual stresses and shape deformations of both kiln-dried and thermally post-treated lumbers were measured and statistically analyzed. The influential mechanisms of lumber thickness and width over the drying stresses and shape deformations of thermally post-treated lumbers were revealed. The drying and residual stress measurement based on the prong test was recommended as a potential quality evaluation strategy for the thermally post-treated larch lumbers. As the lumber width increased from 100 to 150 mm, and then to 200 mm, the cupping deformation of thermally post-treated larch lumber increased substantially. These results provided some practical foundations for the quality evaluation of thermally treated wood.

[98] Yang, X. H.; Zhang, Q.; Wang, J.; Deng, L. Z.; Kan, Z., Innovative superheated steam impingement blanching (SSIB) enhances drying rate and quality attributes of line pepper. Information Processing in Agriculture, 2017, 4, 283-290, DOI: 10.1016/j.inpa.2017.07.004.

Blanching is an essential step before processing of agricultural products as it can inactivate enzymes that cause undesirable changes. In current work the effects of superheated steam impingement blanching (SSIB) time and temperature on drying characteristics and red pigments content of line pepper were investigated. Results showed that after a 3-min SSIB pretreatment at 110 °C the pepper epidermis covered with wax coat was damaged. In addition, the drying time was extensively decreased and the loss of red pigments of dried products was reduced. Results showed that the whole drying process took place in the falling rate period, which indicated that diffusion was the dominant physical mechanism governing moisture movement in the samples. Therefore, the second Fick's law of diffusion was used to determine the effective moisture diffusivity (Deff) of line pepper, which increased from 1.193 × 10−10 to 3.128 × 10−10 m2/s with increasing of the drying temperature and air velocity. The drying activation energy (Ea) of pretreated samples was 34.31 kJ/mol, which decreased by 3% compared with the non-pretreatment group. The findings of this work indicate that SSIB is very promising pretreatment technique as it not only enhances drying process but

also improves bioactive substance preservation of red pepper. © 2017 China Agricultural University.

[99] Xia, L.; Zhang, H.; He, J.; Yao, Y.; Yu, C., Simulation investigation of single oil shale particles drying in superheated steam and experimental validation. Oil Shale, 2017, 34, 232-249, DOI: 10.3176/oil.2017.3.03.

Oil shale is an important unconventional energy and has enormous reserves in the world. However, the high moisture content reduces the efficiency of oil production in the pyrolysis process. In this paper, experimental and numerical studies were conducted on the drying performance of single Liu Shu River oil shale particles in superheated steam. A 3-D model was developed to simulate the heat and mass transfer process inside the particle, taking into account its property of anisotropy transfer. Generally, it is concluded that the moisture removal rate increases as the steam temperature increases, while increasing the particle size decreases the moisture removal rate. In the whole drying process, the decreasing drying rate period was longer than the constant drying rate period. The anisotropy had an influence on moisture transfer rather than heat transfer process. The moisture content profiles and temperature fields inside the particle were determined at selected times. Several experiments were carried out under the conditions of different temperatures (463-483 K) and particle sizes (5-9 mm). It was found that the developed model predictions agreed well with the experimental data. It is significant to get the microscopic parameters for the investigation of oil shale drying in superheated steam fluidized bed. © 2017 Estonian Academy Publishers.

[100] Tawatsinlapasorn, N.; Kuljarachanan, T.; Chiewchan, N.; Devahastin, S., Effects of drying techniques on selected functional properties and bioactive compounds of dietary fiber from the outer leaves of cabbage. Chiang Mai University Journal of Natural Sciences, 2017, 16, 19-30, DOI: 10.12982/cmujns.2017.0002.

The outer leaves of cabbage (Brassica oleracea L. var. capitata), which are usually discarded during processing or selling at the market, have been reported as a good raw material for producing functional dietary fiber powder. This study investigated the effects of different drying techniques, i.e., hot-air drying, vacuum drying and low-pressure superheated steam drying at 80°C, on selected functional properties and bioactive compounds of dietary fiber powder from the outer leaves of cabbage. The results showed that vacuum drying improved water retention capacity and swelling capacity of the dietary fiber powder compared to the hot-air dried sample. Neither the pressure level (5 and 10 kPa absolute pressure) nor steam injection before vacuum

drying at 10 kPa affected the water retention or swelling capacities of the powder. No significant differences in the oil holding capacity (OHC) were observed among the samples prepared using different drying schemes. Vacuum-dried samples contained the highest contents of glucosinolates and phenolics. Overall, the results showed that powder undergoing vacuum drying at 80°C at 5 kPa possessed good functional properties and contained the most glucosinolates and phenols.

[101] Tatemoto, Y., Drying of wet material in fluidized bed under reduced pressure. Journal of the Society of Powder Technology, Japan, 2017, 54, 311-317, DOI: 10.4164/sptj.54.311.

A fluidized bed dryer is used in various fields since it has high drying rate. For the drying of heat sensitive materials, the drying should be performed at low temperature. The fluidized bed drying under reduced pressure is one of the methods to dry the heat sensitive materials at low temperature with high drying rate. In this paper, fundamental of the fluidized bed drying under reduced pressure is explained. The drying in the fluidized bed of medium particles is also treated in this paper.

[102] Stenström, S., Drying of biofuels from the forest—A review. Drying Technology, 2017, 35, 1167-1181, DOI: 10.1080/07373937.2016.1258571.

The literature during 2000–2016 about drying of biofuels from the forest has been reviewed. Biofuels constitute a low-cost energy resource that is likely to continue to increase and the dryers for such products should be simple, robust, and easy to operate. In 1970s and 1980s, rotary dryers and flash dryers were the most common types, and in 1990s, superheated steam (SHS) dryers became common. Maintenance costs and use of medium pressure steam for the SHS dryers are important topics to consider and one drawback for the rotary dryers is that high-temperature heat sources are used. The development during the last 15 years has moved toward moving bed dryers because of the possibility to use cheap low-temperature energy sources, robust design, and direct capacity control that is achieved by controlling the air temperature in the dryer. A price for the dry biofuel of 15–20 Euro/MWh has been indicated to make a dryer installation profitable based on no cost for the thermal energy and 40 Euro/MWh as the cost for the electrical energy. Shrinkage and the internal transport of moisture and heat in large particles of biofuels will need more considerations in the future. Fractionation of the biofuels, codrying with other products, the total cost for the drying process,

environmental issues, and development of drying processes operating at high dew points are the other things to consider. © 2017 Taylor & Francis.

[103] Sommier, A.; Anguy, Y.; Pradére, C. Optimization of French bread baking using superheated steam. in Proceedings of the 9th International Congress FLOUR-BREAD 2017 - 11th Croatian Congress of Cereal Technologists. 2017.

French bread is well known all around the world. We see the bread-maker as an "artist" making many different products with only a few simple ingredients: flour, salt, water, sometimes, yeast along with a few other ingredients (ascorbic acid, bean flour, exogenous enzymes). French bread requires energy, time and dexterity. In this paper, the link between the heat and the mass transfer for a French loaf of bread is highlighted, as well as the interaction between the oven and the product. The link between thickness, mass and internal pressure of the product as driven by temperature and relative humidity in the oven is addressed. The stress is on the impact of steam on the porosity and the size of the starch grains. Using this knowledge, it becomes clear that the baking process is two-fold: the first phase is the expansion of the dough and the second phase is a drying process leading to crust formation. Based on this knowledge, superheated steam is used as an energy vector added to the classical ones, namely, radiative and contact. We present a pilot oven and a new baking process using superheated steam at the key time. This strategy leads to a baking time reduction (26%) and to a lowering of energy consumption (12%). The obtained product was tested by an expert panel and jugged to be of the quality of a traditional product. © 2018 Ingenta.society or author(s) as specified within the article.

[104] Sittiritkawin, P.; Achariyaviriya, S.; Achariyaviriya, A.; Namsanguan, K., Investigation of drying pumpkin slices by low-pressure superheated steam. International Agricultural Engineering Journal, 2017, 26, 200-212.

This paper aims to investigate the use of low-pressure superheated steam (LPSS) drying for pumpkin slices. The experiments were conducted at the drying temperatures of 80°C-120°C and absolute pressures of 7-40 kPa to examine the drying kinetics, quality of dried products viz. color, shrinkage, rehydration, microstructure, texture (hardness and crispness) and β-carotene degradation, and the specific energy consumption(SEC) of the process. Results showed that drying at higher temperature and lower pressure reduced the drying time and SEC, except at pressures of 30-40 kPa. Page's equation was used to describe the drying kinetics, in which its kinetic parameters were expressed as a function of drying conditions. Higher drying temperature resulted in lower

shrinkage, better rehydration and texture whereas pressure had no obvious effect on almost all quality, however, lower pressure provided better β-carotene retention. Furthermore, the product color was not obviously affected by these drying conditions. LPSS drying at 120°C and 7 kPa was proposed as the most favorable condition for drying pumpkin slices.

[105] Ramachandran, R. P.; Bourassa, J.; Paliwal, J.; Cenkowski, S., Effect of temperature and velocity of superheated steam on initial condensation of distillers' spent grain pellets during drying. Drying Technology, 2017, 35, 182-192, DOI: 10.1080/07373937.2016.1166123.

Initial condensation on the sample surface during superheated steam (SS) drying leads to increased sample moisture affecting its mechanical and thermal properties. A study was conducted to understand the effect of temperature and velocity of SS on the amount of initial condensation on distillers' spent grain pellets with an initial moisture content of 25% (wet basis). These pellets were dried using SS at 120, 150, and 180°C with velocities 0.5, 1.0, 1.2, and 1.4 m/s. Separate experiments were conducted for recording mass and surface temperature of the pellets during SS drying. Mass recorded over the drying period was then compared with the predicted mass obtained by solving the standard heat balance and film condensation equations. The predicted values of mass flux due to initial condensation were in close agreement with directly measured values with a maximum mean square error of 0.20. There was a 60–64% decrease in the amount of initial condensation as the temperature of SS was increased from 120 to 180°C. The results indicate that the initial condensation can be minimal when the temperature of SS is equal or above 180°C with SS velocity equal or above 1 m/s using a preheated drying chamber. © 2017 Taylor & Francis.

[106] Ramachandran, R. P.; Akbarzadeh, M.; Paliwal, J.; Cenkowski, S., Three-dimensional CFD modelling of superheated steam drying of a single distillers' spent grain pellet. Journal of Food Engineering, 2017, 212, 121-135, DOI: 10.1016/j.jfoodeng.2017.05.025.

The classic method of modelling drying processes using the transfer coefficients can be replaced by a method of solving Reynolds-Averaged Navier-Stokes equations applicable to the drying medium. This specifically applies to superheated steam (SS) as the drying medium, where the mass transfer coefficient cannot be defined by heat transfer analogy. In this study, the heat and mass transfer phenomena of SS drying of distillers' spent grain (DSG) pellets were numerically studied using a commercial

Computational Fluid Dynamics (CFD) package by combining the drying models related to the moist cylinder with the model describing the external flow of SS. A three-dimensional (3D) model of the DSG pellet and the drying chamber was created. The governing differential equations for mass and energy balance of the pellet and steam-flow around it were solved using the finite volume method and SIMPLEC algorithm within the CFD package (ANSYS CFX). The validation of the numerical model with experimental observations showed a good agreement with a mean relative percentage error less than or equal to 10%. The obtained mathematical model could serve as a basic tool for optimization and design of large-scale SS dryers for DSG. © 2017 Elsevier Ltd.

[107] Pham, N. D.; Ghnimi, S.; Abesinghe, A. M. N. L.; Joardder, M. U. H.; Petley, T.; Muller, S.; Karim, M. A., Effects of process conditions of intermittent drying on quality of food materials, in Intermittent and Nonstationary Drying Technologies: Principles and Applications. 2017. p. 97-121.

Consumer acceptance of the dehydrated product is strongly influenced by the nutrient and sensorial quality of dried food. The quality of the dehydrated product can be improved significantly in terms of chemical, physical, and microbial attributes, while reducing the total energy supply and effective drying time by controlling thermal energy supply, airflow, humidity of drying medium, and drying chamber pressure at intervals during drying. This book chapter investigates the effect of different intermittent drying methods on physical, chemical, nutritional, and microbiological characteristics of food. Different intermittent drying methods including intermittent convective, heat pump, microwave, superheated steam, and fluidized bed drying are discussed, and their effects on food quality parameters such as vitamin C, carotenoids, polyphenol, antioxidant activity, and microbiological stability have been presented. Comparison of different models in predicting quality change during intermittent drying is also made. © 2017 by Taylor & Francis Group, LLC.

[108] Park, Y.; Jang, S. K.; Park, J. H.; Yang, S. Y.; Chung, H.; Han, Y.; Chang, Y. S.; Choi, I. G.; Yeo, H., Changes of major chemical components in larch wood through combined treatment of drying and heat treatment using superheated steam. Journal of Wood Science, 2017, 63, 635-643, DOI: 10.1007/s10086-017-1657-9.

The effects of the combined treatment of drying and heat treatment using superheated steam (SHS) were studied relative to the changes of the major chemical components in larch wood. The green lumber was dried and heat-treated in SHS conditions of 250 °C and 0.5 MPa for 18 h, and the relative percentage contents of sugars, lignin, and

extractives were investigated and compared with the relative percentage contents in the lumber heat-treated in hot air conditions of 250 °C and atmospheric pressure for 18 h. After both heat treatment methods, the relative percentage contents of xylan, mannan, galactan, and arabinan were greatly decreased, whereas that of the Klason lignin was increased, additionally that of glucan and extractives remained almost unchanged. Lignin may bind with furan compounds decomposed from hemicellulose following heat treatment, thus contributing to the increase in the apparent relative percentage contents of the Klason lignin. In addition, the condensate collected in the condenser after combined drying and heat treatment using SHS was investigated qualitatively and quantitatively by high-performance liquid chromatography (HPLC). A large amount of furfural and acetic acid decomposed from hemicellulose was detected and some sugar components composed of cellulose and hemicellulose were detected in the liquid condensate. © 2017, The Japan Wood Research Society.

[109] Park, Y.; Han, Y.; Park, J. H.; Chang, Y. S.; Yang, S. Y.; Chung, H.; Yeo, H., Evaluation of the energy efficiency of combined drying and heat treatment by superheated steam. Drying Technology, 2017, 35, 1460-1467, DOI: 10.1080/07373937.2016.1254651.

This study compares energy efficiency of a combined drying and heat treatment with that of conventional hot air heat treatment, the theoretical heat consumptions required for each treatment were determined, and the actual heat consumptions for each treatment were measured at a pilot scale. Conventional heat treatment method separately performs kiln-drying and heat treatment for wood with hot air in different equipment. On the contrary, in the combined treatment, the wood is simultaneously dried and heat-treated in the same enclosed space. Because of the time and energy savings, the economic feasibility of combined treatment is much higher than that of conventional heat treatment. Although the theoretical required energy of the combined treatment was similar to that of the two-stage method, the actual energy consumption of combined treatment was less than that of the two-stage method. And, the energy efficiency of the combined treatment was calculated to be two times higher than that of the two-stage method. From the results of this study, decreases in the processing time and energy consumption and increases in the energy efficiency of the combined treatment by superheated steam were quantitatively shown when compared to two-stage method. © 2017 Taylor & Francis.

[110] Okoro, O. V.; Sun, Z.; Birch, J. Enhanced fatty acid generation from meat processing dissolved air flotation sludge. in European Biomass Conference and Exhibition Proceedings. 2017.

The hydroesterification process is a two-stage biodiesel production process that integrates a hydrolysis step and an esterification step to circumvent the challenges of the high free fatty acid content and high moisture content of low-grade lipid sources. These challenges limit the feasibility of such low grade lipid sources as the feedstock for biodiesel production via the conventional alkaline catalysed transesterification process, due to unwanted saponification side reactions. The esterification step is normally completed efficiently. However, the high temperature and high pressure operating conditions and the concentrated mineral acid catalyst utilised in the initial hydrolysis step constitute major concerns, because a large mass of superheated steam, high pressure pumping systems, and expensive corrosion resistant equipment are required. This study therefore investigated the feasibility of an in-situ lipid hydrolysis of meat processing dissolved air flotation sludge to generate fatty acids. This in-situ lipid hydrolysis process was catalysed using a polystyrene sulphonic microporous resin to enhance fatty acid generation. Such an in-situ approach will enable the invention of a single step lipid extraction and lipid hydrolysis process that will bypass the need for preliminary drying and lipid extraction operations, with the lipid hydrolysis achieved under moderate conditions.

[111] Morikawa, T.; Takada, N.; Miura, M., Effect of decompression drying treatment on physical properties of solid foods. Bioscience, Biotechnology and Biochemistry, 2017, 81, 831-838, DOI: 10.1080/09168451.2017.1281728.

This study used a decompression drying instrument to investigate the effects of a drying treatment on the physical properties of solid foods. Commercial tofu was used as a model food and was treated at different temperature and pressure conditions in a drying chamber. Overall, high temperatures resulted in better drying. Additionally, pressure in the chamber influenced the drying conditions of samples. Differences in physical properties, such as food texture, shrinkage, and color were observed among some samples, even with similar moisture content. This was caused by differences in moisture distribution in the food, which seems to have manifested as a thin, dried film on the surfaces of samples. It caused inefficient drying and changes in physical properties. Control of the drying conditions (i.e. pressure and heat supply) has relations

with not only physical properties, but also the drying efficiency of solid foods. © 2017 Japan Society for Bioscience, Biotechnology, and Agrochemistry.

[112] Mohapatra, D.; Kumar, S.; Kotwaliwale, N.; Singh, K. K., Critical factors responsible for fungi growth in stored food grains and non-Chemical approaches for their control. Industrial Crops and Products, 2017, 108, 162-182, DOI: 10.1016/j.indcrop.2017.06.039.

Fungi contamination in stored food grains is a global concern and affects the food economics directly and indirectly. Fungi invasion causes loss of germination, hot spot generation, colour, flavour, and degradation of nutritive value. Adding to it, the fungi produce toxigenic secondary metabolites, which have several health repercussions. Increasing awareness regarding the ill effects of chemical fungicides had led to exploration of sustainable non-chemical methods of stored grain protection. The current review examines the role of water content, storage temperature, initial infections, the presence of another vector like insects and mites, contaminated storage space, and handling equipment, for fungal growth. The review also explored various non-chemical fungi management practices that include traditional practices like drying to safe moisture level, aeration, dry heating, or new age control measures such as hermetic storage, microwave heating, application of gaseous ozone, cold plasma, ionizing radiation, pulsed light (PL), supercritical carbon dioxide (SC[sbnd]CO2) co-solvent system, ultra-superheated steam (USST). In addition, potentials of plant essential oils (EO), plant derivatives, and vegetable oil, for prevention of storage fungi growth are also explored to mitigate sustainable fungi control strategies. © 2017 Elsevier B.V.

[113] Liu, J.; Zang, L.; Xu, Q.; Wang, R.; Li, Z., Drying of soy sauce residue in superheated steam at atmospheric pressure. Drying Technology, 2017, 35, 1656-1663, DOI: 10.1080/07373937.2016.1273232.

Soy sauce residue needs drying to avoid fermentation and oxidation during storage and transportation, and its reutilization as a useful resource is expected. Superheated steam drying was applied to investigate the effects of drying conditions on the drying characteristics and the content changes of salt and protein. The results showed that the inversion temperature was about 130°C, beyond which superheated steam drying was faster than hot air-drying. The drying time approaching equilibrium moisture content was reduced with elevated drying temperature as well as higher steam mass flow rate in the present experimental conditions. The effect of bed thickness on drying time was not obvious when drying temperature increased. Interestingly, the salt content of soy

sauce residue could be decreased by 34.8% due to condensate water in the initial drying period (wetting), while protein content had no significant loss ($p < 0.05$) after superheated steam drying. © 2017 Taylor & Francis.

[114] Liu, J.; Xue, J.; Xu, Q.; Shi, Y.; Wu, L.; Li, Z., Drying Kinetics and Quality Attributes of White Radish in Low Pressure Superheated Steam. International Journal of Food Engineering, 2017, 13, DOI: 10.1515/ijfe-2016-0365.

In this paper, white radish discs were dried in superheated steam at absolute pressure 95 mbar at four levels of drying temperature from 75 °C to 90 °C. The drying kinetics and various quality attributes of white radish were investigated, compared with the results by vacuum drying. By kinetic modeling of drying processes with Fick's second law, low pressure superheated steam drying (LPSSD) had slightly lower value of effective moisture diffusivity but higher activation energy than vacuum drying. In comparison with vacuum drying, the rehydration capability of dried samples by LPSSD was better due to porous microstructure. Only 25 % or more the total amount of Vitamin C was preserved after drying to the ultimate moisture content, but it was found that some amount of Vitamin C was taken with the exhaust steam and preserved in the condensate. © 2017 Walter de Gruyter GmbH, Berlin/Boston.

[115] Le, K. H.; Kharaghani, A.; Kirsch, C.; Tsotsas, E., Discrete pore network modeling of superheated steam drying. Drying Technology, 2017, 35, 1584-1601, DOI: 10.1080/07373937.2016.1264414.

A nonisothermal two-dimensional pore network model is developed to describe the superheated steam drying of a capillary porous medium. The complex void space is approximated by a network of spherical pores interconnected by cylindrical throats. In this model, the condensation of water vapor at the network surface as well as the network drying are taken into account. During the network drying period, the liquid transport is driven by capillary action, whereas vapor transport occurs because of convection. The condensation of water vapor within the pores is modeled based on newly formulated liquid invasion rules. The simulation results, presented as temperature and moisture content profiles over time, indicate qualitative agreement with available experimental observations. The inclusion of the liquid invasion rules is shown to accommodate more of the condensed water mass compared to earlier models, in which condensation is only partly treated. Due to the viscous vapor flow, the vapor overpressure within the network, which is the driving force of vapor transport, is

reproduced in these simulations. The influence of vapor overpressure on the disintegration of the liquid phase is also discussed. © 2017 Taylor & Francis.

[116] Kim, E.; Lim, J. H.; Choi, Y. S.; Jeon, K. H., Effect of manufacturing process using superheated steam on the quality improvement of pickled radish product. Korean Journal of Food Preservation, 2017, 24, 600-607, DOI: 10.11002/kjfp.2017.24.5.600.

This study was conducted to develop radish as a food product for home meal replacement using superheated steam (SHS). Also, the change of quality characteristics was studied during their storage. The radish cuts were treated with SHS for 0, 3, 5, and 7 min, respectively, followed by complete drying at 80°C for 6 hours. The results showed that radishes restored with mixed solution (drinking water : Sugar : Vinegar : Salt=2:1:0.8:0.1) were harder than those restored with drinking water. All radishes were stored at 5, 10 and 15°C for 56 days to investigate the changes of quality characteristics during the storage. Radishes in the control group, restored with drinking water and stored at 15°C, were spoiled after 7 days of storage. The radish in the experimental group did not show any change in the water content; except an increase on the first day of storage. The hardness of radish decreased with an increase in the storage period. It was found that microbial growth was inhibited due to low pH of the mixed solution, in which radishes of the experimental group were immerse. © 2017 The Korean Society of Food Preservation.

[117] Kim, A. N.; Ko, H. S.; Lee, K. Y.; Rahman, M. S.; Heo, H. J.; Choi, S. G., The effect of superheated steam drying on physicochemical and microbial characteristics of Korean traditional actinidia (Actinidia arguta) leaves. Korean Journal of Food Preservation, 2017, 24, 464-471, DOI: 10.11002/kjfp.2017.24.3.464.

The purpose of this study was to evaluate the effect of superheated steam drying on physicochemical and microbial characteristics of Korean traditional actinidia (Actinidia arguta) leaves. Actinidia leaves were dried at steam temperature of 350°C and oven temperature of 150°C for 40-200 sec. Moisture content and water activity decreased with increasing the drying time, while color values including L, a, and b values and total color difference (ΔE) increased as drying time increased. The relationship between moisture content and water activity showed an exponential fit with high correlation vlaue (R2=0.9909). Total phenolics and flavonoids content and antioxidant activity such as DPPH radical scavenging activity, ABTS radical scavenging activity, and FRAP assay of dried actinidia leaves increased with increasing the drying time up to 160 sec, but dramatically decreased at drying of 200 sec. The numbers of total areobic

bacteria of leaves was not detected at drying time over 120 sec and coliform of all the samples was not detected. As a results, the superheated steam was an very effective drying method of increase to the nutritional and sanitary quality of dried Korean traditional actinidia leaves. Copyright © 2017 The Korean Society of Food Preservation.

[118] Islam, M. Z.; Kitamura, Y.; Kokawa, M.; Monalisa, K.; Tsai, F. H.; Miyamura, S., Effects of micro wet milling and vacuum spray drying on the physicochemical and antioxidant properties of orange (Citrus unshiu) juice with pulp powder. Food and Bioproducts Processing, 2017, 101, 132-144, DOI: 10.1016/j.fbp.2016.11.002.

The aim of this study was to produce concentrated orange juice (OJ) powders by the application of two new techniques, namely micro-wet milling (MWM) and vacuum spray drying (VSD) process. MWM produced OJ with smaller particle sizes (55.0 ± 1.05 μm) than conventional methods and increased the nutritional and antioxidant properties of the concentrated juice over the commercial OJ. VSD process was conducted at low temperature (40–60 °C) using superheated steam (200 °C) as a heating medium and maltodextrin (13DE) as a carrier. The effects of VSD on physicochemical and antioxidant properties of MWM OJ powders produced with four different weight ratios of juice solids to maltodextrin solids; 60:40, 50:50, 40:60 and 30:70 were investigated. The obtained powders were analyzed for moisture content, water activity, bulk density, tapped density, particle density, porosity, and particle size and distributions and microstructure of the particles. The quality in respect to the physical properties of OJ powders was improved except color parameter with increases of maltodextrin solids. The VSD powders retained a higher amount of ascorbic acid, total phenolic content (TPC) and total flavonoid content (TFC) than spray drying. MWM orange powder with overall good quality in terms of color, yield, ascorbic acid, TFC, TPC and DPPH activity was successfully produced by VSD. © 2016 Institution of Chemical Engineers.

[119] Islam, M. Z.; Kitamura, Y.; Kokawa, M.; Monalisa, K., Degradation Kinetics and Storage Stability of Vacuum Spray-Dried Micro Wet-Milled Orange Juice (Citrus unshiu) Powder. Food and Bioprocess Technology, 2017, 10, 1002-1014, DOI: 10.1007/s11947-017-1868-5.

The aim of this work was to evaluate the degradation kinetics and stability of micro wet milled orange juice powders obtained by vacuum spray drying, using maltodextrin as a carrier agent. Powders were produced with four combinations of orange juice

solids/maltodextrin solids 60:40, 50:50, 40:60, and 30:70 by weight. Ascorbic acid degradation, color, and antioxidant activity of powders were evaluated throughout 90 days. Powders were stored at 10, 25, and 35 °C and relative humidity of 33%. Temperature and storage time negatively influenced the stability of ascorbic acid and color, whereas antioxidant activity increased at the beginning of storage at a higher temperature then decreased slightly after 60 days. For stability study, powders were stored at different water activities (0.11 to 0.84) in order to determine the plasticizing effects of water on glass transition temperature. Both water activity and glass transition temperature were used to predict the critical conditions for storage. Vacuum spray dried powder produced with a ratio of 30:70 (orange juice solids/maltodextrin solids) was considered as the most stable, since it showed highest critical water activity (aw = 0.61) and lowest moisture content (0.11 g water/g of dry solid) among the four powders. Vacuum spray drying using superheated steam as the heating medium was proven to be an effective way of producing orange juice powders with minimum loss of nutrients. © 2017, Springer Science+Business Media New York.

[120] Hanifzadeh, M.; Nabati, Z.; Longka, P.; Malakul, P.; Apul, D.; Kim, D. S., Life cycle assessment of superheated steam drying technology as a novel cow manure management method. Journal of Environmental Management, 2017, 199, 83-90, DOI: 10.1016/j.jenvman.2017.05.018.

Common methods of managing dairy manure are directly applying it to the farm field as a fertilizer. For direct application without any type of treatment, the majority of nutrients in the manure run off to the local river and lake during precipitation periods. The algae bloom is one of the environmental outcomes due to eutrophication of the lakes, which may jeopardize the quality of drinking water. In this study, superheated steam drying (SSD) technology is investigated as an alternative manure management method. Rapidly dried cow manure can be used as alternative fuel. Evaluations of energy payback time (EPBT) and life cycle assessment (LCA) of the SSD technology are presented in the SSD scenario and the results are compared with those of the direct field application (FA) of fresh manure and anaerobic digestion (AD). The heat required for the generation of superheated steam in the SSD scenario is provided from combustion of the dry manure to reduce energy costs. The results for the SSD process show 95% and 70% lower eutrophication and global warming potential in comparison to the FA scenario. Acidification potential for SSD turned out to be 35% higher than FA. The comparison of SSD with AD for their EPBT and normalized impacts indicated

that the proposed SSD scenario has higher environmental sustainability than AD (70% lower impact), and is likely an economically better choice compared to conventional AD method (87% lower EPBT) for the future investment. © 2017 Elsevier Ltd.

[121] Eang, R. Tippayawong, N. Superheated Steam Drying of Cashew Kernels with Testa. in Energy Procedia. 2017.

Thermal processing of cashew kernels is determined by removal of moisture, and therefore, an indication of the product quality and the entire process economics. This paper reported an improved design of superheated steam drying system for cashew kernels with the objective of determining the drying characteristics and the effect of superheated steam on product quality. The range of drying steam temperature at atmospheric pressure was 120- 140°C with velocity varied from 1-3 m/s. The total colour difference and browning index were used to examine the change in colour of dried kernels. The results showed that higher temperature and velocity of steam promoted higher drying rate and lower final moisture content of the product. The high temperature of steam was found to be the major cause of colour degradation of dried kernel besides steam velocity. © 2017 The Authors. Published by Elsevier Ltd.

[122] Del Alamo, G.; Kempegowda, R. S.; Skreiberg, Ø.; Khalil, R., Decentralized Production of Fischer-Tropsch Biocrude via Coprocessing of Woody Biomass and Wet Organic Waste in Entrained Flow Gasification: Techno-Economic Analysis. Energy and Fuels, 2017, 31, 6089-6108, DOI: 10.1021/acs.energyfuels.7b00273.

The present work addresses the techno-economics of the decentralized coproduction of Fischer-Tropsch biocrude and liquefied natural gas via thermochemical conversion of woody biomass and wet organic waste to syngas in an entrained flow gasification reactor. The process design considers thermal pretreatment of the feedstock based on integrated drying of both the woody biomass and the organic waste using direct-contact superheated steam, and torrefaction for the dried wood. The superheated steam required for drying is produced from recovery of residual heat from the main conversion process. The overall cost of biocrude production has been shown to decrease when increasing the fraction of organic waste when considering gate fees for the organic waste, at the production site, above 10$/ton. For gate fees of 50$/ton, which are realistic for the current waste market, the cost of biocrude ranges between 25 and 22$/GJ for plant scales between 150 and 600 MW based on the input feedstock energy to the entrained flow gasification. Although the sludge has lower calorific value and higher moisture content, which require higher capital investment for pretreatment, the reduction of

feedstock supply cost with increasing fraction of sludge becomes dominant in evaluating the overall cost of production. Moreover, the overall efficiency for biocrude and LNG production, and therefore the main income to the plant, is comparable for mass fractions of the sludge in the raw feedstock ranging between 0 and 50%. Based on direct-contact superheated steam dryers for the pretreatment of sludge, the residual heat recovered from the main conversion process is sufficient to coprocess up to 50% mass fraction of sludge in the raw feedstock with moisture content up to 80%. © 2017 American Chemical Society.

[123] De Marco, I.; Riemma, S.; Iannone, R., Global Warming Potential analysis of olive pomace processing. Chemical Engineering Transactions, 2017, 57, 601-606, DOI: 10.3303/CET1757101.

The olive pomace is a by-product of olive oil production, obtained after milling operations. The milling process can be done by traditional pressing operations, or through centrifugation (that occurred in two or three phases). Depending on the used process and on the number of phases, the olive pomace has a different moisture content and requires different amounts of energy to be dried. On completion of this stage, the residual oil (up to 4 % by weight) is extracted through a mixture of steam and hexane. The drying and the extraction phase are both obtained using hot air and superheated steam produced in a boiler, which uses exhausted pomace (oil-free pomace) at the end of the process. The aim of this study was the analysis of the CO2 emissions and the evaluation of the Global Warming Potential (GWP) related to the production of 1 kg of pomace oil (widely used by food industry) and 1 kg of exhausted pomace (used as biofuel). The analysis was performed considering the industrial stages (gate-togate approach), varying the type of olive pomace, which depends on the specific milling process. Process data were collected from the chosen industrial site and the life cycle inventory was performed in according to the reference standard ISO 14040-14044. © Copyright 2017, AIDIC Servizi S.r.l.

[124] De Marco, I. Iannone, R., Production, packaging and preservation of semi-finished apricots: A comparative Life Cycle Assessment study. Journal of Food Engineering, 2017, 206, 106-117, DOI: 10.1016/j.jfoodeng.2017.03.009.

Some fruits have a reduced harvesting period or a high degree of perishability, which results in a very short shelf life. Therefore, in order to extend the shelf life of foodstuffs, maintaining low the level at which microbial spoilage and deterioration reactions can occur, fresh fruits have to be treated, obtaining semi-finished products. Those products

are commonly used as starting materials by some food industries, like jams', gelatines' and marmalades' ones, due to the extension of their productions throughout the whole year. Among the possible techniques, the Southern Italy industry under study uses three different techniques to produce, package and preserve semi-finished fruits: one based on individually quick freezing, one on low-pressure superheated steam drying with far-infrared radiation, and one on an ohmic aseptic treatment. In the last years, food industries have focused their attention not only towards high quality products but also towards environmental friendly productions. Therefore, the aim of this work is to use a Life Cycle Assessment (LCA) approach to compare the environmental emissions of the three different production and preservation techniques used by the industry under study. The environmental impacts were evaluated using a detailed LCA analysis, normalizing all the consumptions and emissions to the functional unit (one apricots' kg on dry basis). Data were analysed using SimaPro 8.0.5 software, whereas the Ecoinvent database and information collected from the chosen industrial site were used for the life cycle inventory, according to the reference standard for LCA (i.e., ISO 14040–14044). © 2017 Elsevier Ltd.

[125] Chryat, Y.; Romdhana, H.; Esteban-Decloux, M., Reducing energy requirement for drying of beet-pulp: Simulation of energy integration between superheated steam and air drying systems. Drying Technology, 2017, 35, 838-848, DOI: 10.1080/07373937.2016.1220952.

Beet-pulp dehydration in the sugar industry is a highly energy intensive unit operation. Producing 1 kg of dried beet-pulp requires ~2–3 kg of water to be removed. The cost saving is a real challenge in sugar factory as the current dryers are underperforming (around 3 MJ/kg of water evaporated) because the heat recovery is limited and only a small proportion of dryer exhaust can be reused. The aim of this study was to investigate by simulation the energy efficiency of an independent multistage drying method that combines superheated steam drying (SHSD) and hot air drying (AD). Two case studies awarding the two types of energy coupling (AD then SHSD or SHSD then AD) are presented and compared. An approach of optimization is developed from energy balance. A number of operating parameters of the two drying configurations are investigated using sensitivity analysis. It proves that both cases allow an energy economy around 40% compared to the conventional dryer. Nevertheless, the SHSD-AD plant may present more benefits for a better quality product. © 2017 Taylor & Francis.

[126] Chan, E. W. C.; Ong, A. C. L.; Lim, K. L.; Chong, W. Y.; Chia, P. X.; Krishnan, T.; Chan, K. G., Effects of superheated steam drying on the antibacterial and anti-quorum sensing activities of selected labiatae herbs. Carpathian Journal of Food Science and Technology, 2017, 9, 103-113.

Fresh Labiatae herbs of rosemary, sage, oregano, marjoram, thyme, peppermint and spearmint were analyzed for antibacterial and antiquorum sensing (anti-QS) activities before and after superheated steam drying (SSD) performed at 150 ° and 200°C for 10 min. Commercial dried (CD) herbs available from the market were also analyzed for comparison. Among the fresh, CD and superheated steam-dried (SS-D) herbs, only rosemary and sage displayed antibacterial activity against Gram-positive bacteria. No activity was observed in all herbs against Gram-negative bacteria. Tested at extract concentration of 0.5 mg/mL using Chromobacterium violaceum (ATCC 12472), all fresh, CD and SS-D herbs displayed significant quorum sensing inhibition (QSI) compared to the control at $p < 0.05$. All SS-D herbs displayed enhanced QSI that was significantly stronger than fresh herbs but comparable with CD herbs with the exception of SS-D rosemary which had QSI that was significantly stronger than both fresh and CD herbs. At extract concentrations of 0.25, 0.5, 0.75 and 1.0 mg/mL, none of the fresh herbs had any antibacterial effect towards Escherichia coli [pSB401 and pSB1075]. Results of the bioluminescence assay showed that only rosemary had significant anti-QS activity against E. coli [pSB401]. In this study, the effects of SSD on the antibacterial and anti-QS properties of some Labiatae herbs, and the significant anti-QS activity of rosemary against E. coli [pSB401] are reported for the first time.

[127] Bao, Y. Zhou, Y., Comparation between superheated steam drying and conventional drying of chinese cedar lumber. Linye Kexue/Scientia Silvae Sinicae, 2017, 53, 88-93, DOI: 10.11707/j.1001-7488.20170111.

Objective: In order to provide basis for the high value-added utilization, reducing energy consumption and improving production efficiency of Chinese cedar, superheated steam drying and conventional drying of Chinese cedar (Cryptomeria fortunei)lumber were investigated in this study. Drying quality, microstructure and mechanical properties were compared between two kinds of drying wood. The applicability of superheated steam drying on Chinese cedar lumber was also discussed.Method: The drying quality and mechanical properties of dried lumber were analyzed by national standards. Furthermore, microstructure of Chinese cedar wood under two kinds of drying methods were observed by scanning electron

microscope.Result: As for 50 mm thickness lumber, the drying time and drying rate was 110 h and 1.18%·h-1in superheated steam drying, and 193 h and 0.64%·h-1in conventional drying, respectively. Final moisture content (MC), MC deviation in thickness and residual drying stress of lumber with superheated steam drying met the requirements of the 1stgrade of national standard for lumber drying quality. The corresponding quality index obtained by conventional drying met the 1stgrade, but the final MC was in 2ndgrade. There was no significant difference in MC distribution and residual drying stress between the two drying methods. As for drying defect, the crook, cup and twist of lumber after superheated steam drying met the requirements of the 1stgrade, however, warp index only met the requirements of the 2ndgrade. All defects' index of conventional drying lumber met the requirements of the 1stgrade. As for mechanical properties, the average MOE value of superheated steam drying and conventional drying lumber was 5 508.37 MPa and 5 237.52 MPa, respectively. However, the average MOR value of superheated steam drying and conventional drying lumber was 32.35 MPa and 34.13 MPa, respectively. The observation of cell wall showed that the extent and number of splits in pits membrane after superheated steam drying was greater than that after conventional drying. Thus, the moisture was easier to transfer and the permeability of wood was improved, and led to the increased drying rate. Conclusion: Drying rate of Chinese cedar lumber was extremely affected by drying methods. Compared with the conventional drying, the drying time was shortened by 43% and drying rate was improved by 84% in superheated steam drying. There was no significant difference in drying quality and mechanical properties between the two drying methods, except for the final MC and warp. Porosity in wood after superheated steam drying was greater than that of conventional drying, and this is one of the reasons for improving the wood drying rate. All of these results indicated that the application of superheated steam drying for Chinese cedar lumber would be reasonable, and the drying quality could meet the requirements of wood products.

[128] Bao, Y. Zhou, Y., Comparative study of moisture absorption and dimensional stability of Chinese cedar wood with conventional drying and superheated steam drying. Drying Technology, 2017, 35, 860-866, DOI: 10.1080/07373937.2016.1222417.

The effects of drying methods on equilibrated moisture content (MC) and swelling efficiency of Chinese cedar (Cryptomeria fortunei) wood were studied in this paper. Drying experiments were conducted with conventional (CON) drying and superheated

steam (SHS) drying under atmospheric pressure. Specimens were equilibrated at two environment conditions to measure moisture and dimensional changes, and then the moisture excluding efficiency (MEE) and antiswelling efficiency (ASE) were determined. Results showed that the equilibrated MC of artificial-dried wood was lower than control samples (air drying), and the equilibrated MC of wood with SHS drying was lower than that with CON drying, which indicated that MEE was enhanced in SHS drying process. Similar results were found in swelling efficiency and ASE of artificial-dried wood and the control. The mechanism was studied by dynamic mechanical analysis (DMA) and X-ray diffraction analysis (XRD). The DMA results showed that both of relative storage modulus and relative loss modulus were the highest for SHS-dried wood and the lowest for the control samples. As for the crystalline structure assessed by changes of XRD, the results showed that the cellulose crystallinity and crystallite size of Chinese cedar wood with SHS drying were the highest, and control specimens were the lowest. All the analyses showed that Chinese cedar wood with low hygroscopic and high dimensional stability could be gotten through SHS drying process. © 2017 Research Institute of Wood Industry, Chinese Academy of Forestry.

[129] Aubigny, A., Superheated steam paper drying with heat recovery. ATIP. Association Technique de L'Industrie Papetiere, 2017, 71, 14-16.

The Centre Technique du Papier within a Europen consortium has worked on the idea of drying paper using superheated steam (SHS) for over a long period of time. It has proved that drying paper using SHS is possible and that it allows an increase of the evaporation rate as compared to a conventional drying in a multi-cylinders dryer. The SHS technology is being revived to meet the concerns of papermakers n reducing energy consumption, which comprise of around 30% of production costs. The SHS drying remains a breakthrough technology that can significantly reduce the specific thermal energy consumption f a paper machine.

[130] Zielinska, M., Thermophysical properties of laboratory-prepared corn/wheat dried distillers grains and dried distillers solubles dehydrated with superheated steam and hot air. Drying Technology, 2016, 34, 1147-1161, DOI: 10.1080/07373937.2015.1099543.

The objective of this study was to dry–wet distillers grains and centrifuged solubles and to examine the effect of two different drying media, superheated steam and hot air, at different drying temperatures (110, 130, and 160°C), moisture contents (5–30% wb), and percentages of solubles' presence (0 or 100%) on some thermophysical properties

of laboratory-prepared corn/wheat dried distillers co-products, including geometric mean diameter (dg), particle density (ρp), bulk density (ρb), bulk porosity (ϵb), specific heat (C), effective thermal diffusivity (αeff), and bulk thermal conductivity (λb). The values of dg of corn/wheat dried distillers co-products ranged from 0.358 ± 0.001 to 0.449 ± 0.001 mm. Experimental values of ρp, ρb, and ϵb varied from 1171 ± 6 to 1269 ± 3 kg m−3, from 359 ± 7 to 605 ± 5 kg m−3, and from 0.54 ± 0.01 to 0.71 ± 0.01 kg m−3, respectively. The values of αeff were between 0.58 × 10−7 and 0.93 × 10−7 m2 s−1. The calculated values of C ranged from 1887 ± 11 to 2599 ± 19 J kg−1 K−1, and the values of λb of corn/wheat dried distillers co-products ranged from 0.06 ± 0.01 to 0.09 ± 0.01 W m−1 K−1. Multiple linear regression prediction models were developed to predict the changes in dg, ρp, ρb, ϵb, C, αeff, and λb of laboratory-prepared corn/wheat dried distillers co-products with different operational factors. © 2016, Copyright © Taylor & Francis Group, LLC.

[131] Zhang, X.; Wang, G.; Wen, X.; Zou, J.; Yao, B.; Wu, Q.; Xing, P., Analysis of shrinkage characteristics of sludge in superheated steam and hot air drying processes based on image processing. Nongye Gongcheng Xuebao/Transactions of the Chinese Society of Agricultural Engineering, 2016, 32, 241-248, DOI: 10.11975/j.issn.1002-6819.2016.19.033.

Large amounts of sewage sludge with high moisture content are generated every year. There are varieties of methods to manage sewage sludge such as land filling, composting, pyrolysis, incineration and thermal drying. Decreasing the moisture content of sludge is a critical step in harmlessness, bulkiness reduction, and resource utilization. Thermal drying has been proven to be an effective approach to reduce solid volumes compared with other ways. Drying is a complex process which may consist of molecular diffusion, capillary flow, Knudsen flow, surface diffusion and so on. Generally, the phenomena of shrinkage crack and skin layer formation can be observed during the drying process and each of them occurs can modify the drying kinetics. Currently, there are many studies on sludge shrinkage in hot air drying but lack of studies in superheated steam drying which has the advantages of energy saving, high efficiency and great heat and mass transfer coefficients. Furthermore, most of moisture diffusion models proposed by researchers are not consider the shrinkage and regard the finite regular geometry as an infinite one when they deal with the drying process, it may result in large error or erroneous results. The purpose of this paper is to investigate the shrinkage characteristics of sludge in superheated steam and hot air drying processes

and their influences on the effective diffusion coefficients. The experimental devices for superheated steam drying under atmospheric pressure and hot air drying were built. The drying experiments were carried out with caky sludge samples of 10 mm in thickness and 50 mm in diameter at the temperature of 160 and 200℃. During the drying process, the photographs of sludge samples were obtained with digital camera by taking out the sludge samples from the drying chamber every tem minutes. In order to study the shrinkage phenomenon and its characteristic of caky sludge, the image processing technique was used to processing and analyze the photographs. In addition, the moisture diffusion theory model based on Fick's second law, infinite slab model and infinite cylinder model concerning finite round slab was also built, which considered the shrinkage phenomenon, by superimposition technique. Combining the empirical model, the expression of calculating effective diffusion coefficients was elicited. The results showed that the shrinkage phenomena can be observed remarkably during the drying process and the variation law was corresponding with the moisture that decreased sharply in great range at the forepart and reduced slowly in narrow range after that. The volume ratio is about 0.3 and the volume shrinkage coefficient equal to 0.7 at the end of superheated steam and hot air drying at the temperature of 160 and 200℃.The influences on sludge shrinkage were consistent between superheated steam and hot air drying. The change of effective diffusion coefficients was coincident with the moisture ratio. Considering the shrinkage of sludge samples, the average effective diffusion coefficients of superheated steam drying were equal to 1.92×10-8, 3.75×10-8 m2/s at the temperature of 160 and 200℃, respectively. The average effective diffusion coefficients of hot air drying were equal to 0.94×10-8, 1.31×10-8 m2/s in the same conditions, respectively. The average effective diffusion coefficients were half compared with those without shrinkage. A valuable reference for analysis of drying process mechanism, process parameter optimization of sludge drying and design of drying devices can be provided from the experimental results.

[132] Zhang, X.; Sun, R.; Wang, X.; Wen, X.; Wu, Q.; Xing, P., Characteristics of condensation stage in atmospheric superheated steam drying of thin layer sludge. Chinese Journal of Environmental Engineering, 2016, 10, 311-316.

In order to realize the condensation characteristics in the early stage of drying on a home-made super-heated steam drying test bad, the atmospheric super-heated steam

drying experiment was carried out. The size of the sludge samples was an area of 100 mm×100 mm, whose thicknesses were respectively 2, 4, 6 and 10 mm, and the temperatures were 160, 200, 240 and 280℃, and the fitting equation that the moisture ratio of condensation stage alters with the time was established. The results showed that the mass of the samples increases due to the super-heated steam, and the cold surface of the sludge as the initial temperature of the sludge is close to the room temperature(around 20℃), so that the drying times of sludge samples increase to a certain moisture content. The increase of the mass of condensation water and drying time are greatly influenced by the temperature of the super-heated steam, the higher the temperature, the smaller they increase. It is found that the increase of the mass of condensation water and drying time are influenced by the thickness of the sludge. The quadratic equation model could excellently describe the condensation curves at the primary stage of the super-heated steam drying, for the moisture ratio vs. drying time profiled of model high correlation coefficient(R2=0.984-0.999), and low chi-square($\chi 2$ =5.79×10-6-5.85×10-5) and the low root mean square error(RMSE=6.45×10-4-1.77×10-3). The research results could provide references for both the parameter optimization and the operating conditions of the sludge super-heated steam drying.

[133] Zakrzewski, M.; Sciazko, A.; Komatsu, Y.; Akiyama, T.; Hashimoto, A.; Kaneko, S.; Kimijima, S.; Szmyd, J. S.; Kobayashi, Y. An experimental verification of numerical model on superheated steam drying of Belchatow lignite. in Journal of Physics: Conference Series. 2016.

Due to low production costs, lignite is an important component of energy mixes of countries in its possession. However, high moisture content undermines its applicability as fuel for power generation. Drying in superheated steam is a prospective method of upgrading quality of lignite. The study aimed to validate the drying model of lignite from Belchatow mine in Poland. The experimental investigation on superheated steam drying of lignite was previously conducted. Spheres of 10 mm in diameter were exposed to the drying medium at the temperature range of 110-170oC. The drying behaviour was described in the form of moisture content, drying rate and temperature profile curves against time. With the application of basic coal properties (e.g. density, water percentage, specific heat) as well as the mechanisms of heat and mass transfer in subsequent stages of the process, the numerical model of drying was constructed. It was tentatively verified with reference to experimental results both in terms of drying

parameters and temperature. The model illustrated drying behaviour in the entire range of conditions. Nevertheless, further development of numerical model is desirable regarding accuracy of the process parameters. © Published under licence by IOP Publishing Ltd.

[134] Sotome, I.; Inoue, T.; Katagiri, T.; Takeuchi, H.; Tsuda, M.; Okadome, H.; Sasaki, T.; Isobe, S., Fluidized bed granulation of food powder using superheated steam containing water micro-droplets as binder. Nippon Shokuhin Kagaku Kogaku Kaishi, 2016, 63, 247-253, DOI: 10.3136/nskkk.63.247.

Fluidized bed granulation is widely applied to improve the flowability, dispersibility, and solubility of a variety of powdered food products. In fluidized bed granulation processing of powdered food, water or an aqueous polysaccharide solution is usually sprayed as binder on the powder for granule growth. However, the increased moisture content of granules can result in product spoilage and elongates the successive drying period. To reduce the amount of binder in the granulation process, fluidized bed granulation technology using superheated steam (SHS) containing water micro-droplets (WMD) as binder has been developed. Spraying of SHS accelerated the granule growth by condensing on the powder; however, coarse granules were produced when SHS alone was sprayed. Spraying with an optimal ratio of SHS and WMD produced granules of uniform size, with less binder moisture than conventional processes using polysaccharide solutions. Copyright© 2016, Japanese Society for Food Science and Technology.

[135] Sehrawat, R.; Nema, P. K.; Kaur, B. P., Effect of superheated steam drying on properties of foodstuffs and kinetic modeling. Innovative Food Science and Emerging Technologies, 2016, 34, 285-301, DOI: 10.1016/j.ifset.2016.02.003.

Conventional hot air drying is an energy intensive technique which consumes around 15-25% of national industrial energy in most of the countries. It also often results in unacceptable product quality, nutrient degradation and non-uniform drying. Using air as a drying media leads to oxidation and combustion reaction and releases undesirable components creating environmental issues. Drying operation also needs continuous improvements to reduce energy consumption and preserve quality. Superheated steam drying (SSD) is an innovative drying technology, utilizing heated steam beyond its boiling point as a drying medium in a dryer to remove excess water from the material. Researchers on comparing conventional and SSD claimed that SSD supports product, environment, and energy saving benefits as well as it overcomes many constraints of

hot air and other conventional drying techniques. This review will provide comprehensive detail about the effect of SSD on different properties (texture, microstructure, color, nutrient retention, shrinkage) of foodstuffs. Mathematical modeling and simulation of the SSD process as well as product characteristics undertaken by researchers are also compiled briefly in this article. Industrial relevance SSD offers many advantages over hot air drying which includes low net energy consumption, utilization of exhaust steam, no oxidative reactions and no hazardous gas, dust, dirt emission into environment. Kinetic modeling may prove to be useful for optimization and designing of the process.

[136] Sciazko, A.; Komatsu, Y.; Zakrzewski, M.; Akiyama, T.; Hashimoto, A.; Shikazono, N.; Kaneko, S.; Kimijima, S.; Szmyd, J. S.; Kobayashi, Y., Influence of geological variations on lignite drying kinetics in superheated steam atmosphere for belchatow deposit located in the central Poland. Thermal Science, 2016, 20, 1185-1198, DOI: 10.2298/TSCI151111107S.

Lignite-fired coal power plants suffer from a significant heat loss due to the high moisture content in this energy carrier. Water removal from fuel is an indispensable treatment for improving the combustion process, which will foster the efficient utilization of lignite. Superheated steam fluidized bed drying is expected for this purpose in a power generation sector. Understanding drying kinetics of lignite will greatly reinforce design process of a dryer. Physical features as well as the drying behaviour may be divergent among the lignite originated from different depths and positions in a certain mine. To reveal and clarify the influence of the geological features, the drying characteristics of several grades of lignite from the Belchatow mine in Poland were investigated. The attempts to clarify the influence of the divergent properties of the investigated samples on the drying kinetics in superheated steam were presented in this paper.

[137] Sciazko, A.; Komatsu, Y.; Zakrzewski, M.; Akiyama, T.; Hashimoto, A.; Shikazono, N.; Kaneko, S.; Kimijima, S.; Szmyd, J. S.; Kobayashi, Y., Experimental attempts to investigate the influence of petrographic properties on drying characteristics of lignite in superheated steam atmosphere. Energies, 2016, 9, DOI: 10.3390/en9050371.

A superheated steam fluidized bed dryer (SSFBD) in a self-heat recuperative configuration has a great potential of improving thermal efficiency of a lignite-fired power plant by recovering both of latent heat of vaporization of water kept in the fuel

and part of sensible heat during the fuel processing. However, the optimal design of the dryer requires the fundamental knowledge of drying characteristics in respect to the individual properties of the utilized fuel. Experimental investigation to determine the correlation between a specific coal properties originated from geological background and its drying characteristics is thus the major concern in this paper. The investigated lignite is a representative of Turoszow deposit in Poland. Experimental attempts unveiling drying kinetics were carried out for 5 mm and 10 mm diameter spherical samples in the superheated steam atmosphere in the temperature range of 110 C-170 C. Simultaneous and continuous measurements of changes in weight, surface and interior temperatures and appearance on each tested sample were carried out for describing drying behavior. Analytical investigation was applied to explain the drying characteristics, which are strongly affected by the individual properties of coal and the inherent ash composition.

[138] Rose, M. T.; Perkins, E. L.; Saha, B. K.; Tang, E. C. W.; Cavagnaro, T. R.; Jackson, W. R.; Hapgood, K. P.; Hoadley, A. F. A.; Patti, A. F., A slow release nitrogen fertiliser produced by simultaneous granulation and superheated steam drying of urea with brown coal. Chemical and Biological Technologies in Agriculture, 2016, 3, DOI: 10.1186/s40538-016-0062-8.

Background: The inefficient use of nitrogen (N) fertiliser as a consequence of N losses from soil is a pressing issue in broad-acre agricultural systems. The research reported here tested the hypothesis that granulation of synthetic N fertiliser (urea) with a natural organic C resource (brown coal) would reduce fertiliser N loss from the soil system. Results: Urea-enriched brown coal granules were simultaneously formed and dried within a pilot-scale superheated steam dryer. After application to unplanted soil columns, the urea-brown coal granules reduced nitrous oxide emission by up to 40 %, reduced mineral nitrogen leaching and maintained higher levels of N in topsoil when compared to conventional urea alone. Reduced gaseous N losses without a reduction in plant N uptake were also observed in planted soil columns treated with urea-brown coal granules. Conclusions: Brown coal-urea blended fertiliser showed potential for more efficient use of N in the long term and has environmental benefits in retaining more N in the soil.

[139] Rodchuajeen, K.; Niamnuy, C.; Charunuch, C.; Soponronnarit, S.; Devahastin, S., Stabilization of rice bran via different moving-bed drying methods. Drying Technology, 2016, 34, 1854-1867, DOI: 10.1080/07373937.2016.1236345.

Stabilization of rice bran after milling is a necessary step to avoid subsequent oxidation of lipids in the bran. Selected moving-bed drying methods, i.e., hot-air fluidized bed drying (HAFBD), superheated-steam fluidized bed drying (SSFBD), and infrared vibrated bed drying (IRVD), were used to reduce the moisture content of the bran and, at the same time, inactivate deleterious enzymes, which are the cause of oxidation. Drying kinetics, oxidative stability parameters (i.e., lipase activity, free fatty acid content, and peroxide value), oil extraction yield, and contents of phenolic compounds and γ-oryzanol as well as color changes of the bran were determined. SSFBD could reduce the drying time by 8–22 and 76–79% in comparison with HAFBD and IRVD, respectively. Drying method significantly affected the total phenolic content (TPC) and total color changes but did not significantly affect the γ-oryzanol content of the bran. SSFBD resulted in the lowest levels of all oxidative stability parameters and to the highest TPC and oil extraction yield. SSFBD at 140°C resulted in the bran with the longest shelf life of 55 days and is suggested as an alternative method to shorten the stabilization process and maintain the stability of rice bran. © 2016, Copyright © Taylor & Francis Group, LLC.

[140] Park, Y.; Park, J. H.; Yang, S. Y.; Chung, H.; Kim, H.; Han, Y.; Chang, Y. S.; Kim, K.; Yeo, H., Evaluation of physico-mechanical properties and durability of larix kaempferi wood heat-Treated by superheated steam. Journal of the Korean Wood Science and Technology, 2016, 44, 776-784, DOI: 10.5658/WOOD.2016.44.5.776.

In this study, green Larix kaempferi lumber was heat-Treated by using superheated steam (SHS) at a pilot scale and then various physico-mechanical properties of the heat-Treated wood were evaluated and compared with the properties of conventional hot air (HA) heat-Treated wood. Decay resistance of brown rot fungi and compressive strength parallel to the grain of the SHS heat-Treated wood without occurrence of drying check from green lumber were increased. On the other hand, density, equilibrium moisture content, shrinkage, and bending strength of the SHS heat-Treated wood were lower than those of the conventional HA heat-Treated wood. Because heat transfer and thermal hydrolysis of SHS heat treatment was accelerated by a large amount of water, the effect of SHS heat treatment on the physico- mechanical properties was higher than that of HA heat treatment at the similar conditions of temperature and time. From the

results of this study, because green lumber can be heat-Treated without occurrence of cracks or checks by using SHS and similar heat treatment effect on the physico-mechanical properties of wood can be produced despite a low temperature or short time of heat treatment, it is expected that heat time and energy consumption could be reduced by using SHS.

[141] Park, Y.; Han, Y.; Park, J. H.; Yang, S. Y.; Chung, H.; Yeo, H. Defect-free big square timber drying and heat-treating by saturated steam and superheated steam. in WCTE 2016 - World Conference on Timber Engineering. 2016.

The purpose of this study is to develop a defect-free drying and heat-treating technology for big square timber used widely as a structural component of post and beam construction. The process consists of two steps. The first step is to decrease moisture content (MC) inside of the timber to the fiber saturation point (FSP) while minimizing MC difference between core and surface using saturated steam; the second step is to eliminate bound water and to perform heat treatment (HT) using superheated steam. During the two-step process using saturated steam and superheated steam, drying stress induced by moisture gradient in big square timber was much smaller than that in timber subject to conventional kiln-drying. By the combined drying and HT process suggested in this study, drying defects in and on the big square timber could be considerably prevented, and comparable physico-mechanical performance of the heat-treated wood was revealed.

[142] Lum, A.; Mansouri, S.; Hapgood, K.; Woo, M. W. Superheated steam in spray drying of milk. in Food, Pharmaceutical and Bioengineering Division 2016 - Core Programming Area at the 2016 AIChE Annual Meeting. 2016.

[143] Listyanto, T.; Ando, K.; Yamauchi, H.; Hattori, N., CO2 laser-incised teak and mahogany lumber dried by microwave and steam injection. Forest Products Journal, 2016, 66, 461-466, DOI: 10.13073/FPJ-D-15-00082.

The aim of this study was to investigate the application of microwave and steam injection drying on CO2 laser-incised teak (Tectona grandis) and mahogany (Swietenia mahagoni) lumber. The specimens were teak and mahogany lumber with dimensions of 60 by 120 by 600 mm. Three incising densities, 0, 1,250, and 2,500 holes per m2, were applied to the drying specimens. The drying process was carried out by a combination of microwave and steam injection drying. Microwave irradiation had a power of 3 kW at a frequency of 2.45 GHz, while steam injection drying was done by injecting superheated steam at 105°C to 110°C through a perforated plate at 110°C to

120°C. Drying rate, moisture content (MC) distribution, and checks were observed to evaluate the quality of the drying process. The results indicate that microwave heating and steam injection drying could successfully dry incised teak and mahogany lumber. The highest drying rate was achieved in the specimens with an incising density of 2,500 holes per m2. Interestingly, reducing the MC of teak from 46 to 20 percent required only 20 hours, while lowering the MC of mahogany from 60 to 20 percent took only 24 hours, without the formation of surface and internal checks. Laser incising, microwave heating, and the setting temperature of steam injection drying contributed considerably in creating a more uniform moisture distribution in teak and mahogany lumber, which significantly reduced surface and internal check formation. © 2016 Forest Products Society.

[144] Li, J.; Liang, Q. C.; Bennamoun, L., Superheated steam drying: Design aspects, energetic performances, and mathematical modeling. Renewable and Sustainable Energy Reviews, 2016, 60, 1562-1583, DOI: 10.1016/j.rser.2016.03.033.

This paper presents a comprehensive overview of state-of-the-art of design aspects, energetic performances, and mathematical modeling on superheated steam drying (SSD). In fact, SSD is presented as an efficient drying method because of its high energy efficiency, safety, high drying rate, and high quality of final product. In this study, different SSD systems are classified into two classes: fundamental and basic research and applied research. Three main laboratory scale dryers are used in fundamental and basic research: oven dryer, tunnel dryer, and fixed bed dryer. However, five main types of dryers: kiln dryer, rotary drum dryer, fluidized bed dryer, flash dryer, and impingement dryer that find application in industry, are used in applied research. The general design of superheated steam dryers is constituted of: steam generator, fan, heater, drying chamber, and heat exchanger. The study shows that depending of the characteristics of the tested materials and the different purposes of the research, a proper design of the drying chamber is crucial as it is directly linked to the efficiency of the SSD system. The observation of the drying kinetics has shown that mainly the tested material passed through three clear phases: initial condensation-evaporation phase, constant drying rate phase, and falling drying rate phase. Based on these three phases, mathematical modeling is performed in order to predict the behavior of studied material and the efficiency of drying systems. The inversion temperature is one of the main fundamental parameters that should be studied. Over this temperature the performance of SSD is better than that of hot air drying. The research results show

that the energy consumption in SSD is lower comparing with hot air drying method. Furthermore, the quality of final products dried using SSD is good with a uniform shrinkage and good rehydration capability.

[145] Kozanoglu, B.; Sánchez-Huerta, Á.; Guerrero-Beltrán, J. A.; Welti-Chanes, J., Drying Characteristics of Coriander Seed Particles in a Reduced Pressure Superheated Steam Fluidized Bed. Chemical Engineering Communications, 2016, 203, 1227-1233, DOI: 10.1080/00986445.2016.1160377.

Drying characteristics of coriander seed particles were experimentally analyzed in a reduced pressure superheated steam fluidized bed. The typical moisture gain, reported in some other studies during the warm-up period of the process, was reduced in most of the cases by supplying additional heat into the column. The experimental results demonstrated that the drying rate increases and the equilibrium moisture content decreases by increasing the operating temperature. However, variation of the operating pressure (40–67 kPa) and the superficial steam velocity (2.3–4.0 m/s) did not present significant effects on the moisture contents. The degree of superheating was found to be the most important parameter for the process. The experiments also showed that the equilibrium moisture content decreases upon increasing the degree of superheating. Finally, employing a reduced pressure superheated steam fluidized bed appears as an option to carry out drying processes at relatively lower temperatures.

[146] Komatsu, Y.; Sciazko, A.; Zakrzewski, M.; Fukuda, K.; Tanaka, K.; Hashimoto, A.; Kaneko, S.; Kimijima, S.; Szmyd, J. S.; Kobayashi, Y. Experimental and analytical evaluation of the drying kinetics of Belchatow lignite in relation to the size of particles. in Journal of Physics: Conference Series. 2016.

Water removal is a key technology for enhancing efficient utilization of lignite in power generation. An inherent characteristic of lignite, attributed to the large amount of water kept within the fuel, is the factor decreasing the thermal efficiency of lignite-fired power plants. This paper presents the research results on investigating the drying kinetics of Belchatow lignite excavated in the Central Poland in prior to developing a water removal system. Lignite drying test was conducted in superheated steam atmosphere at the temperature range of 110-170 °C. Spherically shaped samples, of which the diameter is 2.5 mm, was used. The experimental results were then analysed with previously conducted measurements of 5, 10, 30 mm samples to investigate the influence of particle size. The presented analysis shows the agreement of the evaluated

drying rate at the CDRP to the experimental data. The obtained experimental results were used to predict the drying behaviour of the group of particles. The proposed investigation clarifies the size dependence of the drying characteristics of the multisize group of lignite particles. © Published under licence by IOP Publishing Ltd.

[147] Komatsu, Y.; Sciazko, A.; Zakrzewski, M.; Akiyama, T.; Hashimoto, A.; Shikazono, N.; Kaneko, S.; Kimijima, S.; Szmyd, J. S.; Kobayashi, Y., Towards the improvement of thermal efficiency in lignite-fired power generation: Concerning the utilization of Polish lignite deposits in state-of-the-art IGCC technology. International Journal of Energy Research, 2016, 40, 1757-1772, DOI: 10.1002/er.3548.

Integrated coal Gasification Combined Cycle (IGCC) is the most advanced technology for coal-fired power generation. The two-stage entrained flow gasification process allows for the use of a wide range of coal, as long as the gasification temperature is above the ash melting point of a used fuel. In this gasification technology, lignite, which often has a low ash melting point, can be preferably utilized. However, ash fluidity is also another importance, because the behaviour of molten slag can diminish a stable ash discharge from a gasifier. As the eligibility of coal ash properties is a considerable factor, water physically and chemically kept in lignite (30 – 60% in mass) attributes to deteriorating gasification efficiency, because it causes significant heat loss and increasing oxygen consumption. Developing a thermal evaporative lignite drying method will be a necessary attempt to apply lignite to the coal gasification process. For those preceded objectives, coal and ash properties and drying characteristics of several grades of Polish lignite, extracted from Belchatow and Turow deposits, have been experimentally investigated in a preliminary study evaluating the applicability and consideration for its utilization in state-of-the-art clean coal technology, IGCC. This paper particularly discusses the eligibility of Polish lignite from the perspective of the fusibility and fluidity of ash melts and the fundamental drying kinetics of lignite in superheated steam in the light of water removal. The viscosity of ash melts is measured at high temperature up to 1700 °C. In the drying tests, the significant influence of structural issues, because of the provenance and origin of lignite on the drying characteristics, was found by applying the method of sensitivity analysis of physical propensity. This paper concludes that the investigated Polish lignite has characteristics favourable for utilization in IGCC technology, once the precautions related to its high moisture have been carefully addressed. Copyright © 2016 John Wiley & Sons, Ltd. Copyright © 2016 John Wiley & Sons, Ltd.

[148] Jangam, S. V., Recent critical reviews of drying. Drying Technology, 2016, 34, 385, DOI: 10.1080/07373937.2015.1117266.

[149] Jaiboon, P.; Poomsa-ad, N.; Tungtrakul, P.; Soponronnarit, S., Improving head rice yield of glutinous rice by novel parboiling process. Drying Technology, 2016, 34, 1991-1999, DOI: 10.1080/07373937.2016.1154865.

Most commercial parboiled rice is produced from high-amylose content rice. Glutinous rice, which is lacking in amylose content, is generally consumed in Southeast Asian countries. Rare study of parboiling glutinous rice has been observed. In this study, glutinous rice was improved in head rice yield by a novel parboiling process. Two rough glutinous rice, rice department 6 (RD6) and black glutinous rice (BGR) cultivars, were soaked in hot water at 70 ± 5°C for 3 h. The ricer 3moisture content after soaking was 50–52% (d.b.), it was dried with hot air and superheated steam (SHS) at 110, 130, and 150°C in a fluidized bed dryer. The results show that SHS at all drying temperatures can improve the high head rice yield in both parboiled glutinous rice cultivars better than hot air drying. Higher temperature drying caused L* value to decrease but the b* value increases in RD6, whereas in BGR, all color values decreased and ΔE* was increased when the drying temperature increased. Increasing drying temperature presented a softer texture of both glutinous rice cultivars. Upper 130°C, completed gelatinization of both varieties can be obtained and seen by scanning electron microscope and differential scanning calorimeter (DSC). This technique of using high-temperature fluidized bed drying can produce completely parboiled glutinous rice in a single process instead of two conventional processes, steaming and drying, in series. © 2016, Copyright © Taylor & Francis Group, LLC.

[150] Islam, M. Z.; Kitamura, Y.; Yamano, Y.; Kitamura, M., Effect of vacuum spray drying on the physicochemical properties, water sorption and glass transition phenomenon of orange juice powder. Journal of Food Engineering, 2016, 169, 131-140, DOI: 10.1016/j.jfoodeng.2015.08.024.

Vacuum spray drying is a new technique used to produce concentrated orange juice powder using maltodextrin as a drying agent. The dryer was developed for the lowerature (40-50°C) drying powderization of liquefied food using superheated steam (200°C) as a heating medium. The physicochemical properties of orange juice powder with four different combinations of juice solids: maltodextrin solids at 60:40, 50:50, 40:60, and 30:70 were determined. The moisture content, hygroscopicity, water activity, particle size, particle morphology, color characteristics, rehydration and

ascorbic acid retention were significantly affected by the maltodextrin concentration and drying conditions. Water sorption and the glass transition temperature of orange juice powder conditioned at various water activities were also evaluated. The obtained data were well fitted to both BET and GAB models. A strong plasticizing effect of water on Tg was able to predicted by the Gordon-Taylor model, where Tg was greatly reduced by the increasing moisture content of the powder.

[151] Horrungsiwat, S.; Therdthai, N.; Ratphitagsanti, W., Effect of combined microwave-hot air drying and superheated steam drying on physical and chemical properties of rice. International Journal of Food Science and Technology, 2016, 51, 1851-1859, DOI: 10.1111/ijfs.13157.

Jasmine rice (Oryza sativa L.) was subjected to two drying operations: combined microwave-hot air drying (MHA) at initial power intensity of 3, 4 and 6 W g−1 and superheated steam drying (SHS) at 300 °C and 400 °C. During drying, kinetic rate constants of SHS were significantly higher than those of MHA. Both drying operations could decrease enthalpy of starch gelatinisation from 9.28 J g−1 to 1.64–6.17 J g−1, increase gelatinisation extent to 33.51–82.33%, decrease crystallinity from 28.87% to 18.15–21.33%, improve scavenging ability of 1,1-diphenyl-2-picrylhydrazyl, increase ferric reducing antioxidant power and increase hardness of cooked rice from 5.66 N to 5.83–6.55 N, depending on microwave power and drying medium temperature. However, taste profiles and liking scores were comparable to the regular brown rice. Therefore, MHA and SHS operations could be potentially used for reducing drying process and promoting antioxidant activity.

[152] He, Z.; Qiu, S.; Zhang, Y.; Zhao, Z.; Yi, S., Heat transfer characteristics during superheated steam vacuum drying of poplar. Forest Products Journal, 2016, 66, 308-312, DOI: 10.13073/FPJ-D-15-00054.

Superheated steam vacuum drying shows major advantages in terms of reducing the boiling point of water and speedin up the drying process, but to our knowledge, no researcher has addressed the effects of drying conditions on heat transfe characteristics during superheated steam vacuum drying of wood. In this study, we did so using fast-growing poplar Temperatures inside the wood were measured and the convective heat transfer coefficients calculated under temperatur conditions of 358C, 558C, and 708C and absolute pressures of 0.03, 0.06, and 0.1 MPa. The results of our subsequent analysi

showed that the ultimate temperatures inside wood increase alongside increasing absolute pressure at the set temperatur conditions and are lower than that of the drying medium. In addition, we found that convective heat transfer coefficient increase as absolute pressure increases at the set temperatures and also increase as temperature increases at set absolut pressure conditions. We then established a convective heat transfer coefficient model based on the experimental results. Th findings presented here may provide theoretical guidance for maximizing the available advantages of superheated stea vacuum drying and choosing appropriate drying schedules for poplar in future applications. ©Forest Products Society 2016.

[153] Espinoza, O. Bond, B., Vacuum Drying of Wood—State of the Art. Current Forestry Reports, 2016, 2, 223-235, DOI: 10.1007/s40725-016-0045-9.

In this paper, we review the literature published on vacuum drying of wood. Vacuum drying is not a new technology, and its use for drying wood has been suggested since the early 1900s. Technologies for vacuum drying of wood can be classified by the heating method used. In this paper, we define vacuum-drying methods in four groups: conductive heating vacuum, cyclic vacuum, superheated steam vacuum, and dielectric vacuum. Advantages of drying wood below atmospheric pressure are the ability to dry at lower temperatures (and thus lower the probability of developing some drying defects), greatly reduced drying times, color preservation, greater energy efficiency, better control of volatile organic compound emissions, and the ability to dry very large cross sections. Some characteristics that differentiate vacuum from conventional drying are that in vacuum the primary driving force is the total pressure difference, the prevailing moisture transfer mechanism is water vapor bulk flow, and there is greater water migration in the longitudinal direction. While past research has focused on increasing the understanding of the fundamental mechanisms for vacuum drying and applications to specific industries and species, more recent efforts have concentrated on improving existing methods, for example, by improving moisture control and the use of pretreatments to improve drying quality. © 2016, Springer International Publishing AG.

[154] Čermák, P.; Vahtikari, K.; Rautkari, L.; Laine, K.; Horáček, P.; Baar, J., The effect of wetting cycles on moisture behaviour of thermally modified Scots pine (Pinus sylvestris L.) wood. Journal of Materials Science, 2016, 51, 1504-1511, DOI: 10.1007/s10853-015-9471-5.

The moisture behaviour of thermally modified Scots pine (Pinus sylvestris L.) exposed to cyclic conditions was analysed. Specimens of dimensions 15 × 15 × 5 mm3 were thermally modified at 180 °C (TM1) and 220 °C (TM2) using atmospheric pressure and superheated steam. Radial, tangential, volumetric swelling and anti-swelling efficiency (ASE) were calculated during six consecutive drying–soaking cycles. Afterwards, additional specimens were exposed to ten relative humidity cycles (0 and 95 %) at temperature 25 and 40 °C in order to analyse its influence on sorption behaviour. Application of thermal modification led to significant reduction of swelling from original 18.4–13.3 % for TM1 and to 10.5 % for TM2. However, after exposure to six consecutive soaking–drying cycles, the swelling of control specimens slightly decreased, whereas the swelling of thermally modified specimens increased. Due to the increased swelling after repeated cycles, the original ASE (28.6 and 42.7 %) decreased to 22.5 % for TM1 and to 36.88 % for TM2. The presence of leachable compounds and release of internal stresses are mainly attributed to that phenomenon. The EMC of the reference specimens decreases over the repeated humidity cycles for approximately 1 %–units. Same trend was found for the mild thermal modification TM1, but decreasing only in the range of 0.5 %–units. However, the EMC of the TM2 specimens during humidity cycles behaved differently. The results provide a better insight into details of thermal modification of wood and its behaviour under cyclic conditions. © 2015, Springer Science+Business Media New York.

[155] Bujak, J. W., Energy saving and abatement of gas emission in the wood industry. Environment Protection Engineering, 2016, 42, 107-124, DOI: 10.5277/epe160207.

The analysis of heat losses and thermal efficiency of the steam system used for plywood dryers before and after its modernization has been presented. In the wood industry, mainly pressure-free condensate return systems are used. An existing open condensate return system has been improved by the application of a closed condensate tank in order to eliminate secondary steaming. The tested system consisted of three basic parts. One of them was a boiler plant producing superheated steam. Steam and condensate transfer grids connecting the boiler plant with the dryer constituted the next part of the tested steam system. The latter element was a processing device for plywood drying. The application of the closed condensate return system has increased the efficiency of the tested steam system by 15.5%. This resulted in lower emissions of contaminations to the atmosphere. The results of the test were also used to define basic economic indicators of the system in order to determine profitability of its installation.

[156] Bourdoux, S.; Li, D.; Rajkovic, A.; Devlieghere, F.; Uyttendaele, M., Performance of Drying Technologies to Ensure Microbial Safety of Dried Fruits and Vegetables. Comprehensive Reviews in Food Science and Food Safety, 2016, 15, 1056-1066, DOI: 10.1111/1541-4337.12224.

Dried fruits, vegetables, herbs, and spices are produced in and sourced from many countries worldwide, but they have been increasingly reported to be involved in outbreaks and alerts due to the presence of foodborne pathogens such as Salmonella. These dried products are mainly produced by solar drying and conventional air drying, but a wide range of drying technologies are available. From a technological point of view the general trend is to optimize and standardize the drying process to ensure high-quality products to be offered. Drying technologies are mainly evaluated for their performance to reduce water activity at low energy cost while maintaining good sensorial quality of the dried product. However, as low water activity foods are increasingly recognized to support microbial survival and dried products are often consumed as they are, or are used as ingredients in many ready-to-eat foods, there is increasing attention to the microbiological quality and safety aspects of these products. This review presents traditional and emerging technologies to dry fruits, vegetables, herbs, and spices and discusses their potential to inactivate bacteria and viruses throughout the drying process. Overall, the microbial inactivation effect of the presented technologies has not yet been thoroughly assessed, even for traditional methods like solar drying, conventional air drying, or freeze-drying. Emerging technologies such as dielectric (assisted) drying and low-pressure superheated steam drying have been shown to reduce microbial populations; however, the number of studies is still low. Very few studies have focused on viral inactivation during drying processes. © 2016 Institute of Food Technologists®.

[157] Bantle, M.; Eikevik, T. M.; Jokiel, M. Development and performance analysis of an object-oriented turbo-compressor model for steam compression cycles. in Refrigeration Science and Technology. 2016.

Turbo-compressors are an alternative compression technology to ordinary piston and scroll compressors and are currently investigated for several areas of application. A dynamic high-speed turbo-compressor model for high temperature heat pumps with water vapor as a cycle media has been developed and successfully validated. The potential for using new high temperature heat pumps in the industry is enormous and can be a cost effective way to reduce the energy consumption and carbon dioxide

emissions. However more research needs to be performed in regard to the performance of the turbomachinery. The turbo-compressor model was written in object-oriented Modelica code and implemented into an existing model library. Three different approaches for modelling a turbo-compressor were investigated and compared with regard to the quality of their predictions. The basic equations and unique features of the particular approaches were elaborated and discussed. The validation was conducted with real world measurement data from an actual test rig. The utilization of the turbo-compressor within an industrial application was examined. The performance of the turbo-compressors was assessed in connection to a multi-stage compression set-up for a steam compression cycle. Various multi-stage set-ups were compared in matters of characteristically parameters like the thermal capacity or the coefficient of performance.

[158] Alfy, A.; Kiran, B. V.; Jeevitha, G. C.; Hebbar, H. U., Recent Developments in Superheated Steam Processing of Foods—A Review. Critical Reviews in Food Science and Nutrition, 2016, 56, 2191-2208, DOI: 10.1080/10408398.2012.740641.

Although the use of superheated steam has been known for quite a long time, only in the recent past has it emerged as a viable technology for food processing. Superheated steam, having higher enthalpy, can quickly transfer heat to the material being processed, resulting in its rapid heating. The major advantages of using superheated steam for food processing are better product quality (color, shrinkage, and rehydration characteristics), reduced oxidation losses, and higher energy efficiency. This review provides a comprehensive overview of recent studies on the application of superheated steam for food-processing operations such as drying, decontamination and microbial load reduction, parboiling, and enzyme inactivation. The review encompasses aspects such as the effect of superheated steam processing on product quality, mathematical models reported for superheated steam drying, and the future scope of application in food processing. Recent studies on process improvisation, wherein superheated steam is used at low pressure, in fluidized bed mode, sequential processing with hot air/infrared, and in combination with micro droplets of water have also been discussed.

[159] Zielinska, M.; Blaszczak, W.; Devahastin, S., Effect of superheated steam prefrying treatment on the quality of potato chips. International Journal of Food Science and Technology, 2015, 50, 158-168, DOI: 10.1111/ijfs.12613.

Summary: Superheated steam drying (SSD) was used as a prefrying treatment prior to deep-fat frying for potato slices. The effect of SSD at 130, 150 or 180 °C and steam velocity of 2.0 m s-1 on the fat uptake, colour and texture of fried potato chips was evaluated; microstructure and degree of starch gelatinization were also evaluated to help explain the fat uptake results. SSD and frying yielded potato chips with the fat content from 0.263 ± 0.002 to 0.304 ± 0.002 kg kg-1 (d.b.), while frying without SSD led to chips with the fat content as high as 0.359 ± 0.003 kg kg-1 (d.b.). SSD did not promote starch gelatinization. Lower fat uptake was correlated to modified surface structure and lower moisture content of potato slices prior to frying. Frying with/without SSD pretreatment yielded potato chips of similar hardness, crispness and lightness. On the other hand, SSD significantly increased redness and yellowness of the fried chips. © 2014 Institute of Food Science and Technology.

[160] Zielinska, M., Drying Kinetics and Physicochemical Characteristics of Laboratory-Prepared Corn/Wheat Distillers Grains and Solubles Dried with Superheated Steam and Hot Air. Drying Technology, 2015, 33, 831-846, DOI: 10.1080/07373937.2014.991403.

The effect of superheated steam (SS) drying and hot air (HA) drying on drying kinetics and changes in the color, crude protein, and amino acid concentrations (in particular, lysine content) of corn/wheat wet distillers grains (WDG) and centrifuged solubles (CS) was evaluated. An inversion temperature was reached at 139°C for WDG and 132°C for CS, above which moisture evaporation rate and qualitative changes under SS drying conditions exceeded the values noted in HA, and below which the reverse was observed. A significant decrease (from 8 to 50%) in the lysine content of WDG and CS was reported during SS and HA. The overall changes in the color (ΔE*) of corn/wheat WDG and CS ranged from 7.9 ± 2.6 to 27.2 ± 1.9 during SS drying and from 11.9 ± 3.7 to 32.0 ± 0.5 during HA drying. The observed deterioration in color was attributed mainly to changes in lightness (L*) and yellowness (b*) of dried samples. The values of L* and b* were reliable predictors of the lysine content of corn/wheat distillers co-products. © 2015, Copyright © Taylor & Francis Group, LLC.

[161] Zhu, J.; Wang, Q.; Lu, X., Status and Developments of Drying Low Rank Coal with Superheated Steam in China. Drying Technology, 2015, 33, 1086-1100, DOI: 10.1080/07373937.2014.942914.

Superheated steam drying (SSD) of low rank coal (LRC) is applied to improve the heating value and thermal efficiency and to reduce greenhouse gas emissions and the

danger of spontaneous combustion. It is essential to understand the fundamental aspects of drying LRC with superheated steam supported by funds in China and the development of clean coal technology. It is also important to promote the level of scientific technology relevant to safe energy strategies. The background of SSD based on China's unique energy structure and coal production situation are presented in this article. A comprehensive overview on progress and mechanisms of SSD is provided, including the status of drying technology supported by funds in China, distribution of project field and important research institutions, physical and chemical structure of water in coal, heat and mass transfer processes, mathematical models, and some results for wood, food, hot gas, etc., with particular reference to SSD in drying of LRC in China. There are still many challenges in the application of SSD of LRC in very large-scale power plants, drying equipment, and control technology. Advanced SSD sponsored by the fund project in China shows important significance to energy savings and reducing greenhouse gas emissions.

[162] Zhang, X.; Yao, B.; Wu, Q.; Luo, J.; Xu, G.; Xu, J., Analysis of effective diffusivity of sludge in superheated steam drying based on Fourier number method and optimization method. Nongye Gongcheng Xuebao/Transactions of the Chinese Society of Agricultural Engineering, 2015, 31, 230-237, DOI: 10.3969/j.issn.1002-6819.2015.06.032.

The production of sewage sludge from wastewater treatment plants has been continuously increasing in China. One way to manage sewage sludge is drying, which yields a solid with low humidity. This solid can be easily stored, recycled and transported to other facilities. The drying of sewage sludge has been proved to considerably reduce solid volumes. Using superheated steam in the drying process can lead to substantial energy, if the vapour evaporating from the materials is used elsewhere in overall process. Therefore, superheated steam drying is an attractive drying process for industrial use especially if the cost energy for the drying is a major part of the cost of manufacture such as sewage sludge drying process. In order to further study the moisture diffusion mechanism and effective diffusivity of thin layer of sludge in superheated steam drying, this paper ignoring the influence of sample's moisture content change on effective diffusivity when determining the effective diffusivity through drying method, and adopts Fourier number method and optimization method respectively to calculate the effective diffusivity of sludge thin layers with the thickness

of 2, 4, 6 and 10 mm at superheated steam temperature from 120℃ to 280℃, respectively. Relations of the effective diffusivity with superheated steam temperature and the thickness of thin layer were analyzed. The results showed that the effective diffusivity values derived from Fourier number method and optimization method were basically identical, and the effective diffusivity values and change characteristics of thin layer sludge in superheated steam drying were more accurately reflected based on these two methods. Calculation results derived from the Fourier number method and optimization method showed that the effective diffusivity of sludge with the thickness at 4 mm were 2.52×10-10-2.93×10-9 m2/s and 2.75×10-10-3.32×10-9 m2/s respectively at the temperature 120-280℃,and the effective diffusivity of sludge with thicknesses of 2, 4, 6 and 8 mm were 3.85×10-10-2.28×10-9 m2/s and 4.40×10-10-2.72×10-9 m2/s respectively at the temperature of 160℃. The effective diffusivity increased gradually with the increase of superheated steam temperature and the thickness of thin layer, and had a linear relationship with the two parameters. By using the multiple linear regression method, simplified expressions that reflect the relationship between effective diffusivity and drying temperature and thickness of layer were established respectively according to Fourier number method and optimization method, with the corresponding determination coefficient of 0.9982 and 0.9956. The calculation results can provide a valuable reference for the analysis of moisture diffusion process and effective diffusion coefficient of thin sludge layer in superheated steam drying.

[163] Zhang, X.; Yao, B.; Su, Z.; Sun, R.; Luo, J.; Wu, Q.; Xing, P., Drying characteristics of thin layer sewage sludge in superheated steam drying and hot air drying. Chinese Journal of Environmental Engineering, 2015, 9, 5049-5054.

In order to study the drying characteristics of the sewage sludge thin layer in the process of superheated steam drying and hot air drying, the internal-circulation drying test-bed under normal pressure was built to carry out the superheated steam drying and hot air drying for the sewage sludge thin layer with a thickness of 4 mm and 10 mm, respectively at 160-280℃. The results showed that the drying times of superheated steam and hot air will be more and more near along with drying temperature rising, the drying times of superheated steam and hot air are approximate at 280℃. Because of steam condensation at the beginning of the superheated steam drying process, the mass of the samples increases due to superheated steam coming to the cold surface of the sludge. Thus, the steam condensation mass for the sludge thin layer of 4 mm and 10

mm at the temperature 160-280℃ can be obtained respectively as 3.39-1.07 g and 9.71-3.62 g. As a result, the drying rate at the beginning of the superheated steam drying process will be negative number. The increase of the mass of condensation water and drying time was greatly influenced by the temperature of superheated steam, the higher the temperature, the smaller the increase. The results were also compared with those of hot air drying, the superheated steam drying was found to be most suitable drying method for drying sewage sludge as not oxidized and burnt after superheated steam drying even at high temperatures.

[164] Zhang, X.; Wen, X.; Luo, J.; Wu, Q.; Xu, G.; Xu, J., Process parameters optimization of superheated steam drying for sludge. Nongye Gongcheng Xuebao/Transactions of the Chinese Society of Agricultural Engineering, 2015, 31, 241-248, DOI: 10.11975/j.issn.1002-6819.2015.10.032.

The sludge is known as the byproduct generated in the process of pollution control. It is featured by the high moisture content, complicated components and massive deadly microorganism, thus easily leading to secondary pollution. The dehydration is a necessary process to realize the sludge harmless reduce the sludge amount and improve the resource utilization. The thermal drying is a feasible method to reduce the moisture content. The process of hot air drying will cause a large amount of harmful exhaust gas, adding to the difficulty and cost of controlling exhaust gas. The sludge drying, which uses superheated steam as the drying medium, will further lower the risk of explosion and reduce the harmful gas account due to the absence of oxygen in the drying medium. However, the superheated steam drying of sludge is also faced with the problems such as energy consumption and long drying time. Hence, it has become a major task to dry the sludge in an economic and effective manner. The purpose of this research is to determine the technological parameters for optimal sludge superheated steam drying. Besides building the experimental device for superheated steam drying under atmospheric pressure and choosing the relative unit energy consumption and the average drying strength as the evaluation indices, this paper has also designed the experiment of three-factor quadratic orthogonal rotation combination. A mathematical model is also built, which adopts the technological parameters for sludge superheated steam drying including superheated steam temperature sludge quality and superheated steam flow. In addition, this paper has employed the single-factor and two-factor method to analyze the relationship between various factors and evaluation indices. According to the analysis on experimental data, the established regression equation of

establishing is significant, and the coefficient of determination on the relative unit energy consumption and the average drying strength were 0.842 and 0.797, respectively. The 3 factors listed in the descending order of their importance to the 2 evaluation ind ices are sludge mass, steam flow and steam temperature. For the sludge superheated steam drying in terms of relative unit energy consumption, the optimal technological parameters are presented as follows, steam temperature being 215℃, superheated steam flow being 30 m3/h, sludge mass being 26 g (8 mm thickness approximately) and steam flow being 30 m3/h. Under these conditions, the predicted relative unit energy consumption is 281.313 kJ/g. The actual relative unit energy consumption gained from the validity experiment is 280 kJ/g, with the relative error being 0.467%. Hence, the experimental result can provide reference for parameter optimization of sludge superheated steam drying and the design of drying equipment.

[165] Zakrzewski, M.; Komatsu, Y.; Sciazko, A.; Akiyama, T.; Kimijima, S.; Hashimoto, A.; Shikazono, N.; Kaneko, S.; Szmyd, J. S. Comprehensive study on the efficient superheated steam drying kinetics of the low rank coal from Belchatow deposit in Poland. in ICOPE 2015 - International Conference on Power Engineering. 2015.

Lignite, a low-rank coal, is characterized by low calorific value, mostly attributed to its considerable water content. Upgrading the quality of this energy carrier, which benefits coal-fired power plant's thermal efficiency, can be effectively realized by means of drying. The kinetics of superheated steam drying was studied for 30 mm spherical samples from Belchatow lignite mine in Poland. The experiment featured simultaneous and continuous measurements of weight and temperature. The drying kinetics, described by curves of moisture content, drying rate and temperature profile, were evaluated using the data acquired. The present study is a follow-up of analogical examination conducted on 5 and 10 mm objects from the same lignite deposit. The appearance of the sample throughout the process was video-recorded. Widespread cracking and shrinkage, which differ depending on the conditions, along with series of droplets typical for larger sample, were observed. The examined particles were suitable for predictions of thermodynamically derived drying rate and time, as proposed previously for smaller particles. However, in comparison they exhibit more uniform density distribution. Extensive investigation, revealing features of variously-sized samples as well as diameter dependence of drying behavior, is required for purposes of designing industrial drying system dedicated to specific type of coal.

[166] Yun, M. S.; Zzaman, W.; Yang, T. A., Effect of superheated steam treatment on changes in moisture content and colour properties of coconut slices. International Journal on Advanced Science, Engineering and Information Technology, 2015, 5, 80-83, DOI: 10.18517/ijaseit.5.2.488.

Drying is one of the methods to preserve the quality and prolong the shelf life of food. Coconut meat was sliced and dried using superheated steam oven at 140°C, 160°C and 180°C. Drying was carried out at different drying time (5, 10, 15, 20, 25 and 30 minutes). The effect of drying temperature and time on the moisture content and colour properties (L, a, b and BI) of the coconut slices were studied. The temperature and time significantly ($p < 0.05$) affected the moisture loss and colour values of coconut slices during superheated steam drying. The moisture content decreased with increased drying temperature and time. The values of L decreased with drying temperature and time. The a and b value of coconut slice dried at 140°C decreased initially then increased with time. Coconut slices dried at 160°C had their a values increased up to 20 minutes then decreased and b values increased up to 20 minutes then fluctuated. The a and b values of coconut slices dried at 180°C showed fluctuation. BI values of coconut slices increased with increasing drying time and temperature.

[167] Yifeng, Z. Chun, W., Heat and mass transfer during drying of plant bowl-seeding trays. International Agricultural Engineering Journal, 2015, 24, 39-48.

Drying of plant bowl-seeding tray is a critical step in mechanized rice planting. In order to study the drying of plant bowl-seeding trays, we established mathematical models for heat and mass transfer taking the drying of sheet structural materials of plant bowl-seeding tray by superheated steam as study subject. The mathematical models were solved by numerical methods in MATLAB after determination of the parameters and discretization of the differential equation of the two models. We found that the values predicted by our theoretical models were consistent with the experimental data, measured in drying chamber temperatures of l20°C, l40°C, l60°C. This indicates that our model has good accuracy, can provide a mathematical method for practical application, and will be of great significance for the regulation and development of the scientific basis of the drying process.

[168] Xiao, Z. F.; Le, J. B.; Wu, N. X.; Liu, X. D., Effect of operation pressure on superheated steam fluidized bed drying. Jilin Daxue Xuebao (Gongxueban)/Journal of Jilin University (Engineering and Technology Edition), 2015, 45, 1375-1380, DOI: 10.13229/j.cnki.jdxbgxb201504050.

In superheated steam fluidized bed drying, the operation pressure significantly influences the heat and mass transfer and the steam-particle two-phase flow with nonlinear characteristics. Base on the two-dimensional unsteady model of drying process of rapeseeds, numerical simulation was carried out to investigate the influence of operation pressure on the kinetics of superheated steam fluidized bed drying. Under negative pressure, near atmospheric pressure and high pressure, the relationship between the operation pressure and maximum drying rate was quantitatively analyzed respectively. For superheated steam fluidized bed drying of granular products with the inlet steam temperature and flow rate, the values of the optimal operation pressure were obtained. Simulation results show that, with inlet steam temperature of 358 K, flow velocity of 2.5 m/s and particle diameter of 1.0 mm, the optimal pressure is 0.02 MPa; with inlet steam temperature of 403 K, flow velocity of 2.5 m/s and particle diameter of 1.0 mm, the optimal pressure is 0.1 MPa; with inlet steam temperature of 443 K, flow velocity of 2.0 m/s and particle diameter of 2.0 mm, the optimal pressure is 0.2 MPa.

[169] Sciazko, A.; Zakrzewski, M.; Komatsu, Y.; Akiyama, T.; Kimijima, S.; Hashimoto, A.; Shikazono, N.; Kaneko, S.; Szmyd, J. S. Influence of lignite petrographic properties for drying characteristics in superheated steam atmosphere. in ECOS 2015 - 28th International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems. 2015.

Polish lignite from Turow mine was experimentally investigated to determine the correlation between specific coal properties originated from geological background and its drying characteristics in the superheated steam atmosphere. A superheated steam fluidized bed dryer (SSFBD) in a self-heat recuperative configuration has a great potential of improving thermal efficiency of a lignite-fired power plant. This configuration enables to reduce heat losses in combustion process of lignite by recovering both of latent heat of vaporization of water inherently kept in the fuel and sensible heat during the fuel processing. However, the optimal design of the dryer requires the fundamental knowledge of drying characteristics in respect to the individual properties of the utilized fuel. The investigated lignite is a representative of Turoszow deposit situated in the extreme south-western part of Poland. The samples represent two different seams which currently are under exploitation and have industrial value: Seams I and II. The proximate and ultimate analyses were conducted for all the samples. Experimental attempts unveiling fundamental drying kinetics were carried out

for 5 and 10 mm diameter spherical samples in the superheated steam atmosphere in the temperature range 110-170 oC. Simultaneous and continuous measurements of changes in weight, surface and core temperatures and appearance on each tested sample were carried out for describing drying behavior: moisture content, drying rate and temperature profiles. The time and efficiency of the superheated steam drying depending on the lignite particle size and steam temperature were estimated for all types of investigated samples and shown in the form of average results and individual drying curves. The fundamental studies on correlation between physical properties and drying behavior will be the basis for proposing the innovative and universal design methodology for the industrial lignite pre- Treatment system.

[170] Romdhana, H.; Bonazzi, C.; Esteban-Decloux, M., Superheated Steam Drying: An Overview of Pilot and Industrial Dryers with a Focus on Energy Efficiency. Drying Technology, 2015, 33, 1255-1274, DOI: 10.1080/07373937.2015.1025139.

According to the principle of sustainability, modern industry should preserve nonrenewable energy sources and develop more efficient processes, especially in terms of energy consumption. The depletion of fossil energy reserves, the environmental impact of greenhouse gases, and the possible threats of environmental taxes are the main reasons to develop new processes in general, and new drying processes in particular, for the existing industries. Using superheated steam as a drying medium instead of hot air can improve the energy efficiency by reusing the energy from exhausted steam and prevent gas emission into the atmosphere by condensation. The present review is focused on both lab-scale pilots—including impingement jet, fluid bed, kiln, fixed bed, and flash drying—described in the literature and existing industrial facilities, with a specific analysis focused on energy efficiency. The usefulness of superheated steam drying pilots for experimental research and for the design of industrial dryers is analyzed. The impact on quality specifications of the dried product for different operating conditions is also presented. Documentation on industrial superheated steam dryers is very rare. Nevertheless, this work presents and analyses the key data available for superheated steam drying of beet, alfalfa, industrial pulp, and paint sludge. Energy recovery and process integration, with a focus on specific technological challenges for industrial dryer implementation, are also presented. This document will result in a discussion of some new ideas for possible R&D in superheated steam drying.

[171] Ratnasingam, J. Grohmann, R., Superheated steam application to optimize the kiln drying of rubberwood (Hevea brasiliensis). European Journal of Wood and Wood Products, 2015, 73, 407-409, DOI: 10.1007/s00107-015-0898-9.

A study was conducted to optimize the kiln drying of 50 mm thick rubberwood boards using a combination of superheated steam and hot air. The results revealed that initial application of saturated steam at 100 °C, followed by a period of superheated steam application at 110 °C and finally drying in hot air at 65 °C as in the conventional kiln drying, gave the best result in terms of minimizing drying defects and also shortening the drying time. © 2015, Springer-Verlag Berlin Heidelberg.

[172] Onarheim, K.; Lehto, J.; Solantausta, Y., Technoeconomic Assessment of a Fast Pyrolysis Bio-oil Production Process Integrated to a Fluidized Bed Boiler. Energy and Fuels, 2015, 29, 5885-5893, DOI: 10.1021/acs.energyfuels.5b01329.

The integration of a fluidized bed fast pyrolysis process producing bio-oil to an existing fluidized bed boiler combined heat and power (CHP) plant is presented. The purpose of this work is to assess the cost and performance of the integrated fast pyrolysis bio-oil production compared to a stand-alone fast pyrolysis bio-oil production plant. The reason for integrating bio-oil production into a fluidized bed boiler is to increase overall energy efficiency and profitability and to decrease the production costs of the bio-oil. In the integrated fast pyrolysis concept hot sand from the fluidized bed boiler is used for heating the fast pyrolysis reactor. Simultaneously, fast pyrolysis process byproducts such as char and noncondensable gases are cofired in the CHP boiler together with the primary forest residue boiler fuel. The assessment shows that the integration decreases the primary fuel requirement of the boiler. The integration causes changes in the net power and heat output of the CHP plant, but the integration can still be more profitable than a stand-alone fast pyrolysis process. The differences in pyrolysis feedstock characteristics are important when comparing integration to stand-alone bio-oil production. In this work pine sawdust and forest residue feedstock were evaluated, of which only the forest residue proved to be economically advantageous for integration to a CHP boiler. The advantage is evaluated as a reduction in bio-oil production cost compared to a stand-alone fast pyrolysis process for bio-oil production. For implementation of the integrated process, three potential industrial strategies for boiler operation in combined heat and power plants were assessed. These include keeping the superheated steam mass flow constant, keeping the boiler flue gas mass flow constant, and keeping the electricity output constant. The total integrated process efficiency was

87% for the case of sawdust and 86.2% for the forest residue. Sensitivities were studied for variations in the cost of forest residue boiler fuel, cost of heat, and cost of electricity and for the variations in the capital expenditure benefits obtained due to the integration. It was shown that the advantage of integration is highly sensitive to the cost of heat, primarily because of the energy-intensive pyrolysis feedstock drying. The feedstock cost is also a major factor in estimating the advantage of integration. Utilizing forest residue as feedstock for fast pyrolysis proved to be advantageous in all cases evaluated in this work, whereas the break-even price for a competitive integration utilizing sawdust feedstock is 25 €/MWh. The most beneficial operational integration strategy for the boiler would be to maintain a fixed flue gas flow (exhaust) from the boiler, resulting in an advantage of integrated oil production (reduced bio-oil production cost) compared to stand-alone bio-oil production of 7.9 €/MWh bio-oil. The integrated sawdust case, which is shown to be less competitive in this study, would lead to an additional production cost compared to the stand-alone bio-oil production cost of 1.6 €/MWh bio-oil. The results obtained in this study are independent of process scale. © 2015 American Chemical Society.

[173] Miura, K.; Iyota, H.; Matsumoto, T.; Tsujioka, T.; Morikawa, A.; Tanaka, M.; Uesugi, N. Development of humidity measuring device using porous ceramic based on principle of psychrometer. in Refrigeration Science and Technology. 2015.

Hot air, both dry and moist, has been widely used for heating and/or a reaction atmosphere in a broad range of industrial fields including food processing, material drying, and other heat treatments. In a process that uses hot air and superheated steam, the gas flow temperature, pressure, and humidity inside the treatment chamber have a major impact on the quality of the finished product. However, there is no simple method of measuring humidity that can be used over an extended duration in applications that use superheated steam at temperatures above 100°C. In this paper, we introduce a device developed for measuring humidity, which consists of a wetted porous ceramic probe with thermocouples, a water retention control system, and computing devices. The measured humidity (steam mole fraction) is calculated from the measured wet- and dry-bulb temperatures using the adiabatic saturation line equation on which we previously reported. The equation was extended to enable its application to temperatures of up to 350°C and a humidity up to that of superheated steam. Accuracy measurements were conducted with a humidity generator and a gas flow temperature

of 200°C, a gas flow velocity of 3 m/s, and steam mole fraction ranging from that of hot air to that of superheated steam. The cause of any errors was investigated.

[174] Messai, S.; Sghaier, J.; El Ganaoui, M.; Chrusciel, L.; Gabsi, S., Low-Pressure Superheated Steam Drying of a Porous Media. Drying Technology, 2015, 33, 103-110, DOI: 10.1080/07373937.2014.933843.

The present study aimed at developing a theoretical model to simulate the drying process of a porous particle in low-pressure superheated steam drying (LPSSD). Spherical and porous particles of ceramic and coal are used as the model material in this work. Experimental data for ceramic and coal particles reported in the literature were used for the model validation. The effect of particle thermophysical properties and operating variables is tested. Results showed that a decrease in pressure and an increase in the fluid temperature during drying lead to an elevation of mass flux during the constant rate period (CRP) and the falling rate period (FRP) of the drying process. Moreover, this increase in mass flux is more significant for particles with the highest effective porosity. Thus, we conclude that decreasing pressure and increasing the drying fluid temperature reduce the mass flow. © 2015, Taylor & Francis Group, LLC.

[175] Messai, S.; Sghaier, J.; Chrusciel, L.; El Ganaoui, M.; Gabsi, S., Low-Pressure Superheated Steam Drying—Vacuum Drying of a Porous Media and the Inversion Temperature. Drying Technology, 2015, 33, 111-119, DOI: 10.1080/07373937.2014.933844.

This article deals with comparative study of low-pressure superheated steam drying (LPSSD) and vacuum drying using coal particles as model material. The focus is made on the inversion temperature, which means that the drying rate in the two drying processes becomes equal. This temperature is of great importance because it allows the choice of drying agent for given operating conditions. The effect of external and internal parameters on the drying kinetics and the inversion temperature were investigated. Several studies have shown discrepancies of inversion temperature values basing on the constant rate period (CRP) and the falling rate period (FRP). This work points out gaps in these temperature values using the two calculation methods. © 2015, Taylor & Francis Group, LLC.

[176] Liu, Y.; Kansha, Y.; Ishizuka, M.; Fu, Q.; Tsutsumi, A., Experimental and simulation investigations on self-heat recuperative fluidized bed dryer for biomass drying with superheated steam. Fuel Processing Technology, 2015, 136, 79-86, DOI: 10.1016/j.fuproc.2014.10.005.

An exergy recuperative module was developed and applied to biomass drying. The proposed drying process has an energy consumption 1/20 that of a conventional heat recovery drying system. Experimental work was conducted to confirm the details of the self-heat recuperation technology concept. A high drying rate and a stable heat exchange were found through the experimental drying results. Furthermore, the heat pairing was confirmed in the drying system for the first time. © 2014 Published by Elsevier B.V.

[177] Kovbasyuk, V. I., Energy-saving drying and its application. Thermal Engineering (English translation of Teploenergetika), 2015, 62, 673-677, DOI: 10.1134/S0040601515090062.

Superheated steam is efficiently applied as a coolant for the intensification of drying, which is an important component of many up-to-date technologies. However, traditional drying is extremely energy consuming, and many drying apparatus are environmentally unfriendly. Thus, it is important to implement the proposed drying technique using superheated steam under pressure significantly higher than the atmospheric one with subsequent steam transfer for use in a turbine for electric power generation as a compensation of energy costs for drying. This paper includes a brief thermodynamic analysis of such a technique, its environmental advantages, and possible benefits of the use of wet wastes and obtaining high-quality fuels from wet raw materials. A scheme is developed for the turbine protection from impurities that can occur in the steam at drying. Potential advantage of the technique are also the absence of heating surfaces that are in con- tact with wet media, the absence of the emissions to the atmosphere, and the use of low potential heat for desalination and the purification of water. The new drying technique can play an extremely important part in the implementation in the field of thermal destruction of anthropogenic wastes. In spite of the promotion of waste sorting to obtain valuable secondary raw materials, the main problem of big cities is nonutilizable waste, which makes not less than 85% of the starting quantity of waste. This can only be totally solved by combustion, which even more relates to the sewage sludge utilization. The wastes can be safely and efficiently combusted only provided that they are free of moisture. Combustion temperature optimization makes possible full destruction of dioxins and their toxic analogues. © 2015, Maik Nauka-Interperiodica Publishing, all rights reserved.

[178] Komatsu, Y.; Sciazko, A.; Zakrzewski, M.; Kimijima, S.; Hashimoto, A.; Kaneko, S.; Szmyd, J. S., An experimental investigation on the drying kinetics of a single coarse

particle of Belchatow lignite in an atmospheric superheated steam condition. Fuel Processing Technology, 2015, 131, 356-369, DOI: 10.1016/j.fuproc.2014.12.005.

The efficiency of lignite-fired power plants is sacrificed by the high moisture content of this energy carrier. The most adequate effort for upgrading the potential of lignite is the drying process, influenced by both the drying conditions and the physicochemical features of lignite. This paper presents studies on the drying kinetic of the Belchatow lignite originating from the biggest Polish lignite mine. Experimental attempts were conducted for spherical lignite samples dried in a superheated steam atmosphere at the temperature range of 110-170 °C. Each experiment includes the simultaneous measurements of changes in weight and temperature profiles for a single sample. Additionally, the drying process was recorded to observe the cracking on the surface of the sample and its shrinkage. The kinetics were described in the form of moisture content, drying rate and temperature profiles over the drying process. The time and rate of the superheated steam drying process depending on the sample size and steam temperature were estimated. Those parameters are essential for the design of an effective industrial coal drying system, which allows for the latent heat recovery of water evaporation from the lignite, which in turn will improve the thermal efficiency of the lignite-fired power generation.

[179] Khuenpet, K.; Jittanit, W.; Sirisansaneeyakul, S., Comparison of hot air and superheated steam drying of Jerusalem artichoke (Helianthus tuberosus L.) tubers and inulin powder production. Transactions of the ASABE, 2015, 58, 1113-1125, DOI: 10.13031/trans.58.11020.

Jerusalem artichoke tubers (JAT) are rich in inulin, which can be used in food as a prebiotic and dietary fiber supplement. In this study, hot air drying and superheated steam drying of JAT were compared. The hot air drying was carried out at 55°C, 65°C, and 75°C, while the superheated steam drying temperatures were 120°C, 140°C, and 160°C. JAT samples from a selected drying condition were used for manufacturing JAT powder and inulin powder by applying an extraction process. The aims of this research were to (1) compare the quality of blanched and unblanched JAT dried under different conditions in terms of moisture content, color, and microstructure, (2) investigate the drying kinetics of JAT during hot air and superheated steam drying, and (3) determine the chemical compositions of JAT powder and inulin extracted from JAT powder. The result indicated that superheated steam drying was inappropriate for JAT due to the excessive drying time and unacceptable product color. For hot air drying, Page's model

and the Modilli et al. model were the best-fitting models due to their high R2 and low RMSE values, while the effective moisture diffusivity (Deff) ranged from 1.56 × 10-10 to 3.14 × 10-10 m2 s-1. Additionally, the extraction process applied in this work increased the inulin content from 39.09 g per 100 g (d.b.) in JAT powder sample to 56.29 g per 100 g (d.b.) in inulin powder sample. © 2015 American Society of Agricultural and Biological Engineers.

[180] Johnson, P.; Paliwal, J.; Cenkowski, S., Effect of Solubles on Disintegration of Distiller'rs Spent Grain Compacts During Superheated Steam Drying. Drying Technology, 2015, 33, 671-683, DOI: 10.1080/07373937.2014.967403.

Drying of densified spent grain in superheated steam (SS) may cause breakage and disintegration of the product in the initial stage of SS drying. The present work investigated the effect of solubles (0, 10, 30, 50, and 70% solubles) on the percentage change in length, diameter, volume; hardness; and the asymptotic modulus (EA) of the cylindrical compacts during SS drying. An increase in dimensions along with a decrease in hardness and EA of the compact was observed immediately after exposing it to SS. We observed a 47% increase in length and 12% increase in diameter for compacts having 0% solubles during the first five seconds of SS drying; however, when the soluble content increased to 70%, the percentage increase in length and diameter became 12 and 2%, respectively. Also, with an increase in the amount of solubles in the compact, a considerable increase in the hardness and EA of the compact was observed. The study also aimed to find suitable explanatory variables for predicting the hardness and EA of the compact using a stepwise forward regression method. © 2015, Copyright © Taylor & Francis Group, LLC.

[181] Johnson, P.; Paliwal, J.; Cenkowski, S., Analysing the effect of particle size on the disintegration of distiller's spent grain compacts while drying in superheated steam medium. Biosystems Engineering, 2015, 134, 105-116, DOI: 10.1016/j.biosystemseng.2015.04.005.

Particle size distribution (PSD) in distiller's spent grain compacts was varied and their effect on the disintegration characteristics of compacts while drying in superheated steam (SS) was monitored. Volumetric change and stress-relaxation characteristics, in terms of hardness and asymptotic modulus (EA) for a 40% deformation, were analysed during the warm-up period (5s) and after reaching the moisture levels of 40, 30 and 20% (w.b.) in SS. Results showed that particle size was inversely correlated with the expansion or the increase in volume of the compact during SS drying, and the hardness

as well as the EA of the compact increased with a decrease in particle size of the compact. A stepwise regression method was used to determine appropriate variables for developing a multiple linear regression model for predicting the EA of the compact. © 2015 IAgrE.

[182] Hosseinpour, S.; Rafiee, S.; Aghbashlo, M.; Mohtasebi, S. S., Computer Vision System (CVS) for In-Line Monitoring of Visual Texture Kinetics During Shrimp (Penaeus Spp.) Drying. Drying Technology, 2015, 33, 238-254, DOI: 10.1080/07373937.2014.947513.

In this study, the effects of drying medium temperature and velocity were surveyed on the image texture features of shrimp (Penaeus spp.) batches in a dryer equipped with a perpendicular dual-view computer vision system (CVS). This was carried out by applying an innovative rotation- and scale-invariant image texture processing approach with the capability of eliminating the effects of sample shrinkage on the visual textural features. Moreover, the variations in image texture parameters were investigated with moisture ratio, color, and geometrical characteristics of the shrimp samples. Drying experiments were conducted at hot air drying (HAD) temperatures of 50–90°C and superheated steam drying (SSD) temperatures of 110–120°C with drying medium velocities of 1–2 m/s. Several configurations of a multilayer perceptron artificial neural network (MLP-ANN) were also used to predict the moisture ratio and the geometrical characteristics of the shrimp batch using the image texture parameters. Generally, the image texture features were significantly affected by drying medium temperatures ($p < 0.01$), and the effects of drying medium velocities on the textural properties were nonsignificant ($p > 0.05$). Additionally, the higher drying temperatures generated products with uniform and regular texture patterns. The SSD produced samples with somewhat nonuniform and irregular texture patterns compared with HAD at 90°C. Finally, selected MLP-ANN topologies successfully predicted the moisture ratio and the geometrical characteristics of the shrimp batch using the textural properties with correlation coefficients higher than 0.99. © 2015, Copyright Taylor & Francis Group, LLC.

[183] Hamawand, I.; Da Silva, W. P.; Eberhard, F.; Antille, D. L., Issues related to waste sewage sludge drying under superheated steam. Polish Journal of Chemical Technology, 2015, 17, 5-14, DOI: 10.1515/pjct-2015-0062.

Sewage sludge was dried in a rotary drum dryer under superheated steam. Particle size and moisture content were shown to have significant influences on sticking and

agglomeration of the materials. Pouring partially dried sludge (70-80% moisture content, wet basis) directly into the screw feeder of the drum dryer resulted in a significant sticking to the surface of the drum and the final particle size of the product was greater than 100 mm in diameter. The moisture content of this product was slightly less than its initial value. To overcome this issue, the sludge was mixed with lignite at variety ratios and then chopped before being introduced to the feeding screw. It was found that mixing the sludge with lignite and then sieving the chopped materials through a four millimetre mesh sieve was the key to solve this issue. This technique significantly reduced both stickiness and agglomeration of the material. Also, this enabled for a significant reduction in moisture content of the final product.

[184] Guevarra, D. S.; Luces, J. L.; Baldovino, R. G.; Vista, M. L. A PLC-based adaptive control of superheated steam treatment System (SSTS) for Stabilized Brown Rice (SBR). in Lecture Notes in Engineering and Computer Science. 2015.

Heat treatment is considered to be one of the most common methods in food drying. However, the problem with this conventional method is that the texture of the food sample is often altered from its original state, just like in brown rice. Superheated steam treatment system (SSTS) is introduced as an effective method to remove the moisture of the sample. In order to perform process control, a programmable logic controller (PLC), which served as the main controller, is employed to automate the process. To code the PLC program, combination of ladder logic diagrams (LLD), structured texts (ST) and function block diagrams (FBD) were employed using Omron CP1L. The developed controller is also adaptable to different SSTS setting parameters like pressure, temperature (through the temperature controller) and the speed of the transport or conveyorized-driven bed system (through inverter or variable frequency drive).

[185] Goldsworthy, M. J.; Alessandrini, S.; White, S. D., Superheated Steam Regeneration of a Desiccant Wheel—Experimental Results and Comparison with Air Regeneration. Drying Technology, 2015, 33, 471-478, DOI: 10.1080/07373937.2014.956118.

A commercial zeolite desiccant wheel is tested with atmospheric pressure superheated steam regeneration over a range of air inlet conditions, steam inlet temperatures, and wheel rotation speeds. Results are compared with those from high-temperature air regeneration experiments on the same wheel obtained from the literature. For both cases the air stream to be dried was relatively hot and moist with inlet temperature and

absolute humidity values of 50°C and 25 g · kg−1 chosen to reduce heat carryover. Using steam at 160°C to regenerate the wheel leads to the same dehumidification as using hot air at approximately 90°C. The benefit of superheated steam drying is that a nearly closed-loop regeneration process can be used with potential energy savings on the order of 30%.

[186] Fushimi, C. Dewi, W. N., Energy efficiency and capital cost estimation of superheated steam drying processes combined with integrated coal Gasification Combined Cycle. Journal of Chemical Engineering of Japan, 2015, 48, 872-880, DOI: 10.1252/jcej.14we401.

The Integrated coal Gasification Combined Cycle (IGCC) is one of the clean coal technologies because of its excellent low environmental impact and its high thermal efficiency. In recent years, IGCC plants tend to use low-rank coals (LRC), which contain a large amount of moisture. A drying process based on self-heat recuperation (SHR) technology has been developed to greatly reduce the energy consumption because of its capability of recuperating the latent and sensible heat of water and dried coal. It has been shown that the SHR drying process uses less energy than the mechanical vapor recompression (MVR) drying process. For the commercialization of the SHR drying process, the energy consumption and cost are important. In this study, the thermal efficiency and capital cost of superheated steam drying processes (MVR, original SHR (SHR-A), and simplified SHR (SHR-B)) of LRC (sub-bituminous coal and lignite) combined with the IGCC plant were evaluated by using a commercial process simulator, ASPEN Plus ver. 7.2. The results show that the energy consumption of the SHR-B drying process was smaller than that of MVR and the SHR-A processes when the air flow ratio was small. The reduction of thermal efficiency in the IGCC plant due to drying in these processes was less than only 1.4%. It was found that the cost of a compressor and heat exchangers were the major contributors to capital cost in these drying processes, and that overall heat transfer coefficient in the heat exchanger is a critical factor to determine total capital cost. The estimated fixed capital investment of the SHR-B drying process is in the range of 25.6–66.9 million US$ for sub-bituminous coal and 28.7–75.3 million US$ for lignite when the air flow ratio was 0.02. These values were only 1.79–4.68% of the IGCC plant total capital cost of sub-bituminous coal and 1.86–4.86% of that of lignite.

[187] Chungcharoen, T.; Prachayawarakorn, S.; Tungtrakul, P.; Soponronnarit, S., Quality Attributes of Germinated High-Amylose and Waxy Rice in Superheated Steam and Hot Air Drying. Drying Technology, 2015, 33, 876-885, DOI: 10.1080/07373937.2014.995304.

In this work, the effects of amylose content, drying medium, and drying temperature on the fissure, texture, and glycemic index of germinated paddy (GP) were investigated. The amylose content, drying temperature, and drying medium affected the degree of starch gelatinization and percentage of fissure kernels significantly. Hot air drying at 130 and 150°C insignificantly influenced the hardness of Phitsanulok 2 GP with high amylose content after cooking compared to that of shade-dried GP, and the drying temperatures significantly affected the hardness and stickiness of RD6 GP without amylose content. Superheated steam drying caused a significant change in textural properties for both paddy varieties because of complete starch gelatinization. The high-amylose paddy had higher gamma-aminobutyric acid and lower glycemic index than nonamylose paddy. Drying temperature and drying media did not change the gamma-aminobutyric acid and glycemic index of both GP varieties in comparison to their shade-dried samples.

[188] Cheevitsopon, E. Noomhorm, A., Effects of Superheated Steam Fluidized Bed Drying on the Quality of Parboiled Germinated Brown Rice. Journal of Food Processing and Preservation, 2015, 39, 349-356, DOI: 10.1111/jfpp.12239.

The parboiled germinated brown rice (PGBR) was produced using a superheated steam fluidized bed dryer. Grains with an initial moisture content of 58.16±0.25% dry basis (d.b.) were steamed and dried in a single stage at steam temperatures of 110-150C. After superheated steam drying, grains were tempered for 2h and then ventilated with ambient air until the moisture content reached 16% d.b. as two-stage drying. During superheated steam drying, the results revealed that moisture content, white belly and γ-aminobutyric acid (GABA) content significantly decreased with increasing drying temperature and time, whereas internal fissuring, yellowness and peak viscosity increased. The moisture content of grains after drying should be no lower than 19.19-22.00% d.b. to prevent internal fissuring of grains. Two-stage drying resulted in better quality grains and prevented GABA content reduction. In addition, the cooking quality of PGBR differed significantly from that of germinated brown rice (GBR) because of starch gelatinization in PGBR. Practical Applications: PGBR is a functional food. The superheated steam fluidized bed drying can be used to produce PGBR. In the dryer, the

grains were steamed and dried as a single state to reduce the number of operating steps. Results of this research revealed the effects of superheated steam drying on the quality of PGBR. The superheated steam fluidized bed drying represents a good practice in the production of PGBR with high GABA content. © 2015 Wiley Periodicals, Inc.

[189] Bourassa, J.; Ramachandran, R. P.; Paliwal, J.; Cenkowski, S., Drying characteristics and moisture diffusivity of distillers' spent grains dried in superheated steam. Drying Technology, 2015, 33, 2012-2018, DOI: 10.1080/07373937.2015.1040883.

Distillers' spent grain pellets were prepared from material with an initial moisture content of 25% (wb). These pellets were dried in pairs using superheated steam at 120°C in two orientations, horizontal and vertical. The drying characteristics, modeled by the Page equation, showed that there was a significant difference between orientations. The overall moisture diffusivity was calculated using a finite cylinder model based on Fick's law of diffusion accounting for a change in dimensions over the course of drying. The overall diffusivity values ranged from 4.08×10-10 to 1.48×10-8 m2/s. © 2015 Taylor & Francis Group, LLC.

[190] Batenin, V. M. Kovbasyuk, V. I., On the technology for effective utilization of humid fuels. High Temperature, 2015, 53, 453-454, DOI: 10.1134/S0018151X15030037.

To use effectively the available (but in low demand) humid fuel resources and wastes in power engineering at local facilities, an intensive method of fuel drying by superheated steam under raised pressure with subsequent gasification under the same pressure, and using synthetic gas in a gas-turbine facility with steam injection is proposed. An experiment to investigate such energy-saving drying was optimized on that basis, the layout of the power facilities was performed. © 2015, Pleiades Publishing, Ltd.

[191] Bao, Y. Z. Zhou, Y. D., Application potential and prospect of superheated steam drying of wood. Beijing Linye Daxue Xuebao/Journal of Beijing Forestry University, 2015, 37, 128-133, DOI: 10.13332/j.1000-1522.20150161.

The application and theoretical study of superheated steam drying are summarized in this paper in order to improve wood drying quality and production efficiency. The outcomes of superheated steam drying in other industries are searched, and their application potential in superheated steam drying of wood is discussed based on wood drying characteristics. The effects of superheated steam drying techniques on drying rate, drying quality, physical and mechanical properties and microstructure of materials

are analyzed. The rule of heat and mass transfer and mathematical models of superheated steam drying are described and analyzed in an attempt to establish and improve mathematical model and technology of wood superheated steam drying. Finally, the prospects and suggestions are proposed for research and application of wood superheated steam drying.

[192] Ban, G. H.; Kang, D. H.; Yoon, H., Transcriptional response of selected genes of Salmonella enterica serovar Typhimurium biofilm cells during inactivation by superheated steam. International Journal of Food Microbiology, 2015, 192, 117-123, DOI: 10.1016/j.ijfoodmicro.2014.10.008.

Superheated steam (SHS), produced by the addition of heat to saturated steam (SS) at the same pressure, has great advantages over conventional heat sterilization due to its high temperature and accelerated drying rate. We previously demonstrated that treatment with SHS at 200°C for 10 sec inactivated Escherichia coli O157:H7, Salmonella Typhimurium, and Listeria monocytogenes biofilm cells on the surface of stainless steel to below the detection limit. However, bacteria withstanding heat stress become more resistant to other stress conditions, and may be more virulent when consumed by a host. Herein, we studied the transcriptional regulation of genes important for stress resistance and virulence in Salmonella biofilms after SHS treatments. Genes encoding heat shock proteins and general stress resistance proteins showed transcriptional surges after 1 sec of SHS treatment at 200°C, with parallel induction of stress-related regulator genes including rpoE, rpoS, and rpoH. Interestingly, Salmonella biofilm cells exposed to SHS showed decreased transcription of flagella and Salmonella pathogenicity island-1 (SPI-1) genes required for motility and invasion of host cells, respectively, whereas increased transcription of SPI-2 genes, important for bacterial survival and replication inside host cells, was detected. When the transcriptional response was compared between cells treated with SHS (200°C) and SS (100°C), SHS caused immediate changes in gene expression by shorter treatments. Understanding the status of Salmonella virulence and stress resistance induced by SHS treatments is important for wider application of SHS in controlling Salmonella biofilm formation during food production.

[193] Aziz, M.; Prawisudha, P.; Prabowo, B.; Budiman, B. A., Integration of energy-efficient empty fruit bunch drying with gasification/combined cycle systems. Applied Energy, 2015, 139, 188-195, DOI: 10.1016/j.apenergy.2014.11.038.

A high-energy-efficient process for empty fruit bunch drying with integration to gasification and combined cycle processes is proposed. The enhancement is due to greater exergy recovery and more efficient process integration. Basically, the energy/heat involved in a single process is recovered as much as possible, leading to minimization of exergy destruction. In addition, the unrecoverable energy/heat is utilized for other processes through process integration. During drying, a fluidized bed dryer with superheated steam is used as the main evaporator. Exergy recovery is performed through exergy elevation via compression and effective heat coupling in a dryer and heat exchangers. The dried empty fruit bunches are gasified in a fluidized bed gasifier using air as the fluidizing gas. Furthermore, the produced syngas is utilized as fuel in the combined cycle module. From process analysis, the proposed integrated processes can achieve a relatively high energy efficiency. Compared to a standalone drying process employing exergy recovery, the proposed integrated drying can reduce consumed energy by about 1/3. In addition, the overall integrated processes can reach a total power generation efficiency of about 44%. © 2014 Elsevier Ltd.

[194] Arima, K.; Tsuchiyama, Y.; Suzuki, T.; Sawatsubashi, T.; Kakigami, H.; Kinoshita, M.; Ishii, H., Drying characteristics of wet brown coal particles in a steam fluidized bed. Kagaku Kogaku Ronbunshu, 2015, 41, 100-106, DOI: 10.1252/kakoronbunshu.41.100.

Though the world has abundant resources of brown coal, its moisture content is often high. Thus, a fluidized bed drying system using superheated steam for fluidizing gas has been developed as a high-capacity and low-energy- consumption drying technology. Brown coal contains many small pores and hydrophilic functional groups due to its low coal rank, and the form of water in brown coal is classified to four types: monolayer water, multilayer water, capillary water and free water. Therefore, it is important to understand the drying characteristics of water in brown coal in the design of steam fluidized bed dryers. In this research, experiments were carried out to evaluate the drying characteristics of three kinds of brown coal by using batch-type steam fluidized bed drying test equipment. As a result, a quantitative relationship between moisture content and drying characteristics was obtained. Most water was removed at a constant rate. Critical moisture content was around 35%-dry. The bed temperature for an equilibrium moisture content of 10%-dry was 115°C. A drying model of brown coal in which bed temperature and latent heat were given as functions of moisture content was proposed. The calculated results and the test results agreed well, and the model is

expected to be effective in the design of steam fluidized bed dryers for brown coal. © 2015 The Society of Chemical Engineers, Japan.

[195] Arima, K.; Torii, I.; Takashima, R.; Sawatsubashi, T.; Kinoshita, M.; Oura, K.; Ishii, H., Fluidization of wet brown coal particles with wide particle size distribution. Journal of Chemical Engineering of Japan, 2015, 48, 190-196, DOI: 10.1252/jcej.14we166.

Though the amount of brown coal resources in the world is abundant, and its moisture content is often high (more than 30%, wet basis). Thus, fluidized bed drying systems, using superheated steam for fluidizing gas, has been developed as a large capacity and low energy consumption drying technology. Brown coal particles used in fluidized beds are classified into B particles according to Geldart's classification. However, particle properties, size, density and cohesiveness change with moisture content. Therefore, it is important to know the influence of moisture content on its fluidization characteristics. In this work, experiments were carried out to evaluate the eflect of moisture content and particle size distribution on fluidization characteristics by using a fluidized bed cold model. For fluidization characteristics, minimum fluidization velocity, minimum complete fluidization velocity and minimum complete mixing velocity were measured. As a result, a quantitative relationship between the particle size distribution and fluidization characteristics was obtained. Also, a quantitative relationship between moisture content and fluidization characteristics was obtained by introducing an angle of repose as an index of cohesiveness. © 2015 The Society of Chemical Engineers, Japan.

[196] Arima, K.; Fukuda, N.; Takashima, R.; Katsuki, N.; Sawatsubashi, T.; Kinoshita, M.; Ishii, H., Heat transfer in a fluidized bed of wet brown coal particles. Kagaku Kogaku Ronbunshu, 2015, 41, 140-147, DOI: 10.1252/kakoronbunshu.41.140.

The world's coal resources amount to about 900 billion tons, but about the half of this is sub-bituminous coal and brown coal. Brown coal often contains more than 50% moisture (wet basis) and its pre-drying in large volume with low energy consumption is a key technology for its efficient utilization. A fluidized bed dryer using superheated steam for fluidizing gas is suitable for this purpose. In a steam fluidized bed dryer, heat transfer tubes are installed in fluidized bed and brown coal particles are heated indirectly by saturated steam under pressure of around 0.5 MPa (saturation temperature 150°C) in these tubes. Since brown coal particles have a wide particle size distribution and are cohesive due to their high moisture content, it is important to estimate the heat

transfer coefficient outside of heat transfer tubes in the design of steam fluidized bed dryers. In this study, basic cold tests using nitrogen as fluidizing gas were carried out with two kinds of brown coal with different moisture content. Influence of gas velocity and density of heat transfer tubes on the heat transfer coefficient was evaluated. In order to increase the heat transfer area, square fins were attached to the heat transfer tubes and their pitch was varied. Experimental results of heat transfer coefficient agreed well with the value estimated by the equation of Andeen and Glicksman by giving particle size and density as functions of the moisture content of brown coal. The heat transfer coefficient decreased with the increase in density of heat transfer tubes for high-moisture sticky particles, whereas it increased for dry particles. The fin effectiveness was smaller than the value calculated assuming the same heat transfer coefficient as bare tubes. © 2015 The Society of Chemical Engineers, Japan.

[197] Zzaman, W. Yang, T. A., Moisture, color and texture changes in cocoa beans during superheated steam roasting. Journal of Food Processing and Preservation, 2014, 38, 1364-1370, DOI: 10.1111/jfpp.12098.

Roasting is one of the basic unit operations in the cocoa-based industries. Cocoa beans were roasted using a superheated steam oven in superheated steam mode at 150, 200 and 250C for 50min. The effect of heating time and temperatures with roasting methods on the moisture content, color and texture of the cocoa beans were studied. The changes that occurred in the moisture content, color values (L-, a-, b- and browning index) and textural properties (hardness and fracturability) of the cocoa seeds were investigated. The moisture content decreased with increased time and temperatures. Superheated steam roasting significantly affected the colors and texture values with extended roasting time. The color values and textural properties were affected more by 200 and 250C than 150C during superheated steam roasting. Roasting with superheated steam achieves good results because of the short drying phase although high temperatures are required. Practical Applications: The cocoa production industry is global and economically important worldwide. The introduction of a new method for roasting cocoa beans may interest cocoa production industries. Effective roasting of cocoa beans using superheated steam considerably brings about lucrative prospects in cocoa production. As a new method for food processing, superheated steam roasting is more convenient and flexible. At the same time, the favorable characteristics of food, in terms of color and texture are maintained. The introduction of such new technology would

increase overall economy, and society health and well-being. © 2013 Wiley Periodicals, Inc.

[198] Zhang, Y. F. Wang, C., Research on the effect of composition ratio on the drying quality of plant bowl-seeding tray, in Advanced Materials Research. 2014. p. 1014-1017.

In order to research on the effect of composition ratio on drying quality of the plant bowlseeding tray, the drying test was done in superheated steam drying test-bed, the regression model was established by performance test data, and the best composition ratio was obtained from optimization results, the best composition ratio is 21:7:1:4, at this condition the dry strength value was 0.2112MPa, the wet strength value was 0.2178Mpa. The research results has important meaning to enhance the drying quality of the rice seedling-growing tray made of paddy-straw and to promote planting techniques of bowl sterile. © (2014) Trans Tech Publications, Switzerland.

[199] Zhang, X.; Sun, R.; Wang, X.; Su, Z.; Cao, W., Drying models and characteristics of thin layer sludge in superheated steam drying. Nongye Gongcheng Xuebao/Transactions of the Chinese Society of Agricultural Engineering, 2014, 30, 258-266, DOI: 10.3969/j.issn.1002-6819.2014.14.033.

Generally, sludge exists with high moisture content. De-water is the first and crucial step in disposal processes such as land filling, composting, building materials, and incineration. Currently, there are many studies on sludge drying by different heat transfer modes such as conduction and convection. But in most studies, the sludge drying was carried out under an atmosphere of air, which had disadvantages in high-energy consumption and an abundant quantity of exhaust. Superheated steam drying has been used to dehydrate a variety of products, including meat, grain stillage, lignite, and wood, because of environmental protection, non-oxidation, and higher drying efficiency advantages. The purpose of this study was to investigate the drying characteristics of superheated-steam on a thin layer of sludge. Thin layer drying experiments of sludge samples with different thicknesses under a series of superheated steam temperatures were carried out. Sludge samples were collected in a local wastewater treatment plant after mechanical dewatering. The size of the sludge samples were taken over an area of 100 mm×100 mm, having thicknesses of 2, 4, 6, and 10 mm, respectively. The temperatures of superheated steam were controlled by the amount of the access heaters. The experiments of superheated steam drying were conducted at 160, 200, 240, and 280°C, respectively. Relations between the model parameters and

temperature and thickness for the moisture ratio of sludge in relation to drying time were determined. The results showed that sludge samples were not oxidized or burnt after superheated steam drying even at high temperatures. The dense crack and rough surface of sludge during superheated steam drying were beneficial to the drying process. At the beginning of the drying process, the mass of the samples increased due to superheated steam coming in contact with the cold surface of the sludge as the initial temperature of the sludge is close to room temperature (around 20℃). As a result, the drying time of sludge samples to reach a certain moisture content increased. The increase in the mass of condensation water and drying time was greatly influenced by the temperature of superheated steam. As a result, the higher the temperature, the smaller the increase. However, the increase was hardly influenced by the thickness of sludge. The Effective moisture diffusivity was calculated by using Fick's second law. Thin layers of sludge formed by superheated steam drying having thicknesses of 2, 4, 6, and 10 mm had effective diffusion coefficient variations of 2.0641×10-9-8.8527×10-9, 4.3738×10-9-1.6626×10-8, 6.6082×10-9-2.46×10-8, and 1.1916×10-8-4.0806×10-8 m2/s at the temperature 160-280℃. The linear relationship between the natural logarithm of the effective diffusion coefficient and reciprocal of temperature was built based on the Arrhenius empirical formula. The activation energy values of 2, 4, 6, and 10 mm thicknesses of sludge were 26.250, 22.032, 21.894, and 20.961 kJ/mol. A valuable reference for the parameter optimization and equipment design of sludge superheated steam drying was provided by the experimental results.

[200] Tsotsas, E. Mujumdar, A. S., Modern Drying Technology. Modern Drying Technology. Vol. 5. 2014. 1-372.

The five-volume series provides a comprehensive overview of all important aspects of drying technology like computational tools at different scales (Volume 1), modern experimental and analytical techniques (Volume 2), product quality and formulation (Volume 3), energy savings (Volume 4) and process intensification (Volume 5). Based on high-level cutting-edge results contributed by internationally recognized experts in the various treated fields, this book series is the ultimate reference in the area of industrial drying. Located at the intersection of the two main approaches in modern chemical engineering, product engineering and process systems engineering, the series aims at bringing theory into practice in order to improve the quality of high-value dried products, save energy, and cut the costs of drying processes. Volume 5 is dedicated to process intensification by more efficient distribution and flow of the drying medium,

foaming, controlled freezing, and the application of superheated steam, infrared radiation, microwaves, power ultrasound and pulsed electric fields. Process efficiency is treated in conjunction with the quality of sensitive products, such as foods, for a variety of hybrid and combined drying processes.

[201] Tolstorebrov, I.; Bantle, M.; Hafner, A.; Kuz, B.; Eikevik, T. M. Energy efficiency by vapor compression in super heated steam drying systems. in 11th IIR Gustav Lorentzen Conference on Natural Refrigerants: Natural Refrigerants and Environmental Protection, GL 2014. 2014.

The application of a high temperature heat pump for superheated steam drying (SSD) process was analyzed. The SSD chamber processes 10000 kg h-1 of product into dried pet food. Two different systems ("open" and "closed"), which use water as a refrigerant, were evaluated. Both systems use energy from the surplus steam, which is formed due to evaporation of moisture during drying. It was concluded that compression in three stages is required to achieve temperature of steam at 170.0 °C, when radial turbo compressors were used to fulfill the volumetric flow demand. The most efficient system is the "open" system, which provides a coefficient of performance (COP) of steam generation at 3.84. Drying efficiency (DE) is calculated at 0.19 kWh kg-1 of evaporated water. The system provides hot tap water (371.0 kW). The "open" system provides annual saving of 7.45 mln. NOK. Also low investment cost of compressor make the system beneficial.

[202] Thakhiew, W.; Devahastin, S.; Soponronnarit, S., Combined Effects of Drying Methods, Extract Concentration, and Film Thickness on Efficacy of Antimicrobial Chitosan Films. Journal of Food Science, 2014, 79, E1150-E1158, DOI: 10.1111/1750-3841.12488.

An idea of using a suitable drying method to minimize the loss of added antimicrobial agent and, at the same time, to modify the structure, and hence the release characteristics of chitosan films was proposed. Chitosan film-forming solution was incorporated with galangal extract (0% and 1.5% w/w) and formed into films with the thickness of 15 and 30 μm via hot air drying (HD) (40 °C) and low-pressure superheated steam drying (LPSSD) (70 °C, 10 kPa). The extract retention, release characteristics, and antimicrobial efficacy of the films were then assessed; fresh-cut cantaloupe was used as the test food material, while Staphylococcus aureus was the test pathogenic microorganism. The retention and release of 1,8-cineole, a major bioactive compound

in the galangal extract, was monitored during 5-d storage at 25 °C. The film swelling was also evaluated and their results used to interpret the release characteristics of 1,8-cineole from the films to the cantaloupe. At the same thickness, the films prepared by HD had lower extract retention and higher degree of swelling, thus exhibiting faster extract release and lower antimicrobial efficacy than the films prepared by LPSSD. Within the same drying method, the increased film thickness led to higher extract retention and antimicrobial efficacy. The concentration of the extract in the cantaloupe matched well with the extract retention and release characteristics as well as the antimicrobial efficacy of the films. © 2014 Institute of Food Technologists®.

[203] Tatemoto, Y. Michikoshi, T., Drying Characteristics of Carrots Immersed in a Fluidized Bed of Fluidizing Particles Under Reduced Pressure. Drying Technology, 2014, 32, 1082-1090, DOI: 10.1080/07373937.2014.883630.

The drying characteristics and properties (color and shrinkage) of carrots (as a representative agricultural product) were experimentally examined in a fluidized bed under reduced pressure. Dry hot air and superheated steam were used as the drying gases. Rice and carrot powders (0.125-0.355 mm in diameter) were used as the fluidizing particles, in addition to glass beads (0.12 mm in diameter). It was confirmed that the drying rate using a fluidized bed was much higher than without a fluidized bed (hot-air drying), regardless of the type of fluidizing particles used. Under reduced pressure, both with and without a fluidized bed, the drying rate was higher than that at atmospheric pressure using hot air. The drying rate was sufficiently high for fluidized-bed drying with superheated steam, though the drying rate was higher with hot air than with superheated steam. As the drying temperature increased, the volume ratio (befor/after drying) of the sample increased. At high drying temperatures (373 and 423 K in the present study), the color of the sample changed; in other words, a heat-induced change in the properties of the carrot was observed. At a low drying temperature (333 K in the present study), the drying method did not affect the color of the carrot; i.e., the color of the dried material was maintained even in a fluidized bed under reduced pressure when the drying rate was higher. © 2014 Copyright Taylor & Francis Group, LLC.

[204] Tahmasebi, A.; Yu, J.; Han, Y.; Zhao, H.; Bhattacharya, S., A kinetic study of microwave and fluidized-bed drying of a Chinese lignite. Chemical Engineering Research and Design, 2014, 92, 54-65, DOI: 10.1016/j.cherd.2013.06.013.

The drying kinetics of Chinese lignite in nitrogen fluidized-bed, superheated steam fluidized-bed and microwave were investigated. The changes in the mass as a function of drying time were measured under various drying conditions. The variations of moisture ratio with time were used to test ten different thin-layer empirical drying models given in the literature. In studying the consistency of all the models, some statistical tests, such as $\chi 2$, residual sum of squares (RSS) and F-value were also used as well as coefficient of determination R2. In nitrogen fluidized-bed and superheated steam fluidized-bed, the Midilli-Kucuk model best described the lignite drying process. Drying data in microwave were best described by the Page model, indicative of a difference in kinetics between the two drying methods. This difference was attributed to different heat transfer mechanisms under conventional and microwave drying conditions. The effects of drying parameters in nitrogen fluidized-bed, superheated steam fluidized-bed and microwave drying on the constants and coefficients of the selected models were studied by multiple regression analysis. The apparent diffusion coefficient of moisture in samples was obtained from the kinetics data and the apparent activation energies under nitrogen fluidized-bed, superheated steam fluidized-bed and microwave drying were found to be rather similar. © 2013 The Institution of Chemical Engineers.

[205] Sotome, I.; Inoue, T.; Katagiri, T.; Takeuchi, H.; Tsuda, M.; Okadome, H.; Isobe, S., Reduction of water addition in fluidized bed granulation by steam-water tow-phase binder. Japan Journal of Food Engineering, 2014, 15, 25-35, DOI: 10.11301/jsfe.15.25.

In the fluidized bed granulation process of powdered food, aqueous solution is usually sprayed as a binder to the powder to grow the granules, however, increase in the moisture content of granules often spoils the product quality and elongates successive drying period. In this study, Steam-Water Tow-Phase (SWTP) binder has been applied for fluidized bed granulation to reduce the amount of water added to the powder. In the SWTP binder granulation, superheated steam and water (127°C, 138 kPaG) were sprayed at 18.8 g/min and 0～40 g/min respectively through a signle-fluid nozzle to the mixed powder of maize starch (800 g) and dextrin (200 g). In the SWTP binder granulation, the amount of water sprayed to the powder decreased to 40～84% to produce the granules having equivalent size with that obtained by the conventional fluidized bed granulation using the liquid binder. At lower water spraying rates, the

reduction effect of binder water increased, however, coarse particles were produced in these conditions. The steam effectively grew the granules by condensing on the nuclear generated by the water droplets, however, the lack of sufficient number of nuclear permitted the steam to increase the ununiformity in granule size.

[206] Rumruaytum, P.; Borompichaichartkul, C.; Kongpensook, V., Effect of drying involving fluidisation in superheated steam on physicochemical and antioxidant properties of Thai native rice cultivars. Journal of Food Engineering, 2014, 123, 143-147, DOI: 10.1016/j.jfoodeng.2013.08.025.

This paper is aiming at investigating the effects of drying process on physicochemical and antioxidant properties of Thai native rice cultivars Sung Yod Phattalung and Nauykaur. A combination of fluidisation and superheated steam is the selected protocol for the first stage of drying. Two-stage drying process, i.e. fluidisation drying under superheated steam as a medium followed by shade drying at ambient temperature is employed to dry wet Thai native paddy at 170 C for different length of time (2.5-4 min), then followed by shade drying at ambient temperature until the final moisture content of the paddy comes down to 13-14% (w.b.). The results of physicochemical and antioxidant properties of native paddy after drying showed that the longer drying time in superheated steam resulted in changes of pasting properties such as peak viscosity, breakdown, final viscosity and set back of the native rice. The values of the pasting properties decreased while pasting temperature increased. The antioxidant activity of Sung Yod Phattalung was reduced, but that of Nauykaur increased when drying time in superheated steam increased.

[207] Rattanamechaiskul, C.; Soponronnarit, S.; Prachayawarakorn, S., Glycemic response to brown rice treated by different drying media. Journal of Food Engineering, 2014, 122, 48-55, DOI: 10.1016/j.jfoodeng.2013.08.022.

During high-temperature treatment, starch is gelatinized and amylose can simultaneously form with lipids to be the amylose-lipid complexes. These complexes can resist to enzymatic attack and useful for decreasing risk of developing type 2 diabetes and cardiovascular disease. The effects of drying media, hot air (HA), humidified hot air (HHA) and superheated steam (SHS), and their operating conditions on drying characteristics and the glycemic index (GI) of three rice varieties i.e. Phitsanulok 2, Kao Dok Mali 105 and RD 31 was therefore investigated experimentally. Drying temperature and drying medium strongly influenced the drying rate, degree of

starch gelatinization, amylose-lipid complex formation and the GI value. Rice variety also took an effect on the starch gelatinization and GI value. To obtain the GI value as low as possible, the SHS should be applied to dry rice with high gelatinization temperature while HA or HHA should be used for drying rice with low gelatinization temperature.

[208] Park, Y.; Eom, C. D.; Han, Y.; Park, J. H.; Chang, Y. S.; Yang, S. Y.; Choi, J. W.; Yeo, H., Combined treatment of green pitch pine wood by heat and superheated steam and the effects on physical properties of the products. Holzforschung, 2014, 68, 327-335, DOI: 10.1515/hf-2013-0054.

Pitch pine (P. rigida) wood was treated with superheated steam (SHS) and the subsequent effects due to drying and heat treatment (HT) were observed. The following treatment parameters were tested: 180°C air HT, 220°C air HT, 0.1 MPa-180°C SHS HT, 0.1 MPa-220°C SHS HT, 0.5 MPa-180°C SHS HT, and 0.5 MPa-220°C SHS HT. No drying checks were observed in the specimens (500 ×150 ×50 mm3) treated at 0.5 MPa-220°C SHS and with these treatment parameters, equilibrium moisture content (EMC) was the lowest. Low EMC has an effect on physical properties such as shrinkage, compressive strength parallel to the grain, bending strength, hardness, and decay resistance. Based on the results, it is expected that the green wood in a large scale is possible to be simultaneously dried and heat-treated without occurrence of checks by the SHS HT process.

[209] Mujumdar, A. S., Superheated steam drying, in Handbook of Industrial Drying, Fourth Edition. 2014. p. 421-432.

Although the concept was originally proposed over 100 years ago and the rst industrial applications were reported some 60 years ago in Germany, superheated steam drying has emerged only in the past decade or so as a viable new technology with immense potential. Essentially, superheated steam drying (SSD) involves the use of superheated steam in a direct (convective) dryer in place of hot air, combustion, or flue gases as the drying medium to supply heat for drying and to carry off the evaporated moisture. Any direct or direct and indirect (e.g., combined convection and conduction) dryer can be operated as an SSD, in principle. The technology involved is more complex and hence this conversion is not simple. Additional criteria must be considered when selecting a dryer for SSD operation.

[210] Morey, R. V.; Zheng, H.; Kaliyan, N.; Pham, M. V., Modelling of superheated steam drying for combined heat and power at a corn ethanol plant using Aspen Plus

software. Biosystems Engineering, 2014, 119, 80-88, DOI: 10.1016/j.biosystemseng.2014.02.001.

A superheated steam drying (SSD) model was developed in Aspen Plus software to determine energy and water recovery for drying the co-products in a corn ethanol plant. The SSD was integrated into a biomass integrated gasification combined cycle (BIGCC) heat and power production model developed for a 190 million litre per year corn ethanol plant. The BIGCC system was fuelled with either corn stover or a mixture of syrup and corn stover at a rate of 110MW. Results were compared to estimates for steam tube drying (STD). Energy consumed for the SSD was 759-804kJ kg-1 of water removed compared to 2660-2690kJkg-1 for the STD. Approximately 1.3l of water were recovered per litre of ethanol produced with the SSD, with none for the STD. Less power was generated in the BIGCC system with SSD due to its smaller heat sink than for the BIGCC system with STD. © 2014 IAgrE.

[211] Lekcharoenkul, P.; Tanongkankit, Y.; Chiewchan, N.; Devahastin, S., Enhancement of sulforaphane content in cabbage outer leaves using hybrid drying technique and stepwise change of drying temperature. Journal of Food Engineering, 2014, 122, 56-61, DOI: 10.1016/j.jfoodeng.2013.08.037.

Sulforaphane is a hydrolysis product of glucosinolates, which are plant secondary metabolites found in various kinds of Brassica vegetables including white cabbages (Brassica oleracea L. var. capitata). Sulforaphane is of interest as it is claimed to possess chemoprotective effect against an array of cancers. The formation of sulforaphane is via enzymatic reactions and the rates of formation and degradation are strongly dependent on the temperature. Careful regulation of the material temperature during drying to maximize the formation and minimize the degradation of sulforaphane should therefore be possible. In this study, the effect of stepwise change of medium temperature during hot air drying, vacuum drying and hybrid drying, i.e., low-pressure superheated steam drying (LPSSD) followed by vacuum drying, on the evolution of sulforaphane in white cabbage outer leaves was investigated; the results were compared with those in the cases of constant drying medium temperature. Similar evolution patterns of sulforaphane were noted in all cases; sulforaphane first increased before reaching the maximum and then decreased towards the end of drying. Nevertheless, the cabbages undergone LPSSD at 60 C for 10 min and then vacuum drying at 45 C until reaching the final moisture content exhibited the highest amount of sulforaphane. © 2013 Elsevier B.V.

[212] Law, C. L.; Chen, H. H. H.; Mujumdar, A. S., Food Technologies: Drying, in Encyclopedia of Food Safety. 2014. p. 156-167.

Drying is an energy intensive unit operation in food processing to reduce product moisture content to a level that is safe for storage and transportation, to avoid microbial multiplication and inactivate microbial activity. Generally, dryers are classified into different categories based on drying strategy, drying medium, mode of handling of drying material, and mode of heat transfer. With reference to the dryer classification, dryers that permit high temperature drying or low temperature have the potential to avoid microbial multiplication and inactivate microbial activity. In addition, hybrid drying which combines different drying techniques can also be considered. Further, pretreatments can be applied in order to reduce or eliminate microbial load of a product before drying. Drying material can also be exposed to irradiation or ionized environment for elimination of microorganisms during the drying process. This chapter discusses and elaborates drying from the food safety point of view.

[213] Kudra, T. Mujumdar, A. S., Special drying techniques and novel dryers, in Handbook of Industrial Drying, Fourth Edition. 2014. p. 433-490.

Increasing demands for new and high-quality products, energy-efcient processes, environment protection, and the like have stimulated progress in drying science and technology. Mujumdar has presented a summary of the motivation for development of new drying technologies and identied a number of trends, which include the following [1]: • Use of superheated steam in direct dryers • Increased use of indirect (conduction) heating • Use of combined (or integrated) heat transfer modes • Use of volumetric heating (microwave [MW]/radio- frequency [RF] elds) in specialized situations • Use of two-stage (or multistage) dryers • Use of intermittent heat transfer • Use of novel combustion technologies (e.g., pulse combustion for flash drying) • Use of novel gas-solid contactors (e.g., 2D spouted beds, intermittent or rotating spouted beds) • Design of flexible, multiprocessing dryers • Combination of different dryer types Many of these topics are covered in detail elsewhere in this handbook. There are numerous other technologies that have reached various stages of maturity-ranging from concepts and pilot-scale demonstrations to large-scale industrial applications. Several of these have been reviewed in the recent literature [2].

[214] Jongaroontaprangsee, S.; Chiewchan, N.; Devahastin, S., Composition Profiles and Functional Properties of Dietary Fiber Powder from Lime Residues: Effects of

Pretreatment and Drying Methods. Drying Technology, 2014, 32, 484-493, DOI: 10.1080/07373937.2013.863781.

Lime residues after juice extraction have proven to be a potential raw material for producing dietary fiber (DF) powder due to their good functional properties. Compositions and antioxidant activity of DF powder from lime residues as affected by selected pretreatment (hot-water blanching and ethanolic soaking) and drying methods, viz. hot air drying, vacuum drying, and low-pressure superheated steam drying (LPSSD) at 60-80°C, were investigated. Fresh lime residues contained significant amounts of vitamin C, phenolic compounds, and flavonoids. Hesperidin was a major flavonoid and only one polymethoxyflavone (i.e., tangeretin) was detected in small amounts. A decrease in the amount of interested bioactive compounds and their antioxidant activity was noted at almost all steps of processing. Higher retention of bioactive compounds was noted when the residues were subject either to vacuum drying or LPSSD; the total antioxidant activities were 61-62% and 81-82% when being assessed by the β-carotene bleaching and DPPH assays, respectively. Vacuum drying at 80°C was the most suitable condition for preparing DF powder from lime residues due to its short required drying time and its ability to retain bioactive compounds. The in vitro analyses imply that DF powder prepared by vacuum drying at 80°C has the potential to reduce blood glucose and cholesterol levels by exhibiting high glucose retardation index (GRI) and bile acid retardation index (BRI).

[215] Johnson, P.; Cenkowski, S.; Paliwal, J.; Arntfield, S. Significance of particle size distribution on the disintegration of compacted spent grain during drying in superheated steam. in American Society of Agricultural and Biological Engineers Annual International Meeting 2014, ASABE 2014. 2014.

Drying of distiller's spent grain in conventional hot-air dryers is difficult because of the sticky and slurry nature of spent grain. Also, drying of spent grain is done at high temperature creating a high potential for dryers catching fire. One method to address this problem is to compact the wet spent grain and dry wet compacts in a superheated steam (SS) dryer although, the SS technology also brings some new technical challenges. Crumbling and disintegrating of biomass compacts while they are being dried in SS is a prevalent problem observed during the initial stage of SS drying. In the current study, this problem unique to the SS drying process was analyzed by changing the particle size distribution (PSD) of the distiller's spent grain compacts. Samples of 3

different particle size distributions (d(0.9)= 1283.6 urn, d(0.9)= 1069.3, d(0.9)= 812.8 urn) were prepared by grinding and their physical characteristics tested. The volumetric change and stress relaxation characteristics, in terms of asymptotic modulus (EA) for a 40% deformation, of the compacts while being dried in SS at a temperature of 150°C and a velocity of 0.9 m/s were analyzed for each PSD. The study showed that decreasing the particle size of the compact significantly reduces the relaxation of the compact during SS drying. The asymptotic modulus of the compact increased from 0.009 to 0.035 MPa when the PSD of the compact decreased from 1283.6 to 812.8 urn, during the warm-up period of SS drying.

[216] Johnson, P.; Cenkowski, S.; Paliwal, J., Analysis of the Disintegration of Distiller's Spent Grain Compacts as Affected by Drying in Superheated Steam. Drying Technology, 2014, 32, 1060-1070, DOI: 10.1080/07373937.2014.881849.

Breaking and disintegrating of biomass compacts while they are being dried in superheated steam (SS) is a common problem observed during the initial stage of SS drying. The present work investigated the moisture and temperature changes, volume and density variation, crushing resistance, and tensile strength of single cylindrical compacts produced from wet distiller's spent grain (WDG) under SS drying conditions. The wet compacts were dried in SS at 110, 130, and 150°C with SS velocities of 0.9, 1.1, and 1.4 m/s. For a specific temperature and velocity, the compacts were exposed to SS for time periods of 5, 120, 300, and 600 s and the changes in physical properties were analyzed. An increase in a percentage increase in volume by 78-130% and a decrease in density by 51-61% were observed as a result of drying the compact in SS. The results obtained from the study were compared with hot-air dried compacts for 600 s, indicating that SS drying had a substantial role in stimulating the relaxation of stresses stored in the compacts as compared with a convection hot-air drying process.

[217] Huang, X.; Xiao, B.; Wang, Z.; Yang, D.; Liu, X., Mechanical characteristics of rice dried with superheated steam. Nongye Jixie Xuebao/Transactions of the Chinese Society for Agricultural Machinery, 2014, 45, 199-203, DOI: 10.6041/j.issn.1000-1298.2014.02.033.

Orthogonal experiments were designed to study the effects of temperature and velocity on the mechanical characteristics of brown rice, and the crack additional percentage of brown rice changing with drying condition and moisture content. The results showed that the modulus of elasticity was effected by both moisture content and drying

conditions. The crack additional percentage of brown rice dried by superheated steam was closed to that of brown rice dried by hot air. Compared with conventional hot air drying, the crack additional percentage of brown rice dried with superheated steam was not worsen although the high temperature used, which had the advantages of higher drying rate and lower energy consumption. It was concluded that the superheated steam drying was a potential technology for drying rice.

[218] Hosseinpour, S.; Rafiee, S.; Aghbashlo, M.; Mohtasebi, S. S., A novel image processing approach for in-line monitoring of visual texture during shrimp drying. Journal of Food Engineering, 2014, 143, 154-166, DOI: 10.1016/j.jfoodeng.2014.07.003.

In this study, a novel image processing approach based on the combination of Radon transform, pseudo Fourier-Mellin transform, and Fourier spectrum-based fractal dimension was proposed to exclude the undesirable effects of samples structural and positional changes on the image texture features. Images were obtained using a dryer equipped with perpendicular dual-view computer vision system (CVS) at hot air drying (HAD) temperatures of 50-90 °C and superheated steam drying (SSD) temperatures of 110-120°C. Three drying medium velocities in the range of 1-2 m/s were adjusted for each drying temperature. Unlike the drying medium velocity, the drying medium temperature had a significant effect on the visual texture parameters of the shrimp batch. The zero-order and fractional conversion models along with a modified Arrhenius model were found as the best models for explaining the kinetics of the visual texture features and the temperature dependency of their constants, respectively. Eventually, the linear and cubic regression models satisfactorily correlated the image texture features with the moisture ratio and geometrical attributes of the samples, respectively.

[219] Hamawand, I.; Yusaf, T.; Bennett, J., Study and modelling drying of banana slices under superheated steam. Asia-Pacific Journal of Chemical Engineering, 2014, 9, 591-603, DOI: 10.1002/apj.1788.

In this research, a steam oven was used to study drying of banana fruit in a variety of steam-air percentages and temperatures. The drying process stopped when the samples reached a moisture content equal or less than 8%. The inversion temperature in this study that has a significant influence on energy consumption in the process has been detected not only as a function of temperature but also as a function of the sample's thickness as well. Inversion temperature was detected at a sample thickness higher than

6 mm and drying medium temperature higher than 160 °C. The modelling of the drying process was divided into three periods: initial condensation-evaporation period, constant rate period and falling rate period. The models for temperature at the centre of the sample during initial condensation period, sample's moisture content during initial condensation-evaporation period, sample's moisture content during constant and falling rate periods showed good agreements with the experimental data with relative absolute errors of 14%, 1.5% and 5%, respectively.

[220] Geng, W. G.; Gao, L.; Ma, X. L.; Li, X. Y., Energy efficiency analysis on drying viscose fiber in superheated steam and hot air, in Advanced Materials Research. 2014. p. 892-896.

The paper presents a novel drying system which includes a superheated steam drying and a hot air drying. The conventional viscose fiber drying is experimental studied and the drying quality and energy consumption were analyzed. In the experiments, the temperature of superheated steam covered the range from 120 °C to 150 °C and, hot air temperature is about 80 °C. A series of drying kinetics curves were determined to optimize the operation parameters. The results show that the combined drying has high energy efficiency because of the exhaust heat recovery from superheated drying period.

[221] Gebreegziabher, T.; Oyedun, A. O.; Yu, Z.; Maojian, W.; Yi, Z.; Jin, L.; Hui, C. W., Biomass drying for an integrated power plant: Effective utilization of waste heat, in Computer Aided Chemical Engineering. 2014. p. 1555-1560.

Unlike fossil fuels, biomass offers potential benefits due to its low cost and presumed zero-carbon emission for power generation. However, raw biomass contains high moisture level that reduces combustion temperature and causes certain operational problems and due to this reason biomass is often dried prior to combustion. Having multiple advantages however, drying biomass is an energy intensive and relatively low efficiency process. Hence, for making drying process more economical, reasonable waste heat from some other industries or processes should be assessed and extracted for drying purpose. Biomass power plant is one of the process industries where the existing waste heat can be utilized for drying the feedstock before combustion for improved operations. In this work, heat integration studies are performed to a 12.5. MW capacity biomass power plant that burns empty fruit bunches (EFB) as fuel. A multi-

stage drying process that combines, hot air dryer (HAD), superheated steam dryer (SSD) and flue gas dryer (FGD) is considered. Pinch analysis is used to show the effectiveness of the heat integration of different design options. The result of this study shows that, when compared with a system with no drying, nearly 10 % improvement in overall efficiency is achievable by proper integration of the dryers with the power plant. © 2014 Elsevier B.V.

[222] Fushimi, C. Fukui, K., Simplification and Energy Saving of Drying Process Based on Self-Heat Recuperation Technology. Drying Technology, 2014, 32, 667-678, DOI: 10.1080/07373937.2013.851085.

A simplified drying process based on self-heat recuperation (SHR), which can further reduce energy consumption compared to previous SHR drying processes, is proposed. The specific energy consumption (SEC) of the SHR drying process was evaluated at various air flow rates and compared with a mechanical vapor recompression (MVR) drying process with superheated steam. The results show that the SEC of SHR can be reduced from 474 to 147 kJ (kg-H2O evaporated)-1 by removing heat exchangers for preheating. The SEC of the simplified SHR process was only 1/16 of a conventional drying process with heat recovery and 3/5 of an MVR process. Exergy transfer of the process was also analyzed and summarized as exergy flow diagrams. © 2014 Copyright Taylor & Francis Group, LLC.

[223] Elustondo, D.; Ahmed, S.; Oliveira, L., Drying Western Red Cedar with Superheated Steam. Drying Technology, 2014, 32, 550-556, DOI: 10.1080/07373937.2013.843190.

This exploratory study evaluated the possibility of drying 50-mm-thick western red cedar with superheated steam. Since there are no industrial facilities in Canada drying western red cedar with superheated steam, the study was designed to explore the potential of this technology in terms of lumber quality, moisture content distribution, and drying time. The experiments showed that the 50-mm-thick product can be dried in less than three days without jeopardizing lumber quality (in comparison with the two weeks that is currently required in conventional kilns), and the percentage of pieces that remained wet after drying was within the 10% to 15% range that is typically tolerated in industry. © 2014 Taylor & Francis Group, LLC.

[224] Devahastin, S. Mujumdar, A. S., Superheated Steam Drying of Foods and Biomaterials, in Modern Drying Technology. 2014. p. 57-84.

[225] Chaisamlitpol, S.; Hiranvarachat, B.; Srichumpoung, J.; Devahastin, S.; Chiewchan, N., Bioactive compositions of extracts from cabbage outer leaves as affected by drying pretreatment prior to microwave-assisted extraction. Separation and Purification Technology, 2014, 136, 177-183, DOI: 10.1016/j.seppur.2014.09.002.

In order to add value to cabbage outer leaves, which are generally considered as a waste product, extraction and use of their health-beneficial bioactive compounds should be made. Among many extraction alternatives microwave-assisted extraction (MAE) is one of the most promising and has indeed been applied to extract bioactive compounds from cabbages. However, study is lacking on the effect of drying prior to MAE, which is sometimes required since extraction cannot always be performed on fresh materials. This study was divided into 2 parts, with the first part investigating the effects of selected drying methods, i.e., hot air drying (HD) and low-pressure superheated steam drying (LPSSD), on selected bioactive compounds, namely, glucosinolates (GLS), sulforaphane, phenolics, as well as the total antioxidant activity (TAA) of the dried cabbages. In the second part the effects of the drying methods on subsequent MAE were assessed. The results suggested that HD but not LPSSD led to a significantly decreased GLS content of the dried cabbages. Sulforaphane and total phenolics contents as well as TAA of the dried cabbages decreased upon both HD and LPSSD. The GLS and total phenolics contents as well as TAA of the extracts from the dried cabbages prepared by HD and LPSSD were lower than those from the fresh sample. The results on the sulforaphane content of the extracts were nevertheless opposite. © 2014 Elsevier B.V. All rights reserved.

[226] Berghel, J. Renström, R., An Experimental Study on the Influence of Using a Draft Tube in a Continuous Spouted Bed Dryer. Drying Technology, 2014, 32, 519-527, DOI: 10.1080/07373937.2013.840648.

Further increasing the production of processed biofuel also increases the demands on drying capacity. With the aim of increasing the heat capacity flow, experimental tests have been performed on the process of drying sawdust in a continuous spouted bed dryer with nine different draft tube designs. The results showed that a draft tube with an increased length and an increased disengagement height decreased the dry substances' flow rate throughout the dryer. The results also showed that the mass of the material in the dryer was approximately the same in all the tests. This means that the

draft tubes, no matter their size, do not influence the amount of material in the dryer. © 2014 Taylor & Francis Group, LLC.

[227] Berghel, J. Renström, R., Superheated steam drying of sawdust in continuous feed spouted beds - A design perspective. Biomass and Bioenergy, 2014, 71, 228-234, DOI: 10.1016/j.biombioe.2014.10.004.

Spouted bed drying technology shows promising results for the drying of unscreened sawdust in superheated steam. In this paper, the experiences from designing, running and evaluating two spouted bed continuous feed dryers are presented. Stable running conditions and drying results have been achieved. This has been particularly important for sawdust that will be compressed into pellets or briquettes. The spouted bed superheated steam dryer also shows high potential for energy efficient integration into sawmills. Our recommendation is thus, to use the outlet steam temperature as the control parameter for the outlet moisture content. A drying rate above and one below the fibre saturation level, can be identified. Visual observations through the viewing glass in the drying zone in both the dryers clearly showed that not all of the material participated in the spout at all times; there were, however, no indications of dead zones. A heat transfer analysis indicated that only about 70% of the surface area of the material was in thermal contact with the steam. This paper sums up the experiences regarding drying properties, control and system properties obtained when sawdust is dried using superheated steam as the drying medium. Further work on standardised dryers in series or in parallel is necessary to increase the capacity in the spouted bed dryer. © 2014 Elsevier Ltd.

[228] Arima, K.; Torii, I.; Takashima, R.; Sawatsubashi, T.; Kinoshita, M.; Oura, K.; Ishii, H., Effect of moisture content on fluidization of wet brown coal particle with wide particle size distribution. Kagaku Kogaku Ronbunshu, 2014, 40, 299-305, DOI: 10.1252/kakoronbunshu.40.299.

The world's coal resources amount to around 900 billion tons, but half of this is sub-bituminous coal and brown coal. Brown coal often contains more than 50% (wet basis) moisture, which reduces the generating efficiency of brown coalfired power plants. Therefore, pre-drying in large quantity with low energy consumption is a key technology for its efficient utilization. A fluidized bed dryer using superheated steam for fluidizing gas is suitable for this purpose, because this technology can simultaneously attain higher heat transfer coefficient, larger capacity of dryer, higher safety (absence of oxygen in the fluidizing gas) and more effective heat recovery by

using evaporated steam as a heat source after compression. However, high-moisture coal is cohesive and it is important to know the influence of moisture content on its fluidization characteristics. In this research, experiments were carried out to evaluate the effect of moisture content on fluidization by visualization using cold fluidized bed test equipment. As a result, a quantitative relationship between moisture content and fluidizing characteristics was obtained by introducing angle of repose as an index of cohesiveness. © 2014 The Society of Chemical Engineers, Japan.

[229] Zhang, X.; Su, Z.; Wang, X.; Ma, Y., Analysis of moisture diffusion and activation energy in superheated steam and hot air sludge thin layer drying. Nongye Gongcheng Xuebao/Transactions of the Chinese Society of Agricultural Engineering, 2013, 29, 226-235, DOI: 10.3969/j.issn.1002-6819.2013.22.027.

Sewage sludge is generated in wastewater treatment processes. It has a solids content of about 1-2% typically. The key step to treating sludge is dewatering.. Dewatering of sludge by belt presses, filters, and centrifuges can lead to dry solids contents in the range of 15-25%. This step can substantially reduce the volume of the sludge. Characteristics of sludge include high water content, bulk mass, and containment of pathogenic microorganisms. Landfilling of sludge has the disadvantages of occupying land and causing secondary pollutions, especially to groundwater. Thermal drying of dewatered sludge is another step to reduce the volume of dewatered sludge. The drying process consists of complex mechanisms such as molecular diffusion, capillary flow, Knudsen flow, water uptake kinetics flow, and surface diffusion. In order to study the effective diffusion coefficient and the activation energy characteristics of the sludge layer in the process of superheated steam drying and hot air drying, an internal-circulation drying test-bed under normal pressure was built to carry out superheated steam drying and hot air drying tests on sludge layers with thicknesses of 4 mm and 10 mm respectively at the temperature range of 160-280°C. The linear relationship between effective diffusion coefficient and drying time was established through the Fick diffusion model. It was found that the effective diffusion coefficients for the 4 mm sludge layer ranged 7.1515×10-9-2.4852×10-8 m2/s and 1.2414×10-8-2.2769×10-8 m2/s for superheated steam drying and hot air drying respectively. The effective diffusion coefficients for the 10 mm sludge layer ranged 1.9659×10-8-5.8811×10-8 m2/s and 2.8042×10-8-5.6095×10-8 m2/s for superheated steam drying and hot air drying respectively. The linear relationship between effective diffusion coefficient and temperature was established based on the Arrhenius empirical formula. Thus, the

average activation energies of 4 and 10 mm sludge layers can be obtained respectively as 21.173 and 18.085 kJ/mol by superheated steam drying and 9.485, 11.191 kJ/mol by hot air drying. These values are mostly in conformity with the effective diffusion coefficient and activation energy obtained by the Midilli thin layer drying model This test showed that when temperature exceeds 260°C, the effective diffusion coefficient of a sludge layer by superheated steam drying is greater than that created by hot air drying. Values obtained showed a linear increase in diffusion coefficients to temperature by superheated steam drying but a curve in hot air drying, suggesting the possibility of oxidation and combustion of the sludge layer by hot air drying.

[230] Yun, T. M.; Puspasari, I.; Tasirin, S. M.; Talib, M. Z. M.; Daud, W. R. W.; Yaakob, Z., Drying of oil palm frond particles in a fluidized bed dryer with inert medium. Chemical Industry and Chemical Engineering Quarterly, 2013, 19, 593-603, DOI: 10.2298/CICEQ120327094Y.

Drying characteristics of oil palm frond fibres were investigated in a fluidized bed dryer in the presence of inert particles. Sand was used as the inert material. Effects of air temperature (60, 70 and 80 °C), air velocity (0.79 and 0.85 m/s) and mass ratio of fibres to sand (1:0, 1:1 and 1:2) on the drying curves were investigated. The results showed that the shortest drying time was obtained with the highest air temperature, air velocity and fibres to sand mass ratio. The experimental drying data were fitted to nine existing drying models, namely the Lewis, Page, Modified Page, Henderson and Pabis, Logarithmic, Two-term, Two-term exponential and Wang and Singh models and a proposed new model. The goodness-of-fit was determined based on the values of r2, $\chi 2$ and RMSE. The results showed that the best quality of the fit was obtained using the proposed model. The new model was also validated for the superheated steam drying of oil palm empty fruit bunch from other work.

[231] Xiao, Z.; Zhang, F.; Wu, N.; Liu, X., CFD modeling and simulation of superheated steam fluidized bed drying process, in IFIP Advances in Information and Communication Technology. 2013. p. 141-149.

An unsteady mathematical model of superheated steam fluidized bed drying process is established based on the transport process principles and computational fluid dynamics (CFD) method. The vapor-solid two-phase turbulent flow in the drying chamber is described with the Eulerian-Eulerian multiphase model. The model is solved by computer numerical simulation. The drying experiments of wet rapeseeds are conducted in a normal atmosphere. The experimental results agreeing well with the

simulation results show that the mathematical model of drying process is effective. © 2013 IFIP International Federation for Information Processing.

[232] Xiao, Z.; Wu, N.; Liu, X., Experiment on flow characteristics of fluidized bed drying with superheated steam. Nongye Jixie Xuebao/Transactions of the Chinese Society for Agricultural Machinery, 2013, 44, 183-186, DOI: 10.6041/j.issn.1000-1298.2013.07.032.

Based on the theoretical analysis of flow characteristics between superheated steam and granules materials in the fluidized bed drying chamber, the fluidization experiment with superheated steam and hot air was conducted by using the dried rapeseed particles as the experimental material. A small experimental device was established. The experimental results showed that the operating velocity of superheated steam fluidized bed drying was faster than the traditional hot air fluidized bed dying under the same conditions. Under the given conditions, the critical fluidization velocity of the rapeseed particles was 1.26 m/s during superheated steam fluidized bed drying.

[233] Xiao, Z.; Bao, X.; Wu, N., Flow behaviors study on superheated steam fluidized bed drying, in Applied Mechanics and Materials. 2013. p. 467-470.

In the paper, we theoretical analysis the gas-particle flow behaviors in the drying chamber. Then establish a small experimental device and conduct a comparative fluidization experiment with superheated steam and hot air, which the dried rapeseed particles are the experimental material. The critical fluidizing velocity of the rapeseed particles in superheated steam is 1.26 m/s in the experimental condition. The experimental results show that the inlet operating flow velocity of superheated steam fluidized bed drying is greater than which of the traditional hot air fluidized bed dying under the same conditions. © (2013) Trans Tech Publications, Switzerland.

[234] Wu, Y.; Zhang, Q.; Yang, W.; Blasiak, W., Two-dimensional computational fluid dynamics simulation of biomass gasification in a downdraft fixed-bed gasifier with highly preheated air and steam. Energy and Fuels, 2013, 27, 3274-3282, DOI: 10.1021/ef4003704.

Biomass gasification is regarded as one of the most promising energy recovery technologies for the widespread use of biomass. Mathematical models have been developed to understand this process in downdraft fixed beds using zero- and one-dimensional models, but only a limited number of two-dimensional (2D) models for downdraft fixed-bed reactors can be found in the literature. In this study, a 2D computational fluid dynamics (CFD) model was developed to study the gasification

process in a downdraft configuration, considering drying, pyrolysis, combustion, and gasification reactions. The gas and solid phases were resolved using an Euler-Euler multiphase approach, with exchange terms for the momentum, mass, and energy. The standard k-ε turbulence model was used in the gas phase. The model results were compared to existing data from a demonstration-scale fixed-bed downdraft gasifier. The simulation results exhibit a reasonable agreement with the experimental data. Parameter studies were performed on the basis of the developed model, which indicated that an external heat source for the high-temperature agent gasification (HTAG) technology using superheated air combined with steam resulted in a limited combustion need in the gasifier and produced syngas with a high H2 fraction and low tar content, which is environmentally preferable. © 2013 American Chemical Society.

[235] Woo, M. W.; Stokie, D.; Choo, W. L.; Bhattacharya, S., Master curve behaviour in superheated steam drying of small porous particles. Applied Thermal Engineering, 2013, 52, 460-467, DOI: 10.1016/j.applthermaleng.2012.11.038.

A lump drying model was developed for superheated steam drying of porous particles. Using single particle drying data [1], a unique master curve drying characteristic was obtained for porous ceramic particles dried under different degree of superheating and relative velocities. Further analysis revealed that the mass transfer depression phenomenon is significant under such superheating condition, typically used in drying processes. This highlights the precaution required in the case of future model development. This approach can potentially be a versatile approach in modelling the drying of porous particles, such as brown coal, under superheated steam condition. © 2012 Elsevier Ltd. All rights reserved.

[236] Wang, Q.; Zhu, J.; Zhang, W.; Li, J.; Bo, H. Optimization of superheated steam drying to reduce energy consumption for low rank coal in power plant. in Proceedings of the 26th International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems, ECOS 2013. 2013.

Understanding of fundamental aspects of coal moisture and the principle of drying with superheated steam is known for a long time already. Drying technology effects on physical and chemical characteristics of low rank coal (LRC) is very important in order to develop more excellent technologies to remove coal water effectively. Directly applied higher content moisture of inferior coal to combustion in power plant will cause to the boiler thermal efficiency and power plant net efficiency reduce. Drying research focuses on the characteristics and using effect on drying material to achieve on

reduction of greenhouse gas emissions and efficient of moist coal conversion utilization. Use of superheated steam as the drying medium not only could improve the whole efficiency but also reduced the energy consumption of the drying system. But resolving high energy consumption is the important problem to widely apply. The optimization to superheated steam drying of energy system is proved to lesser energy consumption through continue applied potential thermal energy of condensed water after superheated steam fulfilled main function to drying coal in the dryer. We think about two aspects of pre-warm and rearcooling: Pre-warm can be achieved by thermal conversion between condensed water out of main dryer and the moist coal of normal temperature. It warmed the moist coal of normal temperature on the condition of environment to cause the temperature of moist coal rising and the temperature of condensed water reducing. The temperature of moist coal rising helps to improve the rate of drying coal enter the main dryer. On other side, the condensed water after reduced temperature and contacting the coal cooler go to cooling the drying-hot coal out of main dryer to improve the efficiency of cooling coal and reduce the consumption cooling water for the drying-hot coal out of main dryer. The optimization of the superheated steam drying can keep stable and can continuous to dry inferior-moisture coal with the requirements of coal drying practical industrial application in the condition of drying system, we put forward Optimization of Energy Consumption (OEC) technique. The total specific energy consumption of the drying system was around 560-710KJ/kg water (standard atmosphere, 20 °C) at an inle steam temperature of 200°C, reduce 10%-35%more than the original superheated steam drying coal system. The optimization shows better character of drying and energy consumption.

[237] Thakhiew, W.; Devahastin, S.; Soponronnarit, S., Physical and mechanical properties of chitosan films as affected by drying methods and addition of antimicrobial agent. Journal of Food Engineering, 2013, 119, 140-149, DOI: 10.1016/j.jfoodeng.2013.05.020.

Incorporation of an antimicrobial agent into a biopolymer matrix not only affects the antimicrobial property, but also the physical, mechanical and barrier properties of the resulted films. In addition to the effect of antimicrobial agent different drying methods that are used to prepare the films should also be considered. The aim of this study was to investigate the combined effects of drying methods, namely, hot air drying and low-pressure superheated steam drying (LPSSD), and addition of a natural antimicrobial agent, namely, galangal extract, at concentrations of 0%, 0.6%, 0.9%, 1.2% and 1.5%

(w/w film forming solution) on selected physical properties (thickness, moisture content, color and opacity), mechanical properties (tensile strength and percent elongation), barrier properties (water vapor and oxygen permeabilities), degree of crystallinity and degree of swelling of antimicrobial films prepared from chitosan. X-ray diffraction (XRD) analysis, Fourier-transform infrared (FTIR) spectroscopy as well as dynamic mechanical analysis (DMA) were also performed and their results used to explain the observed combined effects. The combined effects were noted to have a statistically insignificant influence on the moisture content, thickness and water vapor permeability of the films. On the other hand, the combined effects had a statistically significant influence on the color, degree of crystallinity, degree of swelling, tensile strength, percent elongation and oxygen permeability of the films. Only the galangal extract concentration had a statistically significant influence on the film opacity. The DMA patterns and FTIR spectra confirmed the formation of crosslinkage interactions between the galangal extract and chitosan matrix.

[238] Tahmasebi, A.; Yu, J.; Bhattacharya, S., Chemical structure changes accompanying fluidized-bed drying of Victorian brown coals in superheated steam, nitrogen, and hot air. Energy and Fuels, 2013, 27, 154-166, DOI: 10.1021/ef3016443.

Chemical structure changes during drying of Victorian brown coals, that is, Loy Yang (LY) and Yallourn (YL), in hot air, nitrogen, and superheated steam are quantitatively studied using the FTIR technique. The infrared (IR) spectra of raw and dried coals were curve-fitted to a series of bands in hydroxyl groups (3500-3000 cm-1), aliphatic hydrogen (3000-2800 cm-1), and carbonyl and aromatic carbon (1850-1500 cm-1) adsorption regions. Following air drying, the IR adsorption of aliphatic structures decreased significantly, indicating that oxidation reaction mainly takes place on these structures. Carbonyl and carboxyl groups decreased up to 130 C by 25.9% and 23.9%, respectively, and then significantly increased at higher temperatures due to oxidation. Drying of brown coals in nitrogen resulted in a significant increase in their aromaticity and a lower concentration of oxygen-containing functional groups. The loss of oxygen was confirmed by measuring the O/C ratio of raw and dried samples. The O/C ratio decreased by 30.8% and 40.7% for LY and YL coals, respectively, after drying at 200 C for 10 min. Superheated steam fluidized-bed drying of both LY and YL coals showed the breakage of some weak aliphatic C-H structures. The decrease in adsorption of hydroxyl, carboxyl, and carbonyl groups leads to loss of oxygen in both LY and YL

steam-dried coals. Superheated steam drying of brown coals showed only minor changes to the coal organic structure as the aromatic carbon content remained relatively unchanged and aliphatic structures decreased negligibly. © 2012 American Chemical Society.

[239] Swasdisevi, T.; Devahastin, S.; Thanasookprasert, S.; Soponronnarit, S., Comparative Evaluation of Hot-Air and Superheated-Steam Impinging Stream Drying as Novel Alternatives for Paddy Drying. Drying Technology, 2013, 31, 717-725, DOI: 10.1080/07373937.2013.773908.

An investigation was conducted on impinging stream drying of moist paddy using hot air and superheated steam as the drying media. Drying experiments were divided into two parts: namely, one-pass and two-pass drying. The volumetric water evaporation rate, volumetric heat transfer coefficient, and specific energy consumption of the drying system at various conditions were assessed; in the case of superheated-steam drying, the effect of steam recycle was also assessed. The quality of dried paddy was evaluated in terms of color, head rice yield, and degree of starch gelatinization. In the case of one-pass drying, an increase in the drying temperature led to a significant increase in the volumetric water evaporation rate and volumetric heat transfer coefficient. On the other hand, in the case of two-pass drying, an increase in the drying temperature led to a significant decrease in the volumetric heat transfer coefficient; the volumetric water evaporation rate was not significantly affected, however. The specific energy consumption decreased with an increase in the drying temperature. At the same temperature, using superheated steam as the drying medium led to lower specific energy consumption; higher level of steam recycle also led to more energy conservation. The color of the dried paddy was not affected by the change in the drying temperature; superheated-steam-dried paddy was redder and more yellow than the hot-air-dried paddy. An increase in the drying temperature led to decreased percentage of head rice yield. Superheated-steam drying helped enhance the level of starch gelatinization in comparison with hot-air drying at the same temperature. Nevertheless, drying at the highest tested temperature led to a lower level of starch gelatinization. © 2013 Copyright Taylor and Francis Group, LLC.

[240] Stokie, D.; Woo, M. W.; Bhattacharya, S., Comparison of superheated steam and air fluidized-bed drying characteristics of Victorian brown coals. Energy and Fuels, 2013, 27, 6598-6606, DOI: 10.1021/ef401649j.

Brown coals represent a large resource for Victoria, with reserves of over 500 years at the current rate of consumption. However, its high moisture content (~60%) impedes its utilization in an efficient manner. Information on drying kinetics of these coals is still scarce, affecting the development of economic and efficient drying technology. This experimental and modeling study presents a comparison of the drying kinetics between steam fluidized-bed drying and air fluidized-bed drying of three Victorian brown coals: Loy Yang, Yallourn, and Morwell. The effects of gas temperature (100-200 °C), gas velocity (0.32-0.61 m/s), and particle size (0.5-1.7 mm) on the drying kinetics have been examined. Both air and steam fluidized bed drying has been found to result in similar trends, with air drying having shorter drying times compared to steam drying. Increase in temperature and velocity, and a reduced particle size decreases the length of time required for complete drying to occur. Comparing air to steam fluidized bed drying, the relative drying ratios for a similar conditions (such as 130-170 °C) remains consistent, with the exception of particle size. The resultant 130 °C dried coal was used to analyze the moisture readsorption properties of the coals. The data show that steam fluidized-bed dried coals readsorb less moisture than air fluidized-bed dried coal, regardless of the coal type, with an average difference in moisture of 1.6%. The physical and chemical characterization of dried coal shows that moisture readsorption is a function of the oxygen functional group content. Several drying models available in the literature were compared against the experimental data acquired during this study. The results indicate that the Midilli-Kucuk model accurately describes the drying kinetics of the three investigated Victorian brown coals. © 2013 American Chemical Society.

[241] Phungamngoen, C.; Chiewchan, N.; Devahastin, S., Effects of various pretreatments and drying methods on Salmonella resistance and physical properties of cabbage. Journal of Food Engineering, 2013, 115, 237-244, DOI: 10.1016/j.jfoodeng.2012.10.020.

The combined effects of pretreatment and drying methods on the resistance of Salmonella attached to vegetable surfaces as well as some physical properties, in terms of color and shrinkage, were investigated. Cabbage was used as a test vegetable and Salmonella Anatum was used as a test microorganism. Cabbage leaves were pretreated either by soaking in 0.5% (v/v) acetic acid for 5 min, blanching in hot water for 4 min or blanching with saturated steam for 2 min prior to either hot air drying, vacuum drying (10 kPa) or low-pressure superheated steam drying (10 kPa) at 60 °C. Based on an

initial Salmonella contamination level of approximately 6.4 log CFU/g, soaking in acetic acid, hot-water and steam blanching resulted in 1.6, 3.8 and 3.6 log CFU/g reduction in the number of Salmonella, respectively. Drying without pretreatment could not completely eliminate Salmonella attached on the cabbage surfaces, while no Salmonella was detected on the pretreated samples at the end of the drying process. Volumetric shrinkage was not affected by the pretreatment and drying methods. Dried blanched samples exhibited greener and darker color than the dried acetic acid pretreated and untreated samples.

[242] Peter Clark, J., Using superheated steam in drying and sterilization. Food Technology, 2013, 67, 91-93.

[243] Niamnuy, C.; Charoenchaitrakool, M.; Mayachiew, P.; Devahastin, S., Bioactive Compounds and Bioactivities of Centella asiatica (L.) Urban Prepared by Different Drying Methods and Conditions. Drying Technology, 2013, 31, 2007-2015, DOI: 10.1080/07373937.2013.839563.

Centella asiatica (L.) Urban has attracted significant research and commercial interest due to its many health-promoting bioactive compounds, especially phenolic compounds and triterpene saponins, which possess several functional capacities, including antioxidant activity and antimicrobial activity. Prior to its use, however, C. asiatica usually needs to be dried to extend its storage life and to prepare the material for subsequent pharmaceutical processing. The present study investigated the effects of selected drying methods and temperature on the drying characteristics, phenolic compounds, triterpene saponins, antioxidant activity, and antimicrobial activity of dried C. asiatica. Hot-air drying (HAD), combined infrared-hot air drying (IR-HAD), and low-pressure superheated steam drying (LPSSD) were carried out at various temperatures (50, 60, 70°C). The results showed that higher drying temperatures led to higher drying rates but to lower levels of total phenolic compounds, total triterpene saponins, antioxidant activity, and antimicrobial activity. At the same drying temperature, IR-HAD resulted in the highest drying rates; this was followed by LPSSD and HAD in a descending order. Nevertheless, LPSSD resulted in the highest levels of the tested bioactive compounds, antioxidant activity, as well as antimicrobial activity. LPSSD at 50°C yielded dried C. asiatica of the best overall quality.

[244] Mujumdar, A. S., Editorial: Why Four Decades of R&D in Drying? Drying Technology, 2013, 31, 617-618, DOI: 10.1080/07373937.2013.793129.

[245] Luk, H. T.; Lam, T. Y. G.; Oyedun, A. O.; Gebreegziabher, T.; Hui, C. W., Drying of biomass for power generation: A case study on power generation from empty fruit bunch. Energy, 2013, 63, 205-215, DOI: 10.1016/j.energy.2013.10.056.

Foreseeing a promising future of utilizing bio-energy, more and more small-scale biomass power plants are recently built. Biomasses with high moisture content such as sludge or Empty Fruit Bunch are often used as fuel in small-scale power plant without proper drying. These highly moist biomasses reduce the efficiency of the boiler but on the other hand drying the biofuel is also an energy intensive process. This paper aims to investigate how drying would affect the overall energy efficiency while proper heat integration in between the drying and power plant is under consideration. A 12.5MW biomass power plant that burns EFB with 60wt% moisture is used as a base case. Two types of dryer, Hot Air Dryer (HAD) and Superheated Steam Dryer (SSD), are proposed for the drying process. These two dryers require heat at different temperature levels to provide a better chance for heat integration. Material and energy balance models of the dryers and boilers are derived in this paper and the steam power plant model is constructed in Aspen Plus. The results of this study show that with proper drying and heat integration, the overall efficiency can be improved by more than 5%, when compared to process without drying. © 2013 Elsevier Ltd.

[246] Liu, Y.; Aziz, M.; Kansha, Y.; Tsutsumi, A., A novel exergy recuperative drying module and its application for energy-saving drying with superheated steam. Chemical Engineering Science, 2013, 100, 392-401, DOI: 10.1016/j.ces.2013.01.044.

A novel exergy recuperative drying module with superheated steam as the drying medium was developed. The process is based on self-heat recuperation technology which can recirculate both the sensible and latent heats without heat addition. This drying module was applied as an exergy recuperative process for the drying of wet solids. The energy consumption for the exergy recuperative drying system could be reduced to 1/7-1/12 that required for a conventional heat-recovery drying system in the case of drying wet solids from 65 to 10. wt% (wet basis, wb) of water content. The effects of adiabatic efficiency of the compressor and the final water content of the dried samples on the energy consumption of the proposed drying system were calculated by the process simulator PRO/II. © 2013 Elsevier Ltd.

[247] Listyanto, T.; Ando, K.; Yamauchi, H.; Hattori, N., Microwave and steam injection drying of CO2 laser incised Sugi lumber. Journal of Wood Science, 2013, 59, 282-289, DOI: 10.1007/s10086-013-1331-9.

To investigate the effect of CO2 laser incising under five drying methods on drying characteristics of Sugi lumber, the squares (120 mm × 120 mm) of Sugi lumber with length of 650 mm were used. A half of samples were incised by CO2 laser with incising density of 2,500 holes/m2. Five types of drying methods were used: microwave drying, steam injection drying, and three combinations of microwave heating and steam injection drying. Steam injection drying was conducted by injecting superheated steam of 120 °C through a perforated plate heated to 140 °C of an injection press. Microwave was irradiated with the power of 3 kW at frequency of 2.45 GHz. The results indicated that incising helps heat through a specimen and thus the whole temperature raised rapidly, which was up to threefolds compared to that of no-incised one. Incised specimens dried by a combination of microwave heating for 1 h and steam injection showed the highest drying rate, which was up to 5.3 %/h. Incising and microwave heating contributed positively to dry lumber under more uniform distribution of moisture content and to reduce surface and internal checks. Incised specimen dried by microwave showed the most uniform distribution of moisture content without surface and internal checks. © 2013 The Japan Wood Research Society.

[248] Kozanoglu, B.; Mazariegos, D.; Guerrero-Beltrán, J. A.; Welti-Chanes, J., Drying Kinetics of Paddy in a Reduced Pressure Superheated Steam Fluidized Bed. Drying Technology, 2013, 31, 452-461, DOI: 10.1080/07373937.2012.740543.

Drying kinetics of paddy are experimentally studied in a superheated steam fluidized bed operating at reduced pressure. During the experiments, different operating pressures (40-67 kPa), operating temperatures (98-118°C), superficial steam velocities (2.9-4.0 m/s), and mass flow rates (0.0061-0.0103 kg/s) were employed. The condensation problem, typically observed in the initial part of the process, was eliminated in the majority of the experiments through some additional heat supplied into the column by electrical resistances.The experiments demonstrated that drying rates increase by increasing operating temperature. Nevertheless, the operating pressure and the superficial steam velocity showed only limited influences over the process. The degree of superheating was identified as the principal parameter controlling the phenomenon. It was also observed that higher degrees of superheating generate lower equilibrium moisture contents and a superheating steam fluidized bed operating at reduced pressure can achieve drying processes at relatively lower temperatures. © 2013 Copyright Taylor and Francis Group, LLC.

[249] Kokocińska, M. Pakowski, Z., High pressure desorption equilibrium of lignite obtained by the novel isochoric method. Fuel, 2013, 109, 627-634, DOI: 10.1016/j.fuel.2013.02.054.

The most promising method of coal drying is the high pressure superheated steam drying (HPSHSD). High temperature and pressure sorptional equilibrium of lignite used in HPSHSD design is rarely available. The measurement requires either complex equipment or is time and labor consuming. In this work a novel isochoric method of high temperature and pressure desorption equilibrium measurement is described which uses a standard autoclave and easy to follow experimental procedure. Using this method the desorption equilibrium of low rank coal of Bełchatów open pit mine was measured in the range of temperatures up to 200°C and pressures up to 23.6 bar. A BET type equation was fitted to the experimental data with correlation coefficient of 0.960. The results obtained compare well to the results obtained for low rank coal using much more sophisticated equipment. © 2013 Elsevier Ltd. All rights reserved.

[250] Kiriyama, T.; Sasaki, H.; Hashimoto, A.; Kaneko, S.; Maeda, M., Experimental observations and numerical modeling of a single coarse lignite particle dried in superheated steam. Materials Transactions, 2013, 54, 1725-1734, DOI: 10.2320/matertrans.M-M2013817.

The drying characteristics of a single coarse lignite particle in superheated steam are investigated. Spherical particles of Loy Yang lignite 30mm in diameter were used. The particles were dried with superheated steam at temperatures ranging from 110 to 170°C under atmospheric pressure, and their weights and temperatures were measured with electronic balance, thermocouples and infrared thermograph. Condensation of water droplets on the surface was observed initially, then constant drying rate period (CDRP) and decreasing drying rate period (DDRP) were observed successively. A numerical model of the drying process was developed based on the results, taking into account transfer of free water inside the particle, equilibrium moisture content and shrinkage of the lignite particle itself. © 2013 The Japan Institute of Light Metals.

[251] Jangam, S. V. Mujumdar, A. S., Recent Developments in Drying Technologies for Foods, in Food Engineering Series. 2013. p. 153-172.

Thermal dehydration is the most common and cost-effective technique for the preservation of foods and for the production of traditional as well as innovative processed products such as snacks with desired functionalities. This chapter provides an overview of recent developments in thermal drying technologies that are already

commercialized or show potential of industrial exploitation upon successful R&D to sort out some limitations. New dehydration technologies are needed to enhance quality, reduce energy consumption, improve safety, and reduce environmental impact. Mathematical modeling can be used for the cost-effective development of novel designs to reduce the cost and time required for innovation. As examples of some emerging drying techniques this chapter provides relevant details on heat-pump-assisted drying, superheated steam drying, pulse combustion spray drying, variable pressure drop drying (swell drying), and novel gas-particle contactors such as impinging streams and pulsed fluidized beds. Multistage drying, intermittent drying, and the use of hybrid drying technologies that combine the advantages of different dryer types without some of their limitations will be outlined. © 2013, Springer Science+Business Media New York.

[252] Hu, S.; Man, C.; Gao, X.; Zhang, J.; Xu, X.; Che, D., Energy Analysis of Low-Rank Coal Pre-Drying Power Generation Systems. Drying Technology, 2013, 31, 1194-1205, DOI: 10.1080/07373937.2013.775146.

Low-rank coal (LRC) is widely used for power generation in many regions of the world. However, due to the high moisture content of LRC, the overall efficiency of LRC-fired power plants without a pre-drying system is relatively low. Studies show that the overall efficiency can be improved by pre-drying the coal, and the fluidized bed drying technique is found to be a desirable choice because of its high drying rate, high processing capacity, and low maintenance cost. In this paper, two novel, fluidized-bed, LRC pre-drying systems were integrated into a 1000 MW LRC-fired power plant. Superheated steam and hot air were used as the fluidizing medium. Models for each component of these power generation systems were developed based on material and energy balances. The performances of these power plants were calculated under the typical operating conditions, and parametric analyses were also performed to evaluate the effect of operating parameters. The power generation efficiency is found to increase remarkably with a properly operated LRC pre-drying system. © 2013 Copyright Taylor and Francis Group, LLC.

[253] Hosseinpour, S.; Rafiee, S.; Mohtasebi, S. S.; Aghbashlo, M., Application of computer vision technique for on-line monitoring of shrimp color changes during drying. Journal of Food Engineering, 2013, 115, 99-114, DOI: 10.1016/j.jfoodeng.2012.10.003.

The effects of drying temperature and drying medium velocity on color change kinetics of shrimp viz. lightness (Llowast), redness (a lowast), yellowness (blowast), total color difference (δE), chroma (CH), hue angle (H°), and browning index (BI) were on-lineally investigated. Drying experiments were carried out on dryer equipped with computer vision systems using hot air drying (HAD) temperatures of 50-90 °C and superheated steam drying (SSD) temperatures of 110-120 °C at drying medium velocities of 1-2 m/s. Zero-, first-order, and fractional conversion models were utilized to describe the color changes of shrimps and the fractional conversion model successfully tracked the experimental data. The results showed that the color parameters were significantly influenced by the studied parameters. Lightness of the samples decreased, while other color parameters increased as drying proceeded. Generally, increasing drying medium temperature decreased Llowast and H°, whereas increased other color parameters. The color characteristic of the SSD finished products were acceptable than the HAD processed samples. Finally, dimensionless moisture content of shrimps during drying was accurately correlated to the color parameters and drying time using a quadratic regression model. Moisture ratio had strong relationship with the lightness change compared with the redness and yellowness variations.

[254] Haque, N. Somerville, M. Techno-economic and environmental evaluation of biomass dryer. in Procedia Engineering. 2013.

The pros and cons of various types of biomass dryers have been documented in this paper. Using dry biomass significantly reduces the cost of handling, transportation and pyrolysis. The main choices for drying biomass are rotary dryers, flash dryers, stationery bed dryers and fluidised bed dryers. The drying medium can be hot air, hot air mixed with steam, and/or superheated steam. A typical example for wood chip drying using a financial model is described, including the environmental performance. The energy requirements and greenhouse gas emissions have been estimated for drying biomass. From this study, it is evident that increasing temperature will decrease drying time and increase throughput but not necessarily decrease the drying cost. This is due to higher energy use and higher cost of capital inputs such as loading/unloading and heat plant. Thus, low drying temperature can be used if throughput is not a key issue for an operation. The global warming potential of the biomass drying process 9.2 kg CO2-e/t of oven-dry biomass. This assumes that wood waste is used as fuel and drying is on a moving belt dryer. If this dry biomass is used in a power station as fuel for steam

boiler, there is a significant reduction potential of CO2 emission from a typical black coal-fired power plant due to fuel switching. This assumes that trees are planted to produce this biomass sustainably. Environmental impacts of any dryer type should be considered for selection in addition to its traditional techno-economic performance. © 2013 The Authors. Published by Elsevier Ltd.

[255] Adamski, R. Pakowski, Z., Identification of Effective Diffusivities in Anisotropic Material of Pine Wood during Drying with Superheated Steam. Drying Technology, 2013, 31, 264-268, DOI: 10.1080/07373937.2012.717152.

Simulation of 3D drying of anisotropic solids requires knowledge of the diffusivities of moisture in all three directions. These are seldom available in the range of temperatures and moisture contents of interest. This article presents methodology for identification of axial and radial diffusivities in wood in superheated steam drying and the results for wood of Pinus silvestris at a steam temperature 160°C and atmospheric pressure. Axial diffusivity (along fibers) was 5.76 times higher than radial diffusivity. © 2013 Copyright Taylor and Francis Group, LLC.

[256] Zielinska, M. Cenkowski, S., Superheated steam drying characteristic and moisture diffusivity of distillers' wet grains and condensed distillers' solubles. Journal of Food Engineering, 2012, 109, 627-634, DOI: 10.1016/j.jfoodeng.2011.06.017.

Samples of distillers' spent grains were prepared by blending different proportions of distillers' wet grains (DWG) with condensed distillers' solubles (CDS). Such samples when dried with superheated steam (SS) at 110, 130 and 160°C showed typical behaviour of drying in the falling rate period. The overall moisture diffusivity (D m) increased with a decrease in moisture content under all drying conditions. An increase in moisture diffusivity with respect to the SS temperature was also observed. For all drying conditions, the values of average diffusivities (D m) avg non-corrected for shrinkage ranged from 0.52 × 10 -9 to 3.08 × 10 -9 m 2/s. For distillers' spent grains of different ratios of DWG to CDS, the decrease in SS temperature from 160 to 110°C caused a decrease in (D m) avg by 69-82%. Increasing the amount of CDS added to the DWG from 0% to 100% caused an increase in (D m) avg by 14-35% for the temperature range tested in this study. The values of (D m) avg corrected for shrinkage ranged from 0.17 × 10 -9 to 0.86 × 10 -9 m 2/s for all drying conditions studied. The decrease in SS temperature from 160 to 110°C caused a decrease in (D m) avg by 70-74%. Not much differences were observed for the same drying temperatures and different ratios of DWG to CDS. The differences between the values of average overall moisture

diffusivity (D m) avg corrected and non-corrected for shrinkage were significant, nearly one order of magnitude.

[257] Zhang, Q.; Xiao, H.; Yang, X.; Bai, J.; Lou, Z.; Gao, Z., Effects of pretreatment on air impingement drying characteristics and product color for line pepper. Nongye Gongcheng Xuebao/Transactions of the Chinese Society of Agricultural Engineering, 2012, 28, 276-281, DOI: 10.3969/j.issn.1002-6819.2012.01.049.

The purpose of this paper was to investigate the effects of different pre-treatments on air impingement drying characteristics and product color of line pepper. The experimental results demonstrated that pre-treatments had important effects on drying characteristics and color. It was found that the drilling hole pre-treatment could significantly decrease the drying time, improve drying rate and reduce red pigment loss as well as browning. Color protection was achieved by blanching line peppers at 90°C for 3 min in hot water. It was discovered that hot water blanching pre-treatment could extend drying time. Application of 110°C superheated steam blanching for 3 min could prevent browning. For all pre-drying treatments, the total drying occurred in the deceleration period.

[258] Xiao, H. W.; Yao, X. D.; Lin, H.; Yang, W. X.; Meng, J. S.; Gao, Z. J., Effect of SSB (Superheated Steam Blanching) time and drying temperature on hot air impingement drying kinetics and quality attributes of yam slices. Journal of Food Process Engineering, 2012, 35, 370-390, DOI: 10.1111/j.1745-4530.2010.00594.x.

The effects of SSB (superheated steam blanching) time (0, 3, 6, 9 and 12 min) and drying temperature (50, 60, 70 and 80C) on drying kinetics and quality of yam slices under air impingement drying were investigated in this paper. Results indicated that the positive effect of SSB on drying rate might be overshowed by the negative effect of starch gelatinization and appropriate SSB could accelerate drying rate, whereas the effect of excessive SSB is reversed. The moisture effective diffusivity ranged from 1.1540 × 10-9to 2.8431 × 10-9 m2/s, calculated using Fick's second law of diffusion. The activation energy determined from the slope of the Arrhenius plot, ln(Deff) versus 1/(T + 273.15), was 20.925 kJ/mol. Moderate increase in SSB time or decrease in drying temperature can improve the whiteness index of dried yam slices, whereas increase in SSB time and drying temperature can decrease the rehydration ratio of dried yam slices. PRACTICAL APPLICATIONS Yam is a nutritional, economical and healthy plant, which has been widely used in traditional Chinese medicine. Fresh yams having relatively high-moisture contents are very sensitive to microbial spoilage.

Drying is one of the most common methods used for yam preservation. In China, the natural sun-drying method is commonly used for drying yam. However, it requires a long drying time and the final product may be contaminated by dust and insects, especially toxic substances. Blanching is an essential step before the processing of vegetables and fruits, as it can accelerate the drying rate and prevent quality deterioration. Air impingement drying is an efficient drying technology, which has been successfully used in paper and textile industries. Understanding the effect of superheated steam blanching time and drying temperature on hot air impingement drying kinetics and quality of yam slices is helpful for improving the drying process efficiency and quality of dried yam slices. © 2011 Wiley Periodicals, Inc.

[259] Tananuwong, K. Malila, Y., Quality of rice as affected by paddy drying and kernel storage, in Rice: Production, Consumption and Health Benefits. 2012. p. 65-88.

Important steps of postharvest handling of rice include threshing, kernel drying and storage. After threshing to remove the paddy kernels out of the panicle, fresh paddy still contain high moisture content (26-30% wet basis, wb). The wet paddy is susceptible to the deterioration caused by mold and insect growth, accumulation of thermal energy due to respiration, and enzymatically induced reactions. Drying of the paddy to gain the final moisture content of 14% wb is thus essential to help prolong shelf life of the kernel. Sun drying and heated air drying of paddy in a batch or continuous flow dryer are widely used. Alternative methods of paddy drying such as fluidized bed drying with hot air or superheated steam have also been investigated. Drying methods and its conditions, such as drying temperature and time, greatly affect milling yield, physicochemical and organoleptic properties of rice, including thermal and pasting properties of rice flours, texture and aroma of cooked rice. During drying, thermal energy may induce partial gelatinization of starch, protein denaturation, lipid oxidation, as well as the loss of volatile compounds from paddy kernels. Optimization of paddy drying is thus required to gain the rice with acceptable quality. After drying, rice may be stored as paddy, hulled or milled rice. Changes in the physicochemical and sensory properties of rice during aging have been reported. Apart from rice aroma alteration, hardening of cooked rice kernels prepared from longer-aged rice commonly occurs. Extent of the changes depends on the storage condition, especially storage temperature and duration. Enzymatic hydrolysis of starch and lipid, formation of disulfide bridges in oryzenin, formation of amylose-lipid complexes, and autoxidation of lipid are among the proposed mechanisms underlying the changes in rice quality during storage. This

chapter will provide an extensive review on the changes in physicochemical properties and sensory attributes of rice induced by two important steps of postharvest treatment, paddy drying and kernel storage. In-depth discussion on the proposed mechanisms of the changes will also be included.

[260] Tahmasebi, A.; Yu, J.; Han, Y.; Yin, F.; Bhattacharya, S.; Stokie, D., Study of chemical structure changes of chinese lignite upon drying in superheated steam, microwave, and hot air. Energy and Fuels, 2012, 26, 3651-3660, DOI: 10.1021/ef300559b.

Chemical changes of Chinese lignite upon drying in superheated steam, microwave, and hot air have been studied in this paper using the Fourier transform infrared (FTIR) spectroscopy technique. The infrared (IR) spectra of raw and dried samples were curve-fitted to a series of bands in aliphatic hydrogen (3000-2800 cm -1) and carbonyl absorption (1850-1500 cm -1) zones. It has been found that aliphatic hydrogen absorbance decreased slightly with an increasing temperature during superheated steam drying, while absorption of carboxyl (COOH) and carbonyl (C=O) groups decreased drastically, indicative of the loss of oxygen functionalities with an increasing drying temperature. During steam drying, aromatic carbon and aromatic ring stretch absorption remained relatively unchanged up to 250 °C and decreased significantly thereafter because of some pyrolysis reactions that took place at higher drying temperatures. Microwave heating of lignite resulted in a significant decrease in the concentration of oxygen-containing functional groups. Aromatic carbon remained relatively unchanged under microwave drying conditions, while aliphatic hydrogen decreased slightly. The aromaticity of coal calculated from curve-fitted spectra of deconvoluted peaks showed a progressive increase with an increasing drying intensity under both steam and microwave drying conditions. Under air drying conditions, aliphatic hydrogen absorbance decreased drastically at 250 °C, while aromatic carbon remained unchanged. It was observed that oxidation in air mainly took place on aliphatic hydrogen sites, especially on methylene groups. Changes of carboxyl and carbonyl groups during air-dried samples showed a different trend compared to those dried in steam and microwave, increasing gradually up to 150 °C and then a sharp increase at 200 °C. The absorption of these groups decreased significantly at an increased air temperature up to 250 °C.

[261] Tabtiang, S.; Prachayawarakon, S.; Soponronnarit, S., Effects of osmotic treatment and superheated steam puffing temperature on drying characteristics and texture properties of banana slices. Drying Technology, 2012, 30, 20-28, DOI: 10.1080/07373937.2011.613554.

A porous structure is an important characteristic of crisp food and can be produced by a puffing process. However, puffed products may brown during puffing. To limit the browning reaction, food, in particular fruits, needs to be osmotically treated before puffing. This research therefore studied how osmotic treatment affects the quality of a puffed fruit sample, viz. banana. Banana with 20-23° Brix total soluble solid was immersed in sucrose solution concentrations at 30, 35, and 40° Brix and dried at 90°C using hot air until the sample moisture content was reduced to 30% dry basis. Then the banana slices were puffed using superheated steam at 180, 200, and 220°C for 150 s and dried again at 90°C until the sample moisture content reached 4% (db). It was found that osmotic dehydration could improve the color of puffed banana, with less browning than the non-osmotically treated puffed banana because the amounts of glucose and fructose in banana, which serve as important reagents for browning reactions, were decreased. The puffing temperature and osmotic concentrations did not enhance the browning rate. Sucrose impregnation resulted in longer drying times and limited banana cell wall expansion due to the interaction between the hydroxyl group of sucrose and that of banana tissue. This interaction further resulted in significantly higher shrinkage of the osmotically treated sample and a denser structure as viewed by scanning electron microscopy. The morphology of osmotically treated banana was a hard and brittle texture. © 2012 Taylor & Francis Group, LLC.

[262] Sinhal, K.; Ghoshdastidar, P. S.; Dasgupta, B., Computer Simulation of Drying of Food Products With Superheated Steam in a Rotary Kiln. Journal of Thermal Science and Engineering Applications, 2012, 4, DOI: 10.1115/1.4005256.

The present work reports a computer simulation study of heat transfer in a rotary kiln used for drying and preheating food products such as fruits and vegetables with superheated steam at 1 bar. The heat transfer model includes radiation exchange among the superheated steam, refractory wall and the solid surface, conduction in the refractory wall, and the mass and energy balances of the steam and solids. The gas convection is also considered. Finite-difference techniques are used, and the steady state thermal conditions are assumed. The false transient approach is used to solve the wall conduction equation. The solution is initiated at the inlet of the kiln and proceeds

to the exit. The output data consist of distributions of the refractory wall temperature, solid temperature, steam temperature, and the total kiln length. The inlet of the kiln is the outlet of the gas (superheated steam), since the gas flow is countercurrent to the solid. Thus, for a fixed solid and gas temperature at the kiln inlet, the program predicts the inlet temperature of the gas (i.e., at the kiln exit) in order to achieve the specified exit temperature of the gas. In the absence of experimental results for food drying in a rotary kiln, the present model has been satisfactorily validated against numerical results of Sass (1967, "Simulation of the Heat-Transfer Phenomena in a Rotary Kiln," Ind. Eng. Chem. Process Des. Dev., 6(4), pp. 532-535) and limited measured gas temperature as reported by Sass (1967, "Simulation of the Heat-Transfer Phenomena in a Rotary Kiln," Ind. Eng. Chem. Process Des. Dev., 6(4), pp. 532-535) for drying of wet iron ore in a rotary kiln. The results are presented for drying of apple and carrot pieces. A detailed parametric study indicates that the influence of controlling parameters such as percent water content (with respect to dry solids), solids flow rate, gas flow rate, kiln inclination angle, and the rotational speed of the kiln on the axial solids and gas temperature profiles and the total predicted kiln length is appreciable. The effects of inlet solid temperature and exit gas temperature on the predicted kiln length for carrot drying are also shown in this paper. © 2012 American Society of Mechanical Engineers.

[263] Sansiribhan, S.; Devahastin, S.; Soponronnarit, S., Generalized microstructural change and structure-quality indicators of a food product undergoing different drying methods and conditions. Journal of Food Engineering, 2012, 109, 148-154, DOI: 10.1016/j.jfoodeng.2011.09.019.

It is well recognized that changes of many physical characteristics of food during drying are due to changes of the product microstructure. However, since both the physical characteristic and microstructural changes depend on the drying methods and conditions, relationships between the physical and microstructural changes are difficult to be generalized. The aim of this work was to determine if it would be possible to develop a generalized indicator that could be used to monitor microstructural changes of a model food product (carrot cubes) undergoing three different drying methods, i.e., hot air drying, vacuum drying and low-pressure superheated steam drying. Two types of indicators, i.e., normalized change of the fractal dimension (ΔFD/FD 0) of the sample microstructure and normalized change of the average sample cell diameter (ΔD/D0), were tested. Further investigation was made to determine if the tested indicators could

be used to correlate the microstructural changes to apparent physical characteristic changes (shrinkage and hardness). It was found that both ΔFD/FD 0 and ΔD/D0 increased with a decrease in the product moisture content, corresponding to an increase in the irregularity of the sample microstructure and a decrease in the sample cell volume; the relationships between the changes of these indicators and product moisture content were similar among all the tested drying methods and conditions. However, ΔFD/FD0 seemed to be a more generalized structure-quality indicator than ΔD/D0.

[264] Sakamoto, K. Katsuoka, T., Model of through-flow drying for beds packed with tobacco cut-filler in a flow of air or superheated steam. Food Science and Technology Research, 2012, 18, 623-629, DOI: 10.3136/fstr.18.623.

A model of through-flow drying was developed in order to simulate the drying properties of beds packed with tobacco cut-filler placed in a flow of air or wet air mixed with superheated steam. This model was simplified as follows: (1) the fluid in the bed is regulated as plug flow; (2) a piece of the cut-filler is taken to have a plane-sheet shape; (3) the internal movement of water in the cut-filler is regarded as a rate-limiting step; and (4) the transfers of mass and heat are specified by a set of one-dimensional equations of convection and diffusion. In a wide range of 373 to 523 K, the calculated curves of moisture content and temperature of the tobacco were in agreement with experimental values. It was concluded that the model is valid and applicable to the estimation of drying properties of tobacco materials.

[265] Park, Y. Yeo, H. Improvement of heat treatment energy efficiency and control of drying check occurrence using superheated steam. in Proceedings of 2012 International Conference on Biobase Material Science and Engineering, BMSE 2012. 2012.

This study was executed to develop a new heat treatment method which uses superheated steam as a medium of heat treatment for reducing the risk of fire while also ensuring a high level of energy efficiency. After a heat treatment under the pressure conditions of 0.1 MPa and 0.5 MPa and the temperature conditions of 180°C and 220°C, a test to measure the surface/inner checks was performed, during which checks were not found in the conditions of 0.5 MPa and 220°C. Also, the required energy and energy efficiency for the superheated steam heat treatment under the same conditions were compared with those of the conventional heat treatment at 220°C. The energy efficiency after the superheated steam heat treatment was much higher than that after

the conventional heat treatment. Finally, through an analysis of the temperature and pressure change during the superheated steam treatment, the time when the wood specimen became an oven-dry state and the basic theoretical basis of the water movement in the wood at a high temperature and high pressure were determined. Through the results of this study, it was uncovered that a wood heat treatment using superheated steam can be used as a highly energy efficient and eco-friendly heat treatment method. © 2012 IEEE.

[266] Pakowski, Z.; Adamski, R.; Kwapisz, S., Effective diffusivity of moisture in low rank coal during superheated steam drying at atmospheric pressure. Chemical and Process Engineering - Inzynieria Chemiczna i Procesowa, 2012, 33, 43-51, DOI: 10.2478/v10176-012-0004-3.

The effective diffusivity of water in brown coal of Belchatów mine was experimentally determined. The experiments were performed in superheated steam at 200°C and atmospheric pressure using slightly compressed pellets of cylindrical shape. The drying and temperature curves of the sample were used to identify diffusivity. An inverse problem was formulated and solved by the finite element method for 3D axially symmetric cylindrical geometry of the sample. A satisfactory fit of the simulated curves to experimental results was obtained. The obtained dependence of effective diffusivity on moisture content and temperature may be used in designing lignite dryers.

[267] Messai, S.; Lecomte, D.; Sghaier, J.; Belghith, A., Experimental study of wood porous particle drying at high temperature. Mechanics and Industry, 2012, 13, 353-356, DOI: 10.1051/meca/2012030.

The present work deals with an experimental study of convective high temperature superheated steam and hot air drying of wood porous spherical particle (beechwood). A "macro-TG" apparatus, where particle was suspended and continuously weighed during drying, was used. For two values of drying agent velocity (superheated steam or hot air), moisture content and product temperature were measured during the two drying process. Next, the product quality was demonstrated to be improved when superheated steam was the drying agent. Indeed, the wood particle dried with superheated steam keeps its natural color while that dried with hot air blackens. Then, superheated steam drying process provides the most demanding requirement of the industry which is product quality. Possible applications of this particles drying is the fabrication of agglomerated wood. © AFM, EDP Sciences 2013.

[268] Liu, Y.; Aziz, M.; Kansha, Y.; Tsutsumi, A. Self-heat recuperative fluidized bed drying of low rank coal. in 29th Annual International Pittsburgh Coal Conference 2012, PCC 2012. 2012.

An advanced drying system for low rank coal drying with a very low energy consumption was designed based on self-heat recuperation technology. In self-heat recuperation technology, all the energy involved in drying is always re-circulated/re-utilized. The proposed advanced system could reduce the total energy consumption significantly up to 70% of which was required in conventional heat recovery drying system. The drying medium (non-condensable gas) is separated from the evaporated steam and only compressed pure steam flows inside the heat exchanger tube. Thus, the proposed advanced-drying system has a significant better performance during heat exchange inside the dryer due to better heat exchange following condensation of pure steam rather than air-steam mixture. Superheated steam was also used for the low rank coal drying. Further energy saving which is 1/7-1/12 of that required in a conventional heat-recovery dryer can be achieved.

[269] Li, H.; Chen, Q.; Zhang, X.; Finney, K. N.; Sharifi, V. N.; Swithenbank, J., Evaluation of a biomass drying process using waste heat from process industries: A case study. Applied Thermal Engineering, 2012, 35, 71-80, DOI: 10.1016/j.applthermaleng.2011.10.009.

Dry biomass provides considerable benefits for combustion, such as increased boiler efficiency, lower flue gas emissions and improved boiler operations, compared to fuels with high moisture. Drying is however an energy-intensive pre-treatment. Utilising low-grade, waste heat - of which large amounts are available from many process industries - could significantly reduce energy consumption. The integration of a drying process into a power station fuel system was investigated; the results are presented here. Waste heat from a process industry plant (100 MW output) was utilised as the heat source for drying. The biomass, pine chips at 60wt% moisture, was dried and could then be provided as the input fuel for a subsequent 40 MW power plant. The process consisted of a belt conveyor as the dryer and either flue gases or superheated steam (generated from the hot cooling water) as the heat source. Flue gas usage would result in lower capital costs (~€2.5 m), but environmental issues, such as pollutant emissions must be considered. Superheated steam can combine short drying times, good heat recovery and environmental protection, but would entail greater capital costs (~€3 m).

A 3-4 year return on the initial investment was calculated for both technologies, but profitability was sensitive to fuel price.

[270] Kutnar, A. Kamke, F. A., Influence of temperature and steam environment on set recovery of compressive deformation of wood. Wood Science and Technology, 2012, 46, 953-964, DOI: 10.1007/s00226-011-0456-5.

Low-density hybrid poplar wood (Populus deltoides × Populus trichocarpa) was densified by mechanical compression under saturated steam, superheated steam, and transient conditions at temperature levels of 150, 160, and 170°C. Furthermore, compression of wood under saturated steam conditions at 170°C, followed by post-heat-treatment at 200°C for 1, 2, and 3 min, was performed. To determine the influence of compression treatment on the set recovery, specimens were subjected to five cycles of water soaking and drying. Modulus of rupture (MOR) and modulus of elasticity (MOE) of specimens compressed under saturated steam conditions at 170°C and post-heat-treated at 200°C were determined in the dry condition and after five soak/dry cycles. Higher temperature of the compression treatment resulted in lower equilibrium moisture content, while the steam conditions during the treatment and the post-heat-treatment did not have significant effect. Furthermore, the highest degree of densification was obtained in specimens compressed under saturated steam conditions at 170°C and post-heat-treated at 200°C. The steam condition and temperature influenced the set recovery of compressive deformation. Reduced hygroscopicity does not necessarily imply reduced set recovery. The results established that considerable fixation of compressive deformation can be obtained by compressing the wood in a saturated steam environment and by post-heat-treatment at 200°C. The short heat-treatment had no influence on MOR or MOE, but soaking/drying treatments caused a decrease in the MOR and MOE.

[271] Kozanoglu, B.; Flores, A.; Guerrero-Beltrán, J. A.; Welti-Chanes, J., Drying of Pepper Seed Particles in a Superheated Steam Fluidized Bed Operating at Reduced Pressure. Drying Technology, 2012, 30, 884-890, DOI: 10.1080/07373937.2012.675532.

A series of drying experiments was performed in a reduced-pressure superheated steam fluidized bed, employing pepper seed particles and some novel data were obtained. Experiments were carried out using different chamber pressures (40-67 kPa), temperatures (90-122°C), steam velocities (2.35-4.10 m/s), and mass flow rates (0.0049-0.0134 kg/s). In the majority of the experiments, the moisture gain observed in

some other studies in the warm-up period of the process was prevented through some supplementary heat provided to the column. The drying rate was found to be increasing by operating temperature; however, it was not affected much by the superficial gas velocity and the operating pressure. Nevertheless, the reduced pressure operation increases the degree of superheating that appears as the most important parameter of the process. The experimental results showed that the equilibrium moisture content decreases by the increasing degree of superheating. On the other hand, the critical moisture content assumes higher values for the greater degrees of superheating. It was concluded that a relatively lower temperature process can be achieved through a reduced-pressure superheated steam fluidized bed.

[272] Kitahara, T.; Iyota, H.; Inoue, T., Development of high-temperature wide-range humidity sensor by wetted material temperature measurement (improvement of measurement accuracy by considering the effect of supplied water). Nihon Kikai Gakkai Ronbunshu, B Hen/Transactions of the Japan Society of Mechanical Engineers, Part B, 2012, 78, 686-696, DOI: 10.1299/kikaib.78.686.

A high-temperature wide-range humidity sensor has been developed using wetted material temperature measurement. A porous ceramic is used as a sensing element; it has a small tube for supplying water to maintain a wetted surface. However, the water supplied to the elements can affect the surface temperature. In this study, we experimentally investigate the accuracy of the developed sensor and its contributing factors-convective heat transfer, evaporation, radiant heat, and the water supplied to the wetted material-under the conditions of a gas flow temperature of 200 °C, gas flow velocity of 3 or 5 m/s, flow rate of supplied water of 0.01-0.05 g/s, and steam mole fraction of 0.03-1.00. Further, we calculate the heat flux and the surface temperature using a one-dimensional heat transfer model to clarify the effects of the each of the abovementioned factors. Consequently, we conclude that the supplied water strongly affects the accuracy of the developed sensor. We also improve the measurement error of the steam mole fraction from 0.07 to 0.03 by the controlling the flow rate of the supplied water.

[273] Iyota, H.; Isshiki, S.; Inoue, T.; Yamagata, J., Simplified measurement method for steam mole fractions based on temperature measurement with wet spherical material (using adiabatic saturation line applied to high temperature and high humidity).

Nihon Kikai Gakkai Ronbunshu, B Hen/Transactions of the Japan Society of Mechanical Engineers, Part B, 2012, 78, 1267-1278, DOI: 10.1299/kikaib.78.1267.

Superheated steam-containing hot air under atmospheric pressure has been used as a heating media for thermal processing such as food processing, cooking, sterilization, drying, and waste treatment. For these types of thermal processing, the steam mole fraction of the media sometimes strongly influences product quality. Hence, a simple method is required for measuring the steam mole fraction under a high temperature of more than 250°. In this report, we propose an equation to calculate the steam mole fraction using the adiabatic saturation temperature for a wide range of temperatures and humidity values, i.e., from room temperature to 350° and from room air to pure superheated steam. We also present a psychrometric chart with the steam mole fraction on the y-axis, which can indicate the presence of dry air and pure superheated steam. The values calculated by the proposed equation were in good agreement with values obtained in previous literature under comparable conditions. For developing a simple and convenient measurement method, a wet spherical gauze/brick is used for measuring the wet-bulb temperature. Its accuracy and applicability are investigated experimentally. The results show that this method can measure the steam mole fraction with an accuracy of less than 0.09 in the temperature range of 160-280°. The causes of error and the methods for intending utilization are also investigated. © 2012 The Japan Society of Mechanical Engineers.

[274] Inoue, T.; Iyota, H.; Isshiki, S., Development of high-temperature wide-range humidity sensor by wetted material temperature measurement (application of porous ceramic into sensing element). Nihon Kikai Gakkai Ronbunshu, B Hen/Transactions of the Japan Society of Mechanical Engineers, Part B, 2012, 78.

We applied the theory of a psychrometer to develop a humidity monitoring system by using cylindrical porous ceramic as a sensing element. This system contains a section for supplying/discharging water. Several types of porous ceramics were made and the effects of porosities and pore size distributions on capillary water transfer were investigated. Also, we tested the performance of this system in terms of its response time and measurement accuracy. The capillary water transfer was higher in the conditions that porosity was larger and pore size distribution was wider. In addition, at a gas flow rate of 1 m/s and a gas temperature less than 310 °C, the error of the steam mole fraction was observed to be less than 10 %. Further, the system had a 90 % response time of less than 60 s and this time was shorter as humidity increased at a gas

temperature of 200 °C, a gas flow of 1 m/s, a flow rate of supplied water of 0.01 g/s and a water temperature of 25 °C when a sensing element diameter was 9 mm. © 2012 The Japan Society of Mechanical Engineers.

[275] Grabowski, S. Boye, J. I., Green technologies in food dehydration, in Food Engineering Series. 2012. p. 413-441.

The massive scale of drying operations in many food processing industries makes this unit operation an important one to focus on in the development of "greener" food production and processing practices. Drying techniques and equipment used by many industries today are characterized by high energy consumption and relatively low thermal efficiency. In this chapter, each step of a typical food dehydration process, that is (1) wet feed pretreatment, (2) preparing (mostly heating) of the drying agent, (3) drying process, (4) maximal retrieval of the dry product, and (5) heat recovery from the exhaust gases, is discussed in detail. Because drying is associated with high investment costs and high energy consumption, elimination of the drying operation from the production process, or its replacement with lower-energy consuming operations, are primary recommendations. If this is not possible, reduction of the initial moisture content of the wet feed (thickening, preconcentration, preforming, etc.), use of environmentally friendly energy sources and energy-efficient drying installations and maximal recovery of energy from exhaust gases are recommended. Reduction or elimination of environmental pollution by complete recovery of finished dry product from exhaust gases is another important issue that needs to be considered. © 2012, Her Majesty the Queen, in Right of Canada.

[276] Dev, S. R. S. Raghavan, V. G. S., Advancements in Drying Techniques for Food, Fiber, and Fuel. Drying Technology, 2012, 30, 1147-1159, DOI: 10.1080/07373937.2012.692747.

Removal of moisture from biological materials, popularly called drying, has numerous benefits, including ease of handling due to reduction in bulk, resulting in reduced handling costs. Moreover, drying prevents microbial growth and spoilage. Though different drying techniques share a common objective, conceptually they are different and require modification/adaptation based on the biomaterial that is dried. There have been significant scientific advancements in the past century in the field of drying of foods, fibers, and fuel. This article will provide an extensive review of various drying pretreatments and different hybrid drying techniques, including supercritical and fluidized bed concepts, microwave drying, superheated steam drying, and heat pump

drying to meet tomorrow's food and energy needs. © 2012 Copyright Taylor and Francis Group, LLC.

[277] Cenkowski, S.; Sosa-Morales, M. E.; Flores-Alvarez, M. C., Protein Content and Antioxidant Activity of Distillers' Spent Grain Dried at 150°C with Superheated Steam and Hot Air. Drying Technology, 2012, 30, 1292-1296, DOI: 10.1080/07373937.2012.686948.

The quality of dried distillers' grain (DDG) is of great importance, and due to concerns regarding drying efficiency, various drying methods have been proposed. The objective of this study was to evaluate the protein content and antioxidant activity of DDG using two different drying media: (1) hot air at 150°C and (2) and superheated steam (SS) at 150°C. The results were compared to a reference sample dried at near ambient air temperature of 30°C. Protein content ranged from 15.1 to 16.4% wb for all samples. With respect to phenolic content, ethanolic extraction (3.1-12.9 mg GAE/g) was more effective than aqueous extraction (0.87-2.9 mg GAE/g). The DDG samples dried with SS had the highest phenolic contents among the analyzed samples ($p < 0.05$). Antioxidant activity ranged between 0.32 and 0.44 mg Trolox/g for aqueous extracts and 0.54-0.57 mg Trolox/g for ethanolic extracts. The results indicate that SS drying can be a suitable method to dry distillers' spent grain without the adverse effect on protein and phenolic contents. © 2012 Copyright Taylor and Francis Group, LLC.

[278] Yang, D.; Wang, Z.; Huang, X.; Xiao, Z.; Liu, X., Numerical simulation on superheated steam fluidized bed drying: I. Model construction. Drying Technology, 2011, 29, 1325-1331, DOI: 10.1080/07373937.2011.592047.

An unsteady axisymmetric two-dimensional mathematical model for a superheated steam fluidized bed drying process is established by using the Eulerian-Eulerian model to describe the turbulent flow of vapor and solid phases. The mathematical model consists of governing equations, a dynamic model of particles, a turbulent flow model, a drag force model, and a heat and mass transfer model. The model takes the effects of initial steam condensation and interaction of vapor and particles into account and can be used to describe the drying process and predict the distribution of various thermodynamic parameters in a normal atmosphere. © 2011 Taylor & Francis Group, LLC.

[279] Yamsaengsung, R. Tabtiang, S., Hybrid drying of rubberwood using superheated steam and hot air in a pilot-scale. Drying Technology, 2011, 29, 1170-1178, DOI: 10.1080/07373937.2011.574805.

A pilot-scale rubberwood dryer was constructed and injected with superheated steam and hot air to study the effect of the hybrid system on the drying rate and mechanical properties of the wood. A total of 300 pieces of rubberwood boards, each with dimensions of 1000mm long × 76.2mm wide × 25.4mm thick, were stacked in 1.0m×1.0m×1.7m (1.7m3) pallet. The stack was impinged with alternating cycles of superheated steam and hot air. The time required for conventional drying was 168 hours, but the drying time for the hybrid system was only 64 hours, resulting in a 62% reduction. After being dried, the rubberwood boards were mechanically tested for static bending, compression strength, hardness, and shear strengths. From the mechanical tests, the hybrid drying system using superheated steam and hot air had no significant effect on the mean shear strength parallel-to-grain; however; the mean compression strength parallel-to-grain was reduced by 24.2% and the mean MOR by 21.4%. Nonetheless, the mean MOE was increased by 30.4% and the mean of hardness by 16.4%. © 2011 Taylor & Francis Group, LLC.

[280] Xiao, G.; Jin, B.; Ni, M.; Cen, K.; Chi, Y.; Tan, Z., A steam dried municipal solid waste gasification and melting process. Frontiers of Environmental Science and Engineering in China, 2011, 5, 193-204, DOI: 10.1007/s11783-010-0268-0.

Considering high-moisture municipal solid waste (MSW) of China, a steam dried MSW gasification and melting process was proposed, the feasibility was tested, and the mass and energy balance was analyzed. Preliminary experiments were conducted using a fixed-bed drying apparatus, a 200 kg per day fluidized-bed gasifier, and a swirl melting furnace. Moisture percentage was reduced from 50% to 20% roughly when MSW was dried by slightly superheated steam of 150°C-350°C within 40 min. When the temperature was less than 250°C, no incondensable gas was produced during the drying process. The gasifier ran at 550°C-700°Cwith an air equivalence ratio (ER) of 0. 2-0. 4. The temperature of the swirl melting furnace reached about 1240°C when the gasification ER was 0. 3 and the total ER was 1. 1. At these conditions, the fly ash concentration in the flue gas was 1. 7 g·(Nm3)-1, which meant over 95% fly ash was trapped in the furnace and discharged as slag. 85% of Ni and Cr were bound in the slag, as well as 60% of Cu. The mass and energy balance analysis indicates that the boiler heat efficiency of an industrial MSW incineration plant reaches 86. 97% when MSW is dried by steam of 200°C. The boiler heat efficiency is sensitive to three important parameters, including the temperature of preheated MSW, the moisture percentage of

dried MS Wand the fly ash percentage in the total ash. © 2011 Higher Education Press and Springer-Verlag Berlin Heidelberg.

[281] Thakhiew, W.; Waisayawan, P.; Devahastin, S., Comparative evaluation of mathematical models for release of antioxidant from chitosan films prepared by different drying methods. Drying Technology, 2011, 29, 1396-1403, DOI: 10.1080/07373937.2011.588816.

Antioxidants are often added to many types of food packagings, especially packaging films, to enhance their effectiveness in protecting food from the environment. This positive action is possible due to release of the agents from the film matrix into food to reduce oxidation, thus extending the product's shelf life. For effective design of antioxidant-added films, the release characteristics of antioxidant from the films under various conditions need to be known and predicted. The aim of this study was to compare various simple mathematical models for prediction of the release of antioxidant from edible chitosan films into distilled water at room temperature. Chitosan films were prepared via hot air drying, vacuum drying, and low-pressure superheated steam drying. Models with different expressions for the effective diffusion coefficient were tested. The model equations were solved numerically using COMSOL Multiphysics software (Comsol AB, Stockholm, Sweden). The prediction efficiency of the models was verified by comparing the predicted release kinetics of the antioxidant, in terms of the total phenolics content (TPC), with the experimental data available in the literature. It was found that the model assuming the effective diffusion coefficient as a function of the phenolics concentration gave the best agreement with the experimental results. © 2011 Taylor & Francis Group, LLC.

[282] Suvarnakuta, P.; Chaweerungrat, C.; Devahastin, S., Effects of drying methods on assay and antioxidant activity of xanthones in mangosteen rind. Food Chemistry, 2011, 125, 240-247, DOI: 10.1016/j.foodchem.2010.09.015.

Rind of mangosteen is one of the best natural sources of xanthones, which have been reported to have high antioxidant activity. In many cases mangosteen rind must be dried prior to extraction of the active compounds. However, information on the effects of different drying methods and conditions on the retention of xanthones in mangosteen rind is still very limited. This work was therefore aimed at studying the effects of selected drying methods and conditions on the changes of the contents as well as the antioxidant activity of xanthones in mangosteen rind. Mangosteen rind was subject to hot-air drying, vacuum drying or low-pressure superheated steam drying (LPSSD) at

60, 75 and 90°C and in the case of sub-atmospheric drying methods at an absolute pressure of 7. kPa. The xanthones contents were analysed by HPLC, while their antioxidant activity was assessed by DPPH radical scavenging capacity and ABTS assays. The results showed that the drying methods significantly affected degradation of xanthones (i.e., α-mangostin and 8-desoxygartanin) and their antioxidant activity. Either hot-air drying or LPSSD at 75°C is proposed as an appropriate drying technique and condition to preserve xanthones in mangosteen rind. © 2010 Elsevier Ltd.

[283] Srisang, N.; Varanyanond, W.; Soponronnarit, S.; Prachayawarakorn, S., Effects of heating media and operating conditions on drying kinetics and quality of germinated brown rice. Journal of Food Engineering, 2011, 107, 385-392, DOI: 10.1016/j.jfoodeng.2011.06.030.

Drying of germinated brown rice (GBR) by hot air (HA) in a fluidized bed causes a large amount of fissured kernels. The superheated steam (SHS) drying technique may be an alternative method that can improve quality attributes, but it may affect the other qualities of GBR. The effects of drying media and drying temperatures on the drying kinetics and quality of GBR, i.e. kernel fissuring, glycemic index, textural properties, γ-aminobutyric acid (GABA) content and microorganisms were therefore investigated. The experimental results show that the heating media and drying temperature affected the drying rate and some quality attributes of GBR. The number of fissured kernels was significantly lower in SHS than in HA drying. The drying media and drying temperature did not significantly affect the GABA content and textural properties of cooked GBR, except at 130 °C for HA drying, but affected the glycemic index. After drying with SHS or HA, the number of microorganisms was in the range of acceptable level for food safety. © 2011 Elsevier Ltd. All rights reserved.

[284] Sotome, I. Isobe, S., Food processing and cooking with new heating system combining superheated steam and hot water spray. Japan Agricultural Research Quarterly, 2011, 45, 69-76, DOI: 10.6090/jarq.45.69.

Superheated steam (SHS) was applied to food processing because of advantages including efficient heat transfer by latent heat, and prevention of product oxidation. SHS heating solves problems such as water absorption and dissolution of solid content from foods caused by hot water or saturated steam heating; however, it causes low product yield due to its high drying capacity. To fix these problems, a new system using SHS around 115°C and a spray of hot water micro droplets (WMD) has been developed. The SHS+WMD system has simultaneously improved the quality and yield of blanched

potatoes and other vegetables. In addition, it was found that WMD increased the heat transfer efficiency of SHS. This was presumably because WMD reduced the thermal resistance of the condensed water layer on the product surface by stirring the condensate. Due to this effect, the required time for the surface pasteurization of some kinds of raw vegetables decreased. A standard plate count of bacterium on cucumber fruit decreased from 105 CFU/g to 300 CFU/g with a slight texture change by SHS+WMD heating for 30 s. The SHS+WMD system is currently used in the food industry for cooking potato salad, and preprocessing meat, as well as the pasteurization of fishery products in Japan.

[285] Song, H.; Dotzauer, E.; Thorin, E.; Yan, J., Annual performance analysis and comparison of pellet production integrated with an existing combined heat and power plant. Bioresource Technology, 2011, 102, 6317-6325, DOI: 10.1016/j.biortech.2011.02.042.

Three optional pellet production processes integrated with an existing biomass-based CHP plant using different raw materials (wood chips and solid hydrolysis residues) are studied. The year is divided into 12 periods, and the integrated biorefinery systems are modeled and simulated for each period. The annual economic performance of three integrated biorefinery systems is analyzed based on the simulation results. The option of pellet production integrated with the existing CHP plant with the exhaust flue gas and superheated steam as drying mediums has the lowest specific pellet production cost of 105€/tpellet, the shortest payback time of less than 2years and the greatest CO2 reduction of the three options. An advantage in common among the three options is a dramatic increase of the total annual power production and significant CO2 reduction in spite of a small decrease of power efficiency. © 2011 Elsevier Ltd.

[286] Shrivastav, S. Kumbhar, B. K., Drying kinetics and ANN modeling of paneer at low pressure superheated steam. Journal of Food Science and Technology, 2011, 48, 577-583, DOI: 10.1007/s13197-010-0167-1.

Drying characteristics, selection of analyticalmodel and development of artificial neural network (ANN) models of 1 cm3 paneer at low pressure superheated steam drying (LPSSD) were studied. Effects of steam temperature and pressure on drying rates were determined. Page's model was selected as the best predictive model. Second degree polynomial, non linear regression analysis resulted in a good agreement of defined model by changing the values of temperature and corresponding pressure. Optimized

ANN models were developed for all data set. The correlation coefficient for all data set was >0.98 in all cases. © 2011 Association of Food Scientists & Technologists (India).

[287] Shi, Y.; Xiao, Z.; Wang, Z.; Liu, X.; Yang, D., Numerical simulation on superheated steam fluidized bed drying: II. Experiments and numerical simulation. Drying Technology, 2011, 29, 1332-1342, DOI: 10.1080/07373937.2011.592050.

Based on the established axisymmetric two-dimensional superheated steam fluidized bed drying model, some required physical parameters and parametric models are measured and determined by experiments. The model can simulate the drying process and inhomogeneous spatial distribution of some thermodynamic and hydrodynamic parameters of rapeseed and superheated steam under normal pressure. The simulated drying dynamic curves are in agreement with the experimental curves. In the short condensing and heating period, a negative drying rate appears and rapeseed cannot be fully fluidized. The simulated and experimental results show that rapeseed is dried evenly without local overheating. © 2011 Taylor & Francis Group, LLC.

[288] Sánchez, A. Herreraz, R. Quantifying the reduction of irreversibility of a cogeneration system, by simulating changes in the steam generator and steam turbine. in Proceedings of the 24th International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems, ECOS 2011. 2011.

This paper presents a quantitative reduction of irreversibility simulating the replacement of a system still in operation in a cogeneration system of a paper processing plant through Thermoflex software (the most important data are: the amount of power output and the amount of fuel used). This system has operated with the same steam turbine for more than 40 years, and superheated steam is required for drying and preparation of pulp processes (42 Yankees and 3 hidrapulpers). Besides, being in an area where conditions are not favorable, the system needs a series of heat exchangers to preheat fuel and replacement water. This contributes significantly to the reduction of the second law of thermodynamics efficiency presented by the system today, which is much more inferior to that obtained in general in any existing cogeneration system. The basis of change is the replacement of the two most important equipments, the steam generator and the steam turbine. The lower the irreversibility, the greater the second law of thermodynamics efficiency, therefore the aim is to observe both the reduction of irreversibility and the exergoeconomic costs, for the same exergetic requirements for both electrical and thermal exergy from the cogeneration system (i.e. without altering

the paper production). Another aim is integrating a proposal to include a carbon credit scheme, because the fuel used in this plant is fuel oil. This proposal allows having shorter recovery times from an economical point of view, which display the percentage of the amount of entropy generated being paid due to the intrinsic and extrinsic irreversibility of each equipment. This is a logical consequence because both the steam generator and steam turbine have a great generation of entropy, and are at the beginning of the productive chain of the cogeneration system. On the other hand, currently the systems burns more fuel to cover the inefficiencies, hence the changes proposed help to reduce the amount of emissions contributing to the reduction of greenhouse gas emissions worldwide.

[289] Sa-Adchom, P.; Swasdisevi, T.; Nathakaranakule, A.; Soponronnarit, S., Drying kinetics using superheated steam and quality attributes of dried pork slices for different thickness, seasoning and fibers distribution. Journal of Food Engineering, 2011, 104, 105-113, DOI: 10.1016/j.jfoodeng.2010.12.002.

Drying pork slice by superheated steam was proposed in this study. Sirloin muscle pork meat was sliced parallel and perpendicular to the fiber direction with thicknesses of 1 and 2 mm. The sliced samples were divided into two groups; unseasoned and seasoned pork, and were dried by superheated steam at a temperature of 140 °C. The experimental results showed that thicker pork slice needed more drying time, which led to more shrinkage, darker and redder dried product as compared to the thinner pork slice. Seasoning also extended the drying time of the seasoned pork slice and made the dried seasoned pork slice darker and yellower, but less in the values of hardness, toughness and shrinkage. Slicing directions did not have any significantly effect on drying time and color of dried pork slice. The parallel slice, however, lowered the values of hardness, toughness and shrinkage of dried pork.

[290] Sa-Adchom, P.; Swasdisevi, T.; Nathakaranakule, A.; Soponronnarit, S., Mathematical model of pork slice drying using superheated steam. Journal of Food Engineering, 2011, 104, 499-507, DOI: 10.1016/j.jfoodeng.2010.12.025.

Superheated steam has received much attention as an effective technique for drying purposes because it produces dried products with high quality attributes. Although currently there are a number of works reporting the development of a mathematical model of superheated steam drying, they do not use a numerical method to estimate the effective moisture diffusivity value (D eff value) of the product. The purposes of this

work, therefore, were to develop a semi-empirical model for estimating the Deff value of pork, and for predicting the evolution of the moisture content and the center temperature of sliced pork during superheated steam drying. The model was based on mass and energy-balance equations and was divided into three periods: heating up, constant drying rate and falling drying rate period. It was solved using an explicit finite difference method and used a grid search method to estimate the Deff value of pork. The predicted results were compared with the experimental data of superheated steam drying of seasoned and unseasoned pork with slice thicknesses of 1 and 2 mm at a drying temperature of 140 °C. The comparison results showed that the developed model could estimate the ranges of the Deff value of pork fairly well (Deff = 3.311-12.471 × 10-10 m2/s for seasoned pork, and 4.200-15.056 × 10-10 m2/s for unseasoned pork) and could reasonably predict the evolution of the moisture content of the sliced pork. The predicted center temperature of the sliced pork was higher than the experimental data in the heating up period and in the first 5 min of the falling drying rate period, but it agreed well in the constant drying rate period and after the drying time of 10 min. Moreover, it was found that the slice thickness and the seasoning had an influence on the drying curves only in the constant drying rate and falling drying rate period.

[291] Phungamngoen, C.; Chiewchan, N.; Devahastin, S., Thermal resistance of Salmonella enterica serovar Anatum on cabbage surfaces during drying: Effects of drying methods and conditions. International Journal of Food Microbiology, 2011, 147, 127-133, DOI: 10.1016/j.ijfoodmicro.2011.03.019.

The effects of selected drying methods, i.e., hot air drying, vacuum drying and low-pressure superheated steam drying (LPSSD), on the heat resistance of Salmonella attached on vegetable surface, which are data that have never been reported elsewhere, were investigated at drying temperatures of 50-70. °C; vacuum drying and LPSSD were carried out at an absolute pressure of 10. kPa. The selected Salmonella serovar, i.e., S. Anatum, was used as a test organism. Cabbage was used as a vegetable model to represent uneven natural surface. The results showed that drying methods had a significant effect on the drying kinetics as well as the destruction rate of Salmonella. Higher drying temperatures resulted in higher destruction rates of S. Anatum. Hot air drying was noted to be the slowest drying process, while vacuum drying and LPSSD could be used to shorten the drying time. By considering the reduction in the number

of Salmonella at the end of drying, LPSSD is recommended as it has proved to yield the highest degree of S. Anatum inactivation. © 2011 Elsevier B.V.

[292] Pakowski, Z.; Adamski, R.; Kokocińska, M.; Kwapisz, S., Generalized desorption equilibrium equation of lignite in a wide temperature and moisture content range. Fuel, 2011, 90, 3330-3335, DOI: 10.1016/j.fuel.2011.06.044.

Brown coal is the most abundant and economically viable source of energy. To increase the efficiency of power generation from brown coal predrying of lignite is probably the first step to be taken. Both air drying, or more energy efficient superheated steam drying, may be considered. For the design of both processes an equilibrium relationship between water activity, moisture content and temperature in a form of working desorption isotherm is needed. This work presents experimentally obtained results of sorption isotherms measurements at seven temperatures and one sorption isobar at atmospheric pressure obtained for Bełchatów brown coal. These results were compared to the results obtained by other authors for Australian and USA coals and due to relatively close fit of all data points one generalized equation of desorption equilibrium was fitted covering a wide range of temperatures from 5 to 260 °C and moisture contents up to 1.5 kg/kg. Adsorption isotherms are not described by the same equation since strong sorptional hysteresis was observed. © 2011 Elsevier Ltd. All rights reserved.

[293] Pakowski, Z. Adamski, R., On prediction of the drying rate in superheated steam drying process. Drying Technology, 2011, 29, 1492-1498, DOI: 10.1080/07373937.2011.576320.

The aim of the study was to determine how the drying rate in the falling drying rate period can be predicted in superheated steam drying. The study presents drying kinetics (determined experimentally) in the range of steam temperatures from 120°C to 200°C, with the superheated steam velocity from 0.18 to 0.40m/s and under atmospheric pressure of a gypsum plate. In the study the drying rate based on the convective heat-transfer coefficient and steam-solid temperature difference was determined. It was proven that in order to predict drying rate in the falling rate period the surface temperature must be known. © 2011 Taylor & Francis Group, LLC.

[294] Niamnuy, C.; Nachaisin, M.; Laohavanich, J.; Devahastin, S., Evaluation of bioactive compounds and bioactivities of soybean dried by different methods and conditions. Food Chemistry, 2011, 129, 899-906, DOI: 10.1016/j.foodchem.2011.05.042.

Soybean has attracted significant research and commercial interests due to its many health-promoting bioactive compounds, especially isoflavones (β-glucosides, malonyl-β-glucosides, acetyl-β-glucosides and aglycones). Isoflavones possess antioxidant activity and α-glucosidase inhibitory activity, which has proved effective in the treatment of type 2 diabetes mellitus. Prior to its use, however, soybean needs to be dried to extend its storage life and to prepare the material for subsequent food or pharmaceutical processing. The present study investigated the effects of drying methods and conditions on the drying characteristics, isoflavones, antioxidant activity and α -glucosidase inhibitory activity of dried soybean. Hot-air fluidized bed drying (HAFBD), superheated-steam fluidized bed drying (SSFBD) and gas-fired infrared combined with hot air vibrating drying (GFIR-HAVD) were carried out at various drying temperatures (50, 70, 130 and150 °C). The results showed that higher drying temperatures led to higher drying rates and higher levels of β-glucosides and antioxidant activity, but to lower levels of malonyl-β-glucosides, acetyl-β-glucosides and total isoflavones. At the same drying temperature GFIR-HAVD resulted in the highest drying rates and the highest levels of β-glucosides, aglycones and total isoflavones, antioxidant activity as well as α-glucosidase inhibitory activity of dried soybean. A drying temperature of 130 °C gave the highest levels of aglycones and α-glucosidase inhibitory activity in all cases. The relationships between all the studied parameters were monitored and simple correlations between them were determined.

[295] Niamnuy, C.; Nachaisin, M.; Devahastin, S., Effect of drying conditions on isoflavones and α-Glucosidase inhibitory activity of soybean [Glycine max (L.) Merrill]. Thai Journal of Agricultural Science, 2011, 44, 300-303.

The health benefits of soybean have been well known. The main bioactive compound in soybean is isoflavones (β-glucoside, malonyl glucoside, acetyl glucoside and aglycone forms).Isoflavones possess α-Glucosidase inhibitory activity that related to the treatment of Type 2 diabetes mellitus. Drying is the important process for shelf-life extension of soybean before soy food or pharmaceutical processing. The objectives of present study, therefore, were to investigate effects of drying method and drying temperature on isoflavones distribution, extraction yield and α-Glucosidase inhibitory activity of dried soybean at the moisture content of 10% (d.b.). Hot air fluidized bed drying (HAFBD), superheated steam fluidized bed drying (SSFBD) and gas-fired infrared combined with vibrating drying (GFIR-HAVD) were carried out at various

dryingtemperature (50, 70, 130, 150°C). The results showed that the higher drying temperature led tolower content of total isoflavones. At the same drying temperature, it was found that GFIR-HAVD resulted in highest content of total, β-glucoside and aglycone isoflavones as well as extraction yield and α-Glucosidase inhibitory activity of dried soybean, followed by SSFBD and HAFBD, respectively. In addition, the drying temperature of 130°C gave the highest α-Glucosidase inhibitory activity in all drying techniques.

[296] Mohapatra, D. Mishra, S., Current trends in drying and dehydration of foods, in Food Engineering. 2011. p. 311-352.

Drying and dehydration techniques have constantly been evolving since ancient time; from sun drying to solar drying, from convective air drying to impingement drying. The heating medium has changed from sunlight to dielectric and electromagnetic radiation, from hot air to jet impingement, from steam to superheated steam etc. Drying essentially is a simultaneous heat and mass transfer process, wherein heating medium or internal heat generation helps in evaporation of free water molecules from the product. Mass transfer rate, during the drying/dehydration process, can be enhanced by different pretreatments, apart from using enhanced temperature, optimum air flow rate in case of convective drying or using high intensity electric field as in case of dielectric and other electromagnetic drying systems however, opting for extreme conditions, product quality may be compromised. To suit the consumer demand for quality product, current technologies are aiming at integrating different pre-treatments like blanching, chemical treatment, physical modification, application of thermal and non-thermal processes, for inactivation of enzymes, reduction in microbial load and structural modification with an aim to enhance mass transfer rate. Enhanced mass transfer rate eventually overcomes the drying cost and deterioration associated with longer drying time. Innovative drying technologies such as refractance window drying, corona air or electrohydrodynamic drying, super-critical CO2 drying and bio-film drying are trying to address some problems associated with drying. Various hybrid drying technologies that manifest judicious integration of several dehydration techniques such as osmosis, convective, vacuum, microwave, radiofrequency, infrared and ohmic heating and freeze drying with non-thermal processing like high pressure, ultrasound, pulse electric field and irradiation are cost effective, as these methods reduce drying time considerably at the same time maintaining the product quality.

[297] Mitra, T. K.; Pai, A.; Kumar, P. Challenges in manufacture of PFBR steam generators. in Energy Procedia. 2011.

Prototype Fast Breeder Reactor (PFBR) is a 500 MWe pool type sodium cooled reactor. The main function of Steam Generator (SG) is to extract the reactor heat through secondary sodium system and convert the feed water into superheated steam in the tubes of SG. The Steam Generator is a vertical, once through, shell and tube type heat exchanger with liquid sodium in the shell side and water/steam in the tube side. The highly reactive nature of sodium with water/steam requires that the sodium to water/steam boundaries of the steam generators must possess a high degree of reliability against failure. This is achieved in design and manufacture by maximizing the tube & tubesheet integrity and more importantly by proper selection of tube to tubesheet joint configuration. Modified 9Cr-1Mo material is selected as major material of construction for steam generator as this material has excellent high temperature mechanical properties and has high resistance to stress corrosion cracking in caustic & chloride environment. Steam Generator has inlet and outlet nozzles which are made from the pullout shells of SG. Pullouts are made by hot forming process by heating the shell inside the furnace to the temperature of 950-1100°C followed by die & punch pressing. After forming, the pullouts are subjected to normalizing at 1040-1050°C followed by tempering at 780°C to restore the original material properties. The forming of nozzle pullouts is really difficult and challenging task as the dimensions are too large & dimensional tolerances are very tight. Steam Generator shell assembly is fabricated in horizontal condition after completion of tube bundle which requires insitu welding of shells around the tube bundle. Dimension control during shell welding is extremely difficult as internal fixtures/spiders for ovality control is ruled out due to existence of tube bundle. Utmost care is required during shell welding to avoid arc strike/fusion on the tube (i.e sodium/water boundary), as the gap between tube bundle and shells is very less. After completion of tube bundle and shell assembly, entire 26 meter length SG undergoes Post Weld Heat Treatment (PWHT) in a single charge at 760±10°C for 4 hours soaking time to relieve the welding stresses and to get the homogenous tempered martensite structure. Special arrangements were made to take care of about 240mm thermal expansion of complete SG assembly during PWHT. Due to asymmetric shape of SG, drying of the water after hydro test & surface treatment is difficult. The effective surface treatment process requires special thought of rotation of the job by 180 degree after completion of partial chemical cleaning due to air pockets on the top surfaces of

the shell assembly. This paper highlights the experience gained during welding of tube to tubesheet joints, hot forming of nozzle pullouts, shell assembly and post shell assembly activities of PFBR Steam Generators in detail. © 2011 Published by Elsevier Ltd.

[298] Messai, S.; Sghaier, J.; Belghith, A., Mathematical modeling of a packed bed drying with humid air and superheated steam. Journal of Porous Media, 2011, 14, 169-177, DOI: 10.1615/JPorMedia.v14.i2.50.

A one-dimensional mathematical model describing heat and mass transfer during the drying of a packed bed of porous particles with superheated steam and humid air has been developed. This model is based on the scale-changing approach. During superheated steam drying, the expression of mass flux is based on the resolution of the single-particle model: new correlations of different drying parameters are determined, whereas in the case of humid air drying the expression of mass flux is deduced from the literature. The numerical resolution of macroscopic equations describing heat and mass transfer during the drying of a packed bed is carried out by the finite-volume method. Experimental data for spherical porous alumina particles reported in the literature were used for the validation of the model. When comparing superheated steam and humid air drying processes, a temperature has been determined at which the drying rates during these two processes are equal. This temperature is called the inversion temperature. The latter is about 418 K for corn. © 2011 by Begell House Inc.

[299] Liu, H.; Wang, Z.; Xu, P., Mass diffusivities of radiata pine in superheated steam drying, in Advanced Materials Research. 2011. p. 357-360.

Superheated steam drying is an energy saving and effective drying technology, in which the waste heat is recycled with the loop system and the moisture removal is much faster than that of conventional low temperature drying. The computation methods for the estimation of wood mass diffusivities were evaluated and the first ten terms of the analytic solution of Fick's Second Law was considered sufficiently accurate, but Crank's method was rejected, due to its large errors. The experimental data show that higher temperature significantly accelerated the drying rate. In addition, no visible surface or internal checks have been found in the superheated steam dried samples (dry-bulb temperature 160, 180, 200, 220 °C). The highly effective super heated steam drying is definitely an advantage. However, samples were browned when dried above 220 °C, which may be regarded as the critical temperature for quality control.

[300] Kristiawan, M.; Sobolik, V.; Klíma, L.; Allaf, K., Effect of expansion by instantaneous controlled pressure drop on dielectric properties of fruits and vegetables. Journal of Food Engineering, 2011, 102, 361-368, DOI: 10.1016/j.jfoodeng.2010.09.014.

The instantaneous controlled pressure drop (DIC) treatment is used for creation of a porous structure during drying of fruits and vegetables. DIC is based on high temperature, short time heating followed by an abrupt pressure drop into a vacuum. This abrupt pressure drop provokes auto-vaporization of the superheated liquid, expansion and breaking of the cell walls and instantaneous cooling. This process step is inserted between two drying stages at a moisture content of about 20% wet basis. The use of microwave radiation would provide more rapid and homogeneous heating than using steam in the DIC treatment and hot air during the final stage of drying. For that purpose the dielectric properties of the raw and DIC treated products were measured. The measurements were carried out with an open-ended coaxial probe at a frequency of 915 MHz in the range of temperatures 20-90 °C and moisture content 5-80% w.b. Three regions were revealed for the dependences of the dielectric constant and loss factor on moisture content. At low moisture content, these properties increased linearly with moisture content. At the middle moisture content, the increase was also linear but much steeper. At high moisture content, the dielectric properties were constant. The limits of these regions were different for ′ and ″ as well as for the products. The dielectric properties were slightly temperature dependent. The penetration depth increased with decreasing moisture content. The DIC treated products exhibited slightly lower dielectric properties than the raw products.

[301] Karlsson, O.; Sidorova, E.; Morén, T., Influence of heat transferring media on durability of thermally modified wood. BioResources, 2011, 6, 356-372.

Studies on the durability and dimensional stability of a series of hardwoods and softwoods after thermal modification in vegetable oils and in steam atmospheres have been performed. Mass loss after exposure to Coniophora puteana (BAM Ebw.15) for 16 weeks was very low for European birch, European aspen, Norway spruce, and Scots pine thermally modified in a linseed oil product with preservative (for 1 hour at 200 °C). Fairly low mass losses were obtained for wood thermally modified in linseed-, tung- and rapeseed oil, and losses were related to the wood species. Low mass loss during rot test was also found for Norway spruce and Scots pine modified in saturated

steam at 180 °C. Water absorption of pine and aspen was reduced by the thermal treatments and the extent of reduction was dependent on wood species and thermal modification method. Thermally modified aspen was stable during cycling climate tests, whereas pine showed considerable cracking when modified under superheated steam conditions (Thermo D). At lower modification temperature (180 °C) an increase in mass after modification in rapeseed oil of spruce, aspen and sapwood as well as heartwood of pine was observed, whereas at high temperature (240 °C) a mass loss could be found. Oil absorption in room tempered oil after thermal modification in oil was high for the more permeable aspen and pine (sapwood).

[302] Johnson, P. W. Langrish, T. A. G., Inversion temperature and pinch analysis, ways to thermally optimize drying processes. Drying Technology, 2011, 29, 488-507, DOI: 10.1080/07373937.2010.512427.

This work studies the compatibility and suitability of a combined inversion temperature and pinch analysis with the process selection for air and superheated steam spray drying of milk solids. The inversion temperature is a good starting point for an energy analysis because it is a simplified rate-based approach to comparing the steam and air drying systems. pinch analysis enables process integration, at least on a heat recovery and heat exchanger network level. The resulting inversion temperature for the studied system was estimated as 182°C for the dryer inlet temperature. However, mass and energy balances showed that a minimum inlet temperature for spray drying of 184°C was required for the superheated steam dryer in order to ensure that the outlet solids temperature above the dew point temperature. The inversion temperature is still very relevant in the early stages of a design process because it allows a quick assessment of which drying medium should result in a smaller dryer. It was evident that the steam system is better from an energy perspective because of the recoverable latent heat of the water vapor carried out of the dryer with the recycled steam. The steam system has between 82 and 92% of thermal energy recovery potential as condensable steam, compared with 13-30% energy recovery of the air system. However, other important design and operational factors are not discussed here in detail. Combining the inversion temperature and pinch analysis suggests that superheated steam drying both gives better energy recovery and is likely to give smaller dryers for all operational conditions.

[303] Jangam, S. V.; Karthikeyan, M.; Mujumdar, A. S., A critical assessment of industrial coal drying technologies: Role of energy, emissions, risk and sustainability. Drying Technology, 2011, 29, 395-407, DOI: 10.1080/07373937.2010.498070.

Low-rank coals (LRCs) constitute about 45% of the total coal reserves and hence will soon be the fossil fuel of choice in many countries despite their high moisture content on mining, which varies from 30% to as high as 66%. It is important to reduce their water content to enhance the heating value and reduce transportation costs while enhancing combustion efficiency, safety, and reduction of emissions on combustion. The level of moisture to be achieved upon drying LRCs depends on the end application; it varies from as low as 0% for hydrogenation processes to 15% for briquetting and gasification processes. Numerous drying technologies have been proposed for drying coal; they include pulse combustion, vacuum, fluid bed, rotary, flash, microwave, and superheated steam drying. Each technology has some pros and cons, which are not always clearly spelled out in the literature. In addition, it is necessary to develop sustainable rather than just cost-effective drying systems for LRC. In this article we assess various coal drying techniques critically and identify their strengths and weaknesses. Some theoretical comparisons of different dryer types are carried out based on energy utilization and carbon footprints. The jury is still out on optimal drying technology for LRC and innovative design concepts should be evaluated before finalizing the selection. © 2011 Taylor & Francis Group, LLC.

[304] Jangam, S. V., An overview of recent developments and some R&D challenges related to drying of foods. Drying Technology, 2011, 29, 1343-1357, DOI: 10.1080/07373937.2011.594378.

Thermal dehydration is the most common and cost-effective technique for preservation of foods and for the production of traditional as well as innovative processed products such as snacks with desired functionalities. The basic intent of this article is to provide a global overview of emerging and innovative thermal drying technologies that are already commercialized or show potential of industrial exploitation upon successful R&D to sort out some limitations. New drying technologies are needed to enhance quality, reduce energy consumption, improve safety, and reduce environmental impact. Mathematical modeling can be used for cost-effective development of untested novel designs to reduce the cost and time required for innovation. As examples of emerging drying technologies we consider selected dehydration techniques with imminent commercialization potential. These include heat pump-assisted drying, microwave-

assisted drying, low-pressure superheated steam drying, pulse combustion spray drying, pulsed and ultrasoundassisted osmotic dehydration, as well as novel gas-particle contactors such as impinging streams and pulsed fluidized beds. Multistage drying, intermittent drying, and the use of hybrid drying technologies- which combine advantages of different dryers without some of their limitations-will be outlined. This article also discusses various methods of energy minimization, and the potential for use of renewable energy will also be discussed briefly. Although this overview emphasizes food dehydration, the themes covered are applicable to other materials as well. © 2011 Taylor & Francis Group, LLC.

[305] Isobe, S.; Ogasahara, Y.; Negishi, Y.; Tonozuka, F., Development of a new heating system by combining superheated steam and a hot water spray (Aqua-Gas TM) and its application to food processing. Nippon Shokuhin Kagaku Kogaku Kaishi, 2011, 58, 351-358, DOI: 10.3136/nskkk.58.351.

Superheated steam was applied to food processing because of advantages that include e cient heat transfer by latent heat and the prevention of product oxidation. Superheated steam solves problems such as water absorption and the dissolution of solid content from foods caused by hot water or saturated steam heating ; however, it causes low product yield due to its high drying capacity. In order to extend the application of superheated steam to food processing, a new oven system (Aqua-gas) using superheated steam and micro droplets of hot water has been developed. In this system, a mixture of superheated steam and hot water was achieved under normal pressure by spraying pressurized boiling water into a heating chamber through a nozzle. It was found that Aqua-gas has a higher heat transfer rate than ordinal superheated steam, especially with cold materials. Fresh vegetables have been pasteurized e ectively with little change in texture by heating with this system. The moisture content of the food product processed with this oven system can be controlled by regulating the amount of micro droplets used in the superheated steam. This system is currently used in the food industry for cooking potato salad, preprocessing meat, and in the pasteurization of fish products in Japan.

[306] Hosseinpour, S.; Rafiee, S.; Mohtasebi, S. S., Application of image processing to analyze shrinkage and shape changes of shrimp batch during drying. Drying Technology, 2011, 29, 1416-1438, DOI: 10.1080/07373937.2011.587620.

In this article, variations in the top-view area and lateral-view area, average area, perimeter, Feret diameter, roundness, elongation, shape of the edge, and diameters of

the shrimp in the batch parallel and perpendicular to the drying medium flow were investigated in defined intervals during drying. For this purpose, a thin-layer dryer based on machine vision was fabricated and image analysis techniques were used. Drying experiments were conducted in triplicate at five drying temperatures of 50, 70, 90, 110, and 120°C and three drying medium velocities of 1, 1.5, and 2 m/s. Purely nearatmospheric superheated steam drying (SSD) was used for the temperatures above the boiling point of water (110 and 120°C). Drying at the other temperatures was done using a hot air convective method. Analysis of batch area shrinkage, average area shrinkage, normalized Feret diameter, dimensionless perimeter, and diameters parallel and perpendicular to the drying medium flow showed that there are almost linear relations with moisture content. Drying medium temperature and velocity had a significant effect on all measured morphological parameters ($P<0.01$). There was a significant difference between shrinkage of diameters parallel and perpendicular to the drying medium flow in all studied drying conditions, which implies that shrinkage of shrimp samples was nonisotropic. Moreover, comparing the top- and lateral-view areas of the shrimp batch showed that there was nonisotropic shrinkage in the shrimp samples during drying process. More regular and irregular edges of shrimp were obtained at low and high temperatures, respectively. Drying took place entirely in the falling rate period. Drying medium velocity had no significant effect on drying time. No regular trend regarding the effect of the studied drying medium velocities on the roundness and elongation of shrimp samples was found. More porous shrimp samples with a lower degree of shrinkage were obtained in superheated steam drying in comparison to hot air drying at high temperatures.

[307] Higo, A.; Teramoto, A.; Isokawa, T.; Hikichi, Y., Effects of heating with multifunctional microwave ovens on the textural properties of white bread. Nippon Shokuhin Kagaku Kogaku Kaishi, 2011, 58, 382-391, DOI: 10.3136/nskkk.58.382.

White bread was heated in convection microwave ovens with multiple functions, including oven (Ov), grill (Gr), steam (Sm), microwave (Mw), superheated steam grill (SSG), and superheated steam oven (SSO) functions. The texture, water content, and browning of the heated breads were investigated. 1) Bread heated with superheated steam softened quickly, and the texture was both soft and crispy. The texture of bread heated with Sm at 180°C was soft. 2) The speed of browning using SSG was 2.5 times faster than with Gr, and that using SSO was 2times faster than with Ov. 3) Based on a water distribution model system, the textural characteristics of SSG and SSO samples

are caused by the rapid speed of drying and surface browning, and the high internal moisture content. 4) The hardening caused by heating using Sm was slow, but the texture of long-heated bread was the same as that using Mw.

[308] Head, D.; Cenkowski, S.; Arntfield, S.; Henderson, K., Storage stability of oat groats processed commercially and with superheated steam. LWT - Food Science and Technology, 2011, 44, 261-268, DOI: 10.1016/j.lwt.2010.05.022.

Storage stability of oat groats processed commercially (conditioning with saturated steam followed by kiln drying) and with superheated steam (SS) was evaluated at room and elevated temperatures (21 and 38 °C, respectively) for 26 and 13 weeks, respectively. Monitoring of hexanal and free fatty acid levels, moisture content, colour, and cold paste (64 °C) viscosity, as well as sensory evaluation of groats were carried out during storage. Both the SS and the commercially processed groats remained shelf stable over the time periods tested. No substantial changes were noted in the colour, cold paste viscosity, and content of free fatty acids of differently heat processed groats as the storage time passed. Changes in the moisture content of stored groats reflected the seasonal changes in the humidity of the surroundings. At both storage temperatures, the amounts of hexanal released from groats processed either with SS or commercially increased with the increase of storage time. However, the groats processed with SS released lower amounts of hexanal than the groats processed commercially. As storage time progressed, both the SS and the commercially processed groats became blander, and it became increasingly difficult for sensory panellists to distinguish between groat samples from the different heat treatments. © 2010 Elsevier Ltd.

[309] Hamawand, I., Effect of colloidal particles associated with the liquid bridge in sticking during drying in superheated steam. International Journal of Engineering, Transactions B: Applications, 2011, 24, 119-126.

It is important in the design of a drying system to evaluate the sticking behaviour of the materials being dried. A new approach to the sticking issue is applied in this study by carrying out a sticking test for the liquid associated with the materials under study. It was found that the liquid bridge is responsible for the initial sticking of the materials to the contact surfaces. The colloidal material in this liquid is eventually responsible of building a sticky solid bridge during drying. The glass transition temperature for the Brewers Spent Grain (BSG) particles and the colloidal solution expelled from these particles were tested using Differential Scanning Calorimetric (DSC). However, the chopped BSG particles showed no glass transition temperature; there were an

appreciable number of particles stuck to the rotary drum dryer and the sample holders during drying. The colloidal particles in the liquid bridge were filtered and concentrated through evaporation and then analysed by DSC where they showed a glass transition temperature at (-23) and (-33) °C. In addition, the associated liquid thus prepared showed a honey consistency and a sticky touch when concentrated. These two properties are indications that this colloidal material may be responsible for sticking the BSG to the steel surfaces during drying.

[310] Fushimi, C.; Kansha, Y.; Aziz, M.; Mochidzuki, K.; Kaneko, S.; Tsutsumi, A.; Matsumoto, K.; Yokohama, K.; Kosaka, K.; Kawamoto, N.; Oura, K.; Yamaguchi, Y.; Kinoshita, M., Novel Drying Process Based on Self-Heat Recuperation Technology. Drying Technology, 2011, 29, 105-110, DOI: 10.1080/07373937.2010.482719.

Significant amounts of energy are used in the conventional methods for drying wet carbonaceous materials such as biomass, low-rank coals, sludge, and manure, because the latent heat for evaporating water is large. An innovative drying process, based on self-heat recuperation technology that recovers not only latent heat but also sensible heat, was developed to save drying energy. Water contained in a wet sample is heated to its boiling point, and the resulting steam is superheated. The superheated steam is compressed to provide a temperature difference for heat exchange. The condensation heat of the compressed steam is exchanged with the evaporation heat of the water from the wet sample. The sensible heat of the compressed steam is utilized to raise the temperature of both evaporated steam (superheating) and water contained in the wet sample (preheating). In addition, the sensible heat of the dried sample is recovered by gas to improve the overall energy efficiency. The amount of energy required for the proposed system was determined using a commercial process simulation tool, PRO/II (v. 8.1, Invensys plc, London, UK). The proposed drying process based on self-heat recuperation was found to drastically reduce the energy consumption to 13.7% of the energy consumption of the conventional drying process with heat recovery. © 2011 Taylor & Francis Group.

[311] Evranuz, E. O., Drying Vegetables: New Technology, Equipment, and Examples, in Handbook of Vegetables and Vegetable Processing. 2011. p. 299-315.

[312] Choicharoen, K.; Devahastin, S.; Soponronnarit, S., Comparative evaluation of performance and energy consumption of hot air and superheated steam impinging

stream dryers for high-moisture particulate materials. Applied Thermal Engineering, 2011, 31, 3444-3452, DOI: 10.1016/j.applthermaleng.2011.06.030.

Impinging stream dryer (ISD) is a novel alternative to flash dryer for drying high-moisture particulate materials. A number of studies have been conducted on various aspects of an ISD; however, in almost all of the previous studies hot air was used as the drying medium. Since it is well recognized that use of superheated steam as the drying medium could lead to much reduced net energy consumption of the drying process, it was the aim of the present study to investigate the use of superheated steam as the drying medium in an ISD. Okara (soy residue) was used as a test high-moisture particulate material. The performance of the drying system, in terms of the volumetric heat transfer coefficient and volumetric water evaporation rate, as affected by the superheated steam temperature, steam velocity, material feed flow rate and the dryer geometric parameter viz. impinging distance was assessed. In addition, the ability to reuse the exhausted steam as well as the specific energy consumption of the system were evaluated. Comparison was made with the hot air drying results. The maximum volumetric water evaporation rate was found to be around 807 kgwater/m3h, while the maximum volumetric heat transfer coefficient was around 7950 W/m3K at the steam recycle ratios of 46-63%. The lowest total specific energy consumption of the system was around 3.1 MJ/kgwater at an inlet steam temperature of 190 °C, inlet steam velocity of 20 m/s, material feed flow rate of 20 kg dry solid/h, impinging distance of 5 cm and steam recycle ratio of 63%. Compared with the hot air drying results at the same corresponding conditions, savings of the total specific energy consumption in the range of 9-46% were noted. © 2011 Elsevier Ltd.

[313] Alberti, F.; Quaglia, N. C.; Spremulli, L.; Dambrosio, A.; Todaro, E.; Tamborrino, C.; Lorusso, V.; Celano, G. V., Radio-frequency technology for fresh stuffed pasta pasteurization/pre- drying process: Preliminary results. Italian Journal of Food Science, 2011, 23, 146-148.

Radio frequency (RF) applications to food process are well known due to the possibility of quickly and uniformly heating food matrix (1). Fresh stuffed pasta conventional production technology consists of a first steam pasteurization for a period varying from 2 to 10 min depending on pasta size and weight, initial microbial density and wet steam or superheated steam, followed by a drying phase with forced hot air at a temperature not exceeding 65°-70°C to increase pasta consistency and stabilize the shape. Fresh semolina pasta RF pasteurization/pre-drying process is already used by some

companies a reduction of microbiological parameters, reduced time pasteurization, a better cooking bheavior, keeping g a great intensity taste and aroma the typical of fresh semolina pasta. Fresh stuffed pasta production has several healthy and technology problems with respect to fresh semolina pasta, thus RF pasteurization/pre-drying process requires a proper implementation and evaluation of effects on different types of products. In this study we have examined three different types of fresh stuffed pasta, cappelletti stuffed with ham, fagottini stuffed with cheese and tortellini stuffed with meat. Three different RF treatments were carried out: 3 kV were applied to fresh pasta stuffed with ham and meat and 2 kV to fresh pasta stuffed with ricotta cheese for a total time of 10 and 8 min, respectively. RF plant consists of a single steel tunnel, in which electrodes are placed and kept at 27.12 MHz, were simultaneously pre-drying and pasteurization of fresh pasta occurs (2). Microbiological analysis of fresh stuffed pasta different samples, pre-and postpasteurization, were made by the Tempo® System (bioMériux, France). Preliminary results in different types of fresh stuffed pasta show that RF pasteurization/pre-drying process cause reduction of some microbiological parameters.

[314] Zhou, M. Y. Guan, J., Mechanism and kinetics of flotation concentrate thermo-compression filtration-drying dewatering. Meitan Xuebao/Journal of the China Coal Society, 2010, 35, 472-475.

According to the in-depth dewatering of fine flotation concentrate, a theoretical and experimental study was made to investigate the mechanism and kinetics involved in the innovative thermo-compression filtration-drying integrated process. It is pointed out that after a saturated filter cake is formed, the thermo-compression drying process can further reduce the cake moisture along with the formation and diffusion of the saturated steam dewatering surface X(t) and superheated steam dewatering surface Y(t). Through this dewatering-drying integrated process, a clear filtrate and a final dry concentrate product with a moisture content of 12.15% can be produced. As compared with conventional thermal drying process, the energy consumption can be reduced by 59.31%.

[315] Wu, Z. H.; Hu, Y. J.; Lee, D. J.; Mujumdar, A. S.; Li, Z. Y., Dewatering and drying in mineral processing industry: Potential for innovation. Drying Technology, 2010, 28, 834-842, DOI: 10.1080/07373937.2010.490485.

Wet beneficiation of minerals necessarily requires removal of large amounts of water-typically contaminated-before further processing of the concentrated ores can be carried

out. Often such concentrates are transported over large instances by ground or sea transport. For economic reasons dewatering/drying are essential unit operations. Often the capacity requirements of the mining operations are very large, the product processed has low unit value, and the material is abrasive. The selection of dryers is often arbitrary. No clear guidelines can be found by noting current practices in different countries. This article provides a global view of the types of dewatering equipment and dryers currently used in the mineral processing industries, provides guidelines for selection of drying systems, and recommends emerging innovative technologies, such as superheated steam and pulse combustion drying for future applications in this industry. A few case studies are examined.

[316] Thakhiew, W.; Devahastin, S.; Soponronnarit, S., Effects of drying methods and plasticizer concentration on some physical and mechanical properties of edible chitosan films. Journal of Food Engineering, 2010, 99, 216-224, DOI: 10.1016/j.jfoodeng.2010.02.025.

In order to alleviate shortcomings of edible chitosan films, which are rigid and brittle in nature, an idea of using advanced drying methods, in combination with appropriate concentration of plasticizer, to improve the mechanical properties of the films was proposed and tested. Physical (thickness and color) and mechanical (tensile strength and percent elongation) properties of edible chitosan films plasticized at four glycerol concentrations (0%, 25%, 75% and 125% w/w chitosan) and prepared by three drying methods, namely, hot air drying (≈40 °C), vacuum drying and low-pressure superheated steam drying (LPSSD) (90 °C, 10 kPa) were investigated. Dynamic mechanical thermal analysis (DMTA) was used to determine the glass transition temperature to verify the compactness of edible chitosan films. It was found that the drying methods and plasticizer concentration significantly affected the drying time, tensile strength, percent elongation and glass transition temperature of the films. On the other hand, the drying methods and plasticizer concentration did not affect the thickness and final moisture content of the film samples at lower glycerol concentrations. In the cases of vacuum drying and LPSSD, there was a limiting value of plasticizer concentration (25% w/w) beyond which the effect of the plasticizer concentration on the mechanical properties was negligible. In all cases, the color of all tested films was not significantly different.

[317] Speckhahn, A.; Srzednicki, G.; Desai, D. K., Drying of beef in superheated steam. Drying Technology, 2010, 28, 1072-1082, DOI: 10.1080/07373937.2010.505547.

Two drying treatments were applied to slices of beef: superheated steam and hot air. Drying kinetics and quality attributes such as color, water activity, and peroxide value were investigated for different drying conditions (drying medium temperature 130, 160, or 180°C; flow rate of the drying medium of 35, 45, or 55 kg/h; and sample thickness 3 mm, 6 mm, 9 mm, or minced beef). The experimental results show that superheated steam drying generally leads to shorter residence times in the dryer when the moisture content needs to be decreased below 8%. Superheated steam drying distinguishes itself by longer constant rate periods, lower critical moisture contents, and higher drying rates for the falling rate period compared to air drying. Reducing the sample thickness or increasing the transferred heat, by increasing the temperature or velocity of the drying medium, result in accelerating the drying process. Temperatures above 160°C, however, cause changes within the and its surface and prevent the bound moisture from getting to the meat's surface to evaporate. This so-called case-hardening effect is worse for air drying than for superheated steam drying and results in even longer drying times and higher final moisture contents. Superheated steam drying reduces the water activity faster than air drying at the beginning of the drying process, but the same values are reached at the end of the drying run. Furthermore, the study proves that the absence of oxygen during superheated steam drying leads to prevention or minimization of lipid oxidation reactions, thus resulting in low peroxide values. Undesired quality changes like off-flavors and off-odors hardly develop during superheated steam drying even at high temperatures and long drying times.

[318] Sinhal, K.; Ghoshdastidar, P. S.; Dasgupta, B. Computer simulation of drying of food products with superheated steam in a rotary kiln. in 2010 14th International Heat Transfer Conference, IHTC 14. 2010.

The present work reports a computer simulation study of heat transfer in a rotary kiln used for drying and preheating food products such as fruits and vegetables with superheated steam at 1 bar. The heat transfer model includes radiation exchange among the superheated steam, refractory wall and the solid surface, conduction in the refractory wall, and the mass and energy balances of the steam and solids. Finite-difference techniques are used, and the steady state thermal conditions are assumed. The false transient approach is used to solve the wall conduction equation. The solution is initiated at the inlet of the kiln, and proceeds to the exit. The output data consist of distributions of the refractory wall temperature, solid temperature, steam temperature, and the total kiln length. The inlet of the kiln is the outlet of the gas (superheated steam),

since the gas flow is countercurrent to the solid. Thus, for a fixed solid and gas temperature at the kiln inlet, the program predicts the inlet temperature of the gas (i.e. at the kiln exit) in order to achieve the specified exit temperature. In the absence of experimental results for food drying in a rotary kiln, the present model has been satisfactorily validated against numerical results of Sass [1] for drying of wet iron ore in a rotary kiln. The results are presented for drying of apple and carrot pieces. A detailed parametric study indicates that the influence of controlling parameters such as percent water content (with respect to dry solids), solids flow rate, gas flow rate, kiln inclination angle and the rotational speed of the kiln on the axial solids and gas temperature profiles and the total predicted kiln length is appreciable. The study reveals that a good design of a rotary kiln requires medium gas flow rate, small angle of inclination and low rotational speed of the kiln. © 2010 by ASME.

[319] Shrivastav, S. Kumbhar, B. K., Textural profile analysis of paneer dried with low pressure superheated steam. Journal of Food Science and Technology, 2010, 47, 355-357, DOI: 10.1007/s13197-010-0059-4.

Paneer is highly perishable at ambient conditions and its shelf-life is very low. At high temperature, it develops a sour smell, and bitter taste. Drying can be one of the methods to increase shelf-life. Drying experiments were conducted at 62, 72 and 82°C and 10, 14 and 18 kPa absolute pressures with superheated steam. The product quality was judged by instrumental texture profile. Hardness, adhesiveness, gumminess and chewiness increased with increase in temperature and decreased with increase in pressure. Springiness and cohesiveness, however, decreased with increase in temperature and pressure. Textural properties of fresh and rehydrated paneer indicated large variation on hardness, adhesiveness and resilience whereas springiness, cohesiveness and chewiness had marginal variation as compared to fresh paneer. © Association of Food Scientists and Technologists (India), Mysore.

[320] Sanfiz, A. C.; Hansen, T. W.; Teschner, D.; Schnörch, P.; Girgsdies, F.; Trunschke, A.; Schlögl, R.; Looi, M. H.; Hamid, S. B. A., Dynamics of the MoVTeNb oxide M1 phase in propane oxidation. Journal of Physical Chemistry C, 2010, 114, 1912-1921, DOI: 10.1021/jp909352u.

Effects of framework and near surface composition of quinternary, phase-pure M1 MoVTeNb oxide catalysts on their catalytic performance in selective oxidation of propane to acrylic acid have been studied. The catalysts were prepared by hydrothermal synthesis, spray-drying, and superheated water vapor treatment. Electron microscopy,

chemical analysis, nitrogen physisorption, and in situ photoelectron spectroscopy have been used to characterize the materials. The yield of acrylic acid normalized to the specific surface area of the catalyst increases with decreasing percentage of Mo and increasing molar ratio of Te/V at the surface. The metal stoichiometry at the surface differs from the stoichiometry in the crystalline bulk and changes in response to the composition of the gas phase. In situ valence band spectroscopy at 623 K in the presence of all reactants revealed a substantial covalent character of the metal-oxygen bonds in M1. The surface restructuring under formation of V- and Te-containing clusters anchored on crystalline, semiconducting M1 is, therefore, considered to establish structurally and electronically isolated active sites. The mobility of Te especially in the presence of water vapor may contribute to the development of site isolation under reaction conditions and to the enhanced selectivity to acrylic acid in the presence of steam in the feed. © 2010 American Chemical Society.

[321] Sakamoto, K.; Tsuchizawa, K.; Katsuoka, T., A drying model of tobacco midrib expanding in air flow. Japan Journal of Food Engineering, 2010, 11, 91-96, DOI: 10.11301/jsfe.11.91.

A drying model was developed to simulate changes in the water content and the temperature of a cylindrical plant material, tobacco midrib, which expands in air flow mixed with or without superheated steam. The model is characterized as follows: (1) mass and heat transfers in the midrib are described by one-dimensional diffusion based on conservation laws; (2) adsorption equilibrium of water is always achieved at a solid-gas interface, so that the internal movement of water is regulated as a rate-limiting step; and (3) transfer phenomena in the expanding diffusion field are simplified by defining the expanded maximum radius as a diffusion length. The curves of water content and temperature calculated by the model were in agreement with each experimental value under various drying conditions: air temperature of 373 to 473 K and flow rate of 10 to 20 m/s. The model also represented drastic rises in temperature caused by condensation heat of water vapor in the initial drying stage. It was therefore judged that the model has validity and can be applied to estimation of the drying curves in expanding diffusion systems for tobacco midribs.

[322] Sagar, V. R. Suresh Kumar, P., Recent advances in drying and dehydration of fruits and vegetables: A review. Journal of Food Science and Technology, 2010, 47, 15-26, DOI: 10.1007/s13197-010-0010-8.

Fruits and vegetables are dried to enhance storage stability, minimize packaging requirement and reduce transport weight. Preservation of fruits and vegetables through drying based on sun and solar drying techniques which cause poor quality and product contamination. Energy consumption and quality of dried products are critical parameters in the selection of drying process. An optimum drying system for the preparation of quality dehydrated products is cost effective as it shortens the drying time and cause minimum damage to the product. To reduce the energy utilization and operational cost new dimensions came up in drying techniques. Among the technologies osmotic dehydration, vacuum drying, freeze drying, superheated steam drying, heat pump drying and spray drying have great scope for the production of quality dried products and powders. © Association of Food Scientists and Technologists (India), Mysore.

[323] Qi, H. Liu, Y. Improving dimensional stability of superheated steam drying-treated wood flooring under high temperature. in 2010 International Conference on Measuring Technology and Mechatronics Automation, ICMTMA 2010. 2010.

Japanese Sugi (Cryptomeria japonica D.Don) wood was dried by superheated steam under the temperature of 140 , 160, 180°C and the relative humidity of 100% to make wood flooring. Moisture absorption and desorption characteristics and chemical composition of treated wood were analyzed to investigate the dimensional stability at saturated and dry ambient condition. The results showed that the dimensional stability of wood treated with superheated steam under high temperature was significantly improved. © 2010 IEEE.

[324] Pronyk, C.; Cenkowski, S.; Muir, W. E., Drying kinetics of instant Asian noodles processed in superheated steam. Drying Technology, 2010, 28, 304-314, DOI: 10.1080/07373930903534545.

The objective for this work was to develop a novel technique for creating instant noodles by determining the drying kinetics of noodles undergoing simultaneous drying and processing using superheated steam. The mathematical model of moisture ratio was differentiated to determine the drying rates of noodles during processing. There was a constant rate drying period for all temperatures at a steam velocity of 1.5 m/s but there was no constant rate drying period at a steam velocity of 0.5 m/s. The constant rate drying period suggested by measurement of internal noodle temperature is much longer and well defined for all processing conditions than from the drying curves. The constant drying rate period, was nearly 200 s at 110°C but decreased to 50 s at 150°C.

Equilibrium moisture content isobars were determined from mass changes during superheated steam processing. It was determined that isotherm equations for equilibrium moisture content in hot air systems may be utilized to model isobars in superheated steam systems. © 2010 Taylor & Francis Group, LLC.

[325] Olufemi, B. A. Udefiagbon, I. F., Modelling the drying of porous coal particles in superheated steam. Chemical and Biochemical Engineering Quarterly, 2010, 24, 29-34.

The modelling and simulation of drying porous coal particles in superheated steam was investigated in this paper. Improved transport and kinetic parameters as well as particle shrinkage were considered in arriving at the results. The resulting partial differential equation describing the drying process was solved numerically using the finite element analysis in addition to other useful equations. This is an improvement over the finite difference analysis that some previous researchers have been using. The simulated results obtained showed very reliable results, as experimental results were properly matched. This is very good justification that the model considerations as well as the good mathematical analysis of the drying process undoubtedly led to a better understanding of the process. This will aid future researchers to design better experiments, equipment and products.

[326] Mujumdar, A. S. Law, C. L., Drying Technology: Trends and Applications in Postharvest Processing. Food and Bioprocess Technology, 2010, 3, 843-852, DOI: 10.1007/s11947-010-0353-1.

Thermal drying technologies have attracted significant R&D efforts owing to the rising demand for improved product quality and reduced operating cost as well as diminished environmental impact. Drying materials may appear in the form of wet solid, liquid, suspension, or paste, which require drying to extend the period of storage, ease of transportation, and for downstream processing to produce value added products. Most of these materials are heat-sensitive and require careful drying; conventional hot air drying can be detrimental to the retention of bioactive ingredients. High temperature tends to damage and denature the product, destroy active ingredients, cause case hardening and discoloration, etc. This article briefly summarizes some of the emerging drying methods and selected recent developments applicable to postharvest processing. These include: heat pump-assisted drying with multimode and time-varying heat input, low and atmospheric pressure superheated steam drying, modified atmosphere drying,

intermittent batch drying, osmotic pretreatments, microwave-vacuum drying, etc. © 2010 Springer Science + Business Media, LLC.

[327] Mujumdar, A. S.; Huang, L. X.; Dong Chen, X., An overview of the recent advances in spray-drying. Dairy Science and Technology, 2010, 90, 211-224, DOI: 10.1051/dst/2010015.

A global overview is presented of recent developments in spray drying. Recent advances in computational fluid dynamics modeling have provided new insights into the flow processes occurring within the spray chamber. This is important since detailed experimental measurements within an operating spray dryer are almost impossible due to the hostile environment of high-temperature two-phase flow, which may be unsteady, and the high cost that would have to incur. Some recent predictive studies on predicted effects of innovative chamber geometry, reduced pressure operation, operation in low dew-point air and superheated steam are presented. Also, a comparison is made between steady and unsteady state computations to highlight the critical issues. Predicted results on a horizontal spray chamber configuration are also presented. Finally, a brief survey is made on the recent literature on spray freeze-drying as well as multi-stage drying processes. © INRA, EDP Sciences, 2010.

[328] Mayachiew, P.; Devahastin, S.; Mackey, B. M.; Niranjan, K., Effects of drying methods and conditions on antimicrobial activity of edible chitosan films enriched with galangal extract. Food Research International, 2010, 43, 125-132, DOI: 10.1016/j.foodres.2009.09.006.

The aim of this work was to study the effects of drying methods and conditions (i.e., ambient drying, hot air drying at 40 °C, vacuum drying and low-pressure superheated steam drying within the temperature range of 70-90 °C at an absolute pressure of 10 kPa) as well as the concentration of galangal extract on the antimicrobial activity of edible chitosan films against Staphylococcus aureus. Galangal extract was added to the film forming solution as a natural antimicrobial agent in the concentration range of 0.3-0.9 g/100 g. Fourier transform infrared (FTIR) spectra and swelling of the films were also evaluated to investigate interaction between chitosan and the galangal extract. The antimicrobial activity of the films was evaluated by the disc diffusion and viable cell count method, while the morphology of bacteria treated with the antimicrobial films was observed via transmission electron microscopy (TEM). The antimicrobial activity, swelling and functional group interaction of the antimicrobial films were found to be affected by the drying methods and conditions as well as the concentration of the

galangal extract. The electron microscopic observations revealed that cell wall and cell membrane of S. aureus treated by the antimicrobial films were significantly damaged.

[329] Mayachiew, P. Devahastin, S., Effects of drying methods and conditions on release characteristics of edible chitosan films enriched with Indian gooseberry extract. Food Chemistry, 2010, 118, 594-601, DOI: 10.1016/j.foodchem.2009.05.027.

The present work was aimed at studying the effects of drying methods and conditions (i.e., ambient drying, hot air drying at 40 °C, vacuum drying and low-pressure superheated steam drying within the temperature range of 70-90 °C at an absolute pressure of 10 kPa), as well as the concentration of Indian gooseberry extract, (added to edible chitosan film-forming solution as a natural antioxidant, at concentrations of 1, 2 and 3/100 g), on the residual total phenolic content (TPC) of the films. The swelling and release behaviour of TPC from the films were also studied. Drying methods and conditions were found to have significant effects on the percentage of residual TPC. The release characteristics, swelling and functional group interaction of the antioxidant films, as assessed by Fourier-transform infrared (FTIR) spectroscopy, were found to be affected by the drying methods and conditions, as well as the concentration of the Indian gooseberry extract.

[330] Kovenskii, V. I.; Borodulya, V. A.; Teplitskii, Y. S.; Pal'Chenok, G. I.; Slizhuk, D. S., Modeling of superheated-steam drying of biofuel in a fluidized bed. Journal of Engineering Physics and Thermophysics, 2010, 83, 764-769, DOI: 10.1007/s10891-010-0395-2.

The drying of a dispersed material in a fluidized bed has been modeled mathematically. The dependence of the bed's mass, which ensures a prescribed final humidity, on the regime parameters of the fluidized system has been established. The superheated-steam drying of wood granules in a fluidized bed has been investigated experimentally.

[331] Kondjoyan, A.; Chevolleau, S.; Grève, E.; Gatellier, P.; Santé-Lhoutellier, V.; Bruel, S.; Touzet, C.; Portanguen, S.; Debrauwer, L., Formation of heterocyclic amines in slices of Longissimus thoracis beef muscle subjected to jets of superheated steam. Food Chemistry, 2010, 119, 19-26, DOI: 10.1016/j.foodchem.2009.02.081.

The kinetics of the formation of heterocyclic amines (HA) were measured on slices of Longissimus thoracis (LT) muscle subjected to impinging jets of superheated steam. Product temperature was either 170 or 200 °C and treatment duration ranged from 1 to

20 min. The concentrations of IQx, MeIQx, 4,8-DiMeIQx and PhIP followed regular kinetic patterns. HA formation increased significantly between 170 and 200 °C. The quantities of IQx and 4,8-DiMeIQx formed in LT slices were 3 to 4-fold smaller than those formed in meat juices, while quantities of MeIQx and PhIP remained comparable. A first-order kinetic model taken from the literature was adapted to describe the results taking into account product temperature variations over the course of the experiment.

[332] Karimi, F., Applications of superheated steam for the drying of food products. International Agrophysics, 2010, 24, 195-204.

Drying is an ancient process used to preserve foods. Conventional drying (hot air) offers dehydrated products that can have an extended life of a year. Unfortunately, the quality of a conventionally dried product is drastically reduced from that of the original foodstuff. Superheated steam drying has been known for over 100 years, but its acceptance in industry has been slow. Before industry accepts a new technology like processing in superheated steam drying, it must be proven to provide these benefits in the area of processing where drying of a product is not the primary concern. The comparison of both preservation processes, hot air and superheated steam drying, was done taking into account several important characteristics such as shrinkage, temperature, process-quality interaction, drying kinetics, costs and new improvements. An updated bibliographic research served to investigate and compare the effects of drying in terms of quality such as shrinkage, colour and microstructure for food products. Theoretical results, from several years of research on the subject, are presented and compiled in order to support the conclusions.

[333] Johnson, P.; Paliwal, J.; Cenkowski, S., Issues with utilisation of brewers' spent grain. Stewart Postharvest Review, 2010, 6, 1-8, DOI: 10.2212/spr.2010.4.2.

Purpose of review: This paper reviews the current utilisation of the bulk generated brewery by-product commonly known as brewers' spent grain (BSG). Various aspects of commonly used preservation technique, ie, drying, are discussed. The significance of various components that can be isolated from BSG is reviewed with a special emphasis on the extraction of proteins. Main findings: BSG has the potential to be used in value-added products by extracting its various nutritionally essential components such as proteins, sugar fractions and phenolic compounds. Different preservation methods can affect the nutritional quality of BSG, for eg, preservation by freezing can

affect the arabinose content. Preservation by drying using membrane separation is less energy intensive and prevents the denaturation of proteins. Superheated steam (SHS) drying has many potential advantages over other drying methods as it removes aroma and flavour in addition to preserving the nutritional quality of BSG. For improving the potential application of the insoluble proteins extracted from BSG, hydrolysis of proteins has proved to be an efficient technique. Limitations: BSG is generated in bulk quantities and can easily deteriorate due to its high moisture content, which makes the transportation, storage and preservation of BSG a major challenge for the brewing industries. In addition, the colour and aroma of BSG make its direct addition into food products difficult. It cannot be directly burned as it leads to atmospheric pollution due to the release of NOx gases. Directions for future research: BSG contains an abundance of nutritionally rich minor components and antioxidants. Research is needed to extract and salvage these valuable fractions. Studies are also needed to develop more economic drying methods capable of removing flavour and aroma without affecting the nutritional quality of BSG. Processes must be developed for improving the shelf-life of BSG without altering its constitutional composition. © 2010 Stewart Postharvest Solutions (UK) Ltd.

[334] Inoue, T.; Iyota, H.; Nishimura, N., Prediction method for drying time of wet porous material in humid hot air and superheated steam. Drying Technology, 2010, 28, 608-614, DOI: 10.1080/07373931003788650.

The effects of dry-bulb and wet-bulb temperatures on the dryingtime of a wet spherical porous material in humid hot air and superheated steam were investigated. A wet spherical brick was used as the sample porous material. The experimental results revealed that the normalized drying characteristics curves in the falling drying rate period obtained under different experimental conditions were all in good agreement. In addition, the time required to reduce the moisture content below the critical moisture content was almost the same under all wet-bulb conditions at the same constant drying rate, regardless of steam condensation. © 2010 Taylor & Francis Group, LLC.

[335] Head, D. S.; Cenkowski, S.; Arntfield, S.; Henderson, K., Superheated steam processing of oat groats. LWT - Food Science and Technology, 2010, 43, 690-694, DOI: 10.1016/j.lwt.2009.12.002.

Superheated steam (SS) processing of oat groats with a lab-scale SS processing system was studied as a method of heat treatment alternative to commercial processing (kiln drying) of groats. The objective of this study was to determine conditions of SS

processing necessary to obtain groats with inactivated peroxidase, moisture content and colour comparable to commercially processed groats, but with pasting properties unique to those obtained in commercial processing. Raw or moisture tempered oat groats (~13 g) were processed with SS at varying processing times (1-30 min) depending on steam temperature (110-160 °C) and velocity (0.35 and 1.00 m/s) used. Generally, groats processed with SS exhibited higher cold paste (64 °C) viscosity than the groats processed commercially. Oat groats processed with SS to final moisture content of 9-10/100 g (wet basis, wb) or less were peroxidase negative. The parameters of SS selected for processing of oat groats were: temperature of 110 °C, a velocity of 1.00 m/s, and two processing times (10 and 14 min). These parameters gave groats with inactivated peroxidase, moisture content at ~9.5/100 g (wb), significantly ($P < 0.05$) brighter colour, and significantly higher cold paste viscosity compared to that of groats processed commercially.

[336] Gong, Y.; Niu, H.; Xiao, Z.; Liu, X.; Yang, D., Simulation on rapeseed drying in superheated steam fluidized bed at atmosphere pressure. Nongye Gongcheng Xuebao/Transactions of the Chinese Society of Agricultural Engineering, 2010, 26, 351-356, DOI: 10.3969/j.issn.1002-6819.2010.04.060.

In order to improve the precision of superheated steam fluidized bed drying model, an unsteady axisymmetric two-dimensional model was established based on the drying mechanism of superheated steam fluidized bed drying and Eulerian-Eulerian theory to simulate the process of superheated steam fluidized bed drying and the distributions of some parameters in this paper. The finite volume method was applied to solve the mathematical model. It showed that the simulated drying dynamic characteristics were coincidence with the experiment results, the established mathematical model could describe the drying process and the behavior of rapeseed during the superheated steam fluidized bed drying at atmosphere pressure.

[337] Dagbro, O.; Torniainen, P.; Karlsson, O.; Morén, T., Colour responses from wood, thermally modified in superheated steam and pressurized steam atmospheres. Wood Material Science and Engineering, 2010, 5, 211-219, DOI: 10.1080/17480272.2010.520739.

In this study, two different methods were used to produce thermally modified wood. One was carried out in a typical kiln drying chamber using superheated steam (SS) and the other used pressurized steam in an autoclave cylinder (PS). Overall, both processes followed the same principles and the wood was not treated with any chemicals. Two

wood species were studied, Scots pine (Pinus sylvestris) and Norway spruce (Picea abies). Treatments in the autoclave were carried out under pressure using temperatures of 160°C, 170°C and 180°C. Temperatures of 190°C and 212°C were used in treatments in the chamber at normal air pressure. The colour was measured using L*C*H colour space. Results for both species showed that similar L* (lightness) can be reached at lower (20-308C) temperatures using PS compared with SS treatment. The hue angle of PS-treated wood was smaller than that of SS-treated wood. No significant difference in C* (chroma) was detected. The difference in E value between PS- and SS-treated wood was smaller for Norway spruce than for Scots pine. The residual moisture content was about 10% higher in wood treated by the PS process compared with the SS process. © 2010 Taylor & Francis.

[338] Chen, J. Y.; Ma, X. J.; Bai, L. Q.; Wang, J., Study on drying ethanol draff with intermittent superheated steam. Huaxue Gongcheng/Chemical Engineering (China), 2010, 38, 14-17.

Intermittent superheated steam drying of ethanol draff was studied with superheated steam drying compartment self-built in the laboratory. The original moisture mass fraction of ethanol grain was 66.7% in the test. The effects of different experimental conditions on drying rate were researched. The results show that when other conditions are the same, the drying rate increases obviously with the increasing of superheated steam temperature, and the drying time decreases as the mass of material drops. With the decreasing of the grain particles diameter, the drying rate keeps at the same level in the constant rate period, while the drying rate increases obviously in the falling rate period. The drying rate increases as the steam mass flow rate rises. So the experiment indicates that the drying rate increases with the increasing of superheated steam temperature and mass flow rate, but decreases with the increasing of grain feeding mass and particle diameter.


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