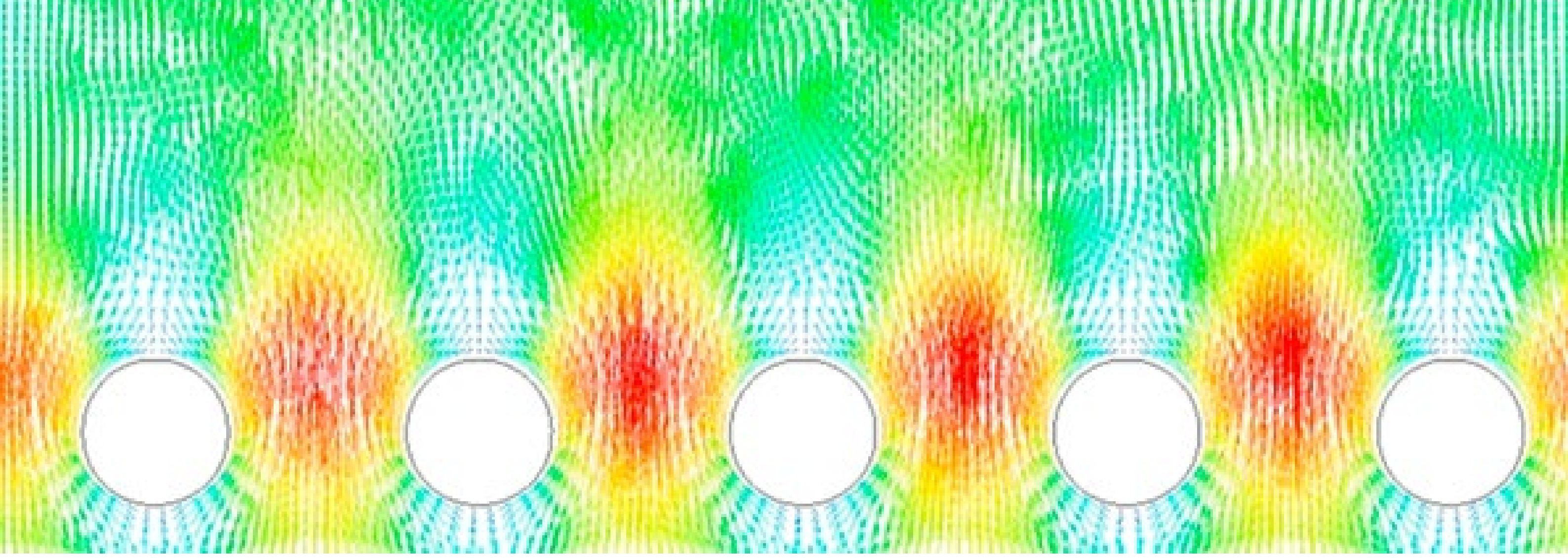
Fraunhofer IGB

FRAUNHOFER INSTITUTE FOR INTERFACIAL ENGINEERING AND BIOTECHNOLOGY IGB

SUPERHEATED STEAM DRYING AT ATMOSPHERIC PRESSURE

INNOVATION THROUGH SYNERGY BETWEEN RESEARCH AND ENGINEERING



The challenge of energy efficiency

Drying is an important and frequently used process in various branches of industry. It is often an essential process step in the production, treatment and processing of solid materials. Conventional drying processes with air consume a large part of the energy required in the overall production process chain. Thus, considering the criticality of energy supply, industry is called to intensify efforts to reduce the energy required for drying and consequently increase the industrial energy efficiency.

On one hand, the choice of the most energy-efficient technology and its correct implementation play a major role. The recovery of previously unused energy e.g. residual or exhaust heat, on the other hand, has become of particular focus of the industry. Only in this way energy costs and CO_2 emissions caused by the production of energy can be significantly reduced.

To meet this challenge, the Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB working on the further development of a drying process with superheated steam at atmospheric pressure. This technology permits significant energy savings, while at the same time maintaining high product quality. Furthermore, the use of this process does not only increase the efficiency of energy utilization, but also of material usage by enabling the capture of valuable volatiles compounds that are carried out together with the steam.

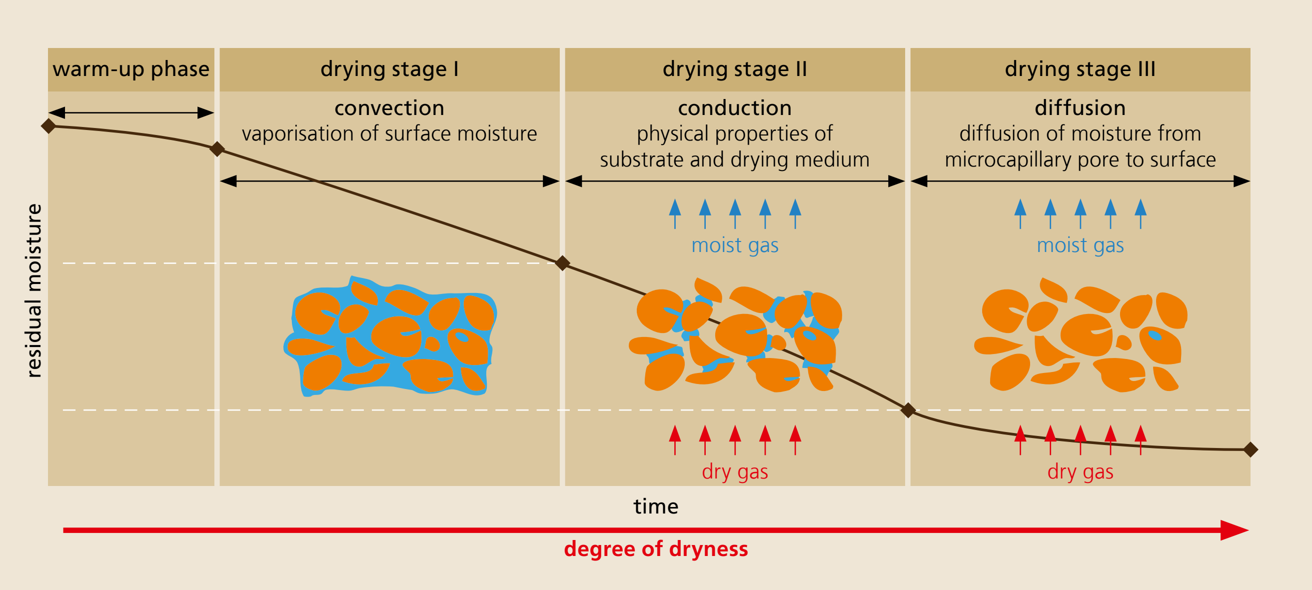
Competences and cooperation

The Fraunhofer IGB possesses proven expertise in the research, development and process application of drying processes for industrial customers and has at its disposal both stationary and mobile laboratory equipment and pilot plants. This includes equipment for the analytical evaluation of the processes used and software tools for modeling and designing prototypes.

Together with industrial partners, the Fraunhofer IGB supports clients from the conception phase by way of process design and assembly to the full in-house operation of the customized solution.

Amongst others, we cooperate with the company Heckmann Metall- und Maschinenbau GmbH, where the drying process developed by the Fraunhofer IGB is already used in practice. Heckmann Metall- und Maschinenbau GmbH has many years of practical experience relating to the design and manufacturing of superheated steam dryers. Using the latest CAD software, special requirements of the clients are implemented. For the manufacturing of drying systems Heckmann has a wide range of machinery and equipment.

INDUSTRIAL DRYING



The current situation

Drying generally represents an essential process step in the production, treatment and processing of solid materials. For example, drying processes are used, for stabilizing the form of granulates, pellets or powders. Other desirable properties of products such as shelf life, weight reduction or microbiological stability are also achieved through drying.

Drying processes typically work with hot or warm air. In many cases, a large part of the energy required in the whole processing chain is used for drying. Furthermore, these drying processes often require a long residence time and therefore considerable space. According to various studies, over 15 percent of the total industrial energy consumption is used for drying[1].

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[1] *Strumillo, C.; Jones, P.; Zylla, R. (1995) Energy Aspects in Drying, Handbook of Industrial Drying, 2nd Ed.; Mujumdar, A. S., Ed.; Marcel Dekker: N. Y.*

The state of the art

Drying is considered a thermal dehumidification process in which the moisture is removed from the moist material by evaporation, transforming liquid water into water vapor. The higher the moisture content of the input material, the more energy is required for drying.

The thermal drying process consists of three essential subprocesses:
(i) transferring the heat from the drying medium to the moist material,
(ii) the phase transition of the moisture, and
(iii) transport of the resulting vapor (evaporated moisture) to the atmosphere of drying medium by means of diffusion.

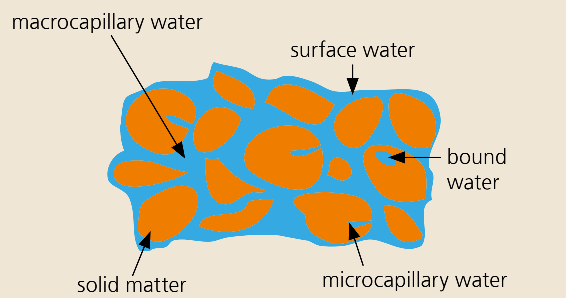
In convective drying processes, the required thermal energy is supplied through the flow of drying gas. Conventionally, ambient air is heated to the desired temperature using a burner or heat exchanger and employed as drying gas. In some cases, if organic solvents are to be removed or ignitable solids are to be dried, a nitrogen-based inert gas circulation method has to be applied. The cost of the drying process depends directly on the volume of drying medium and the drying time required. These determine the size of the dryer and the peripheral equipment.

Technical limitations of conventional hot-air drying

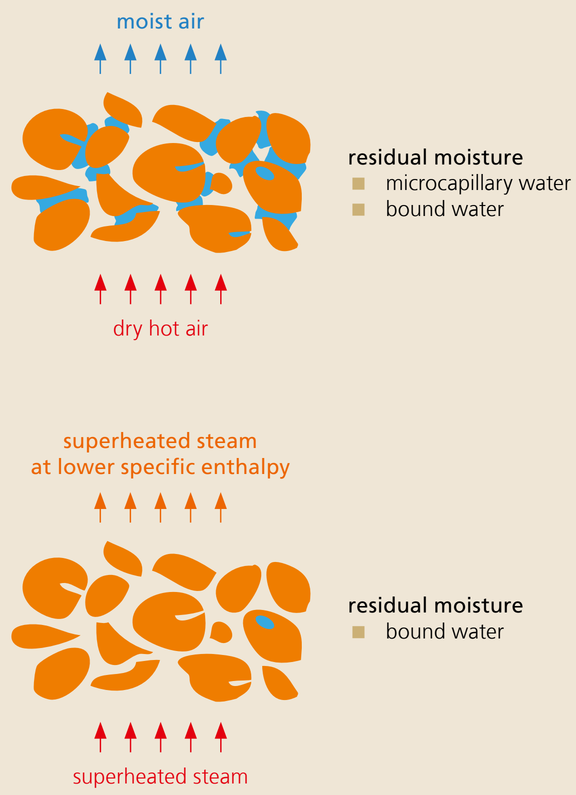
With the currently used drying processes, the environmentally harmful emissions are released together with the offgas. In addition to CO_2, the exhausted gas may contain volatile bases, ammonia, fatty acids, and sulfur compounds, which are also often responsible for odor nuisances. In order to comply with the emission regulations, a costly downstream offgas treatment unit is required additionally. Also, together with the exhausted gas, thermal energy and valuable volatile substances, which could have been valorized for other applications, are also lost .

A further problem in air-based drying processes is the formation of an explosive mixture of oxygen, whirled up dust and/or solvent. To minimize the risk of explosion, the law requires costly measures in accordance with ATEX Guidelines[2], which often result in complex and cost-intensive construction and operation measures of the drying plant, for example pressure-surge protected systems or inert gas operation.

Water distribution in the solid matter



Comparison of convective drying methods: dry hot air vs. superheated steam



[2] *European Commission (2011): ATEX guidelines, ec.europa.eu/enterprise/sectors/mechanical/files/atex/guide/atexguidelines-may2011_en.pdf*

NEW PROCESS WITH SUPERHEATED STEAM

Improvements using superheated steam

Energy consumption is an important economic factor in industrial mass production. Savings can be achieved by means of energy recovery, optimized process engineering or multiple use of the energy flows. For these purposes, superheated steam drying can play an important role.

Reduced specific energy consumption

As a result of the thermodynamic properties compared to hot air (higher thermal conductivity and specific heat capacity) and lower density (better penetration of the material to be dried), higher drying rates can be achieved with superheated steam. Also, the diffusion resistance of evaporated moisture into the atmosphere of superheated steam is lower than of air. This results in a more homogeneous and faster drying of the material with a specific energy consumption of 0.75 – 0.90 kWh per kg of evaporated water in a superheated steam dryer. Whereas 1.10 – 1.70 kWh per kg evaporated water[3] is required in a corresponding hot-air dryer.

No oxidative reactions

Oxidation processes in the material to be dried, resulting in deterioration of the product quality, are minimized due to the absence of atmospheric oxygen. There is also no risk of explosion, which facilitates ease of operation.

Recovery of volatile substances and energy

Simultaneous to energy recovery e.g. by condensation or vapor compression[4], it is possible to recycle the volatile substances released in the drying gas, for example aroma compounds or organic solvents, from the excess steam.

Principle of the superheated steam drying process

The material to be dried is introduced to the superheated steam atmosphere where it is supplied convectively with heat and its moisture evaporates. Through the uptake of vapor released from the material, the volume of superheated steam increases, while its temperature decreases without changing the state to saturated steam. As superheated steam is recirculated and reheated in a closed loop to elevate the temperature to the desired level, evaporated mositure becomes excess steam and is carried off along with volatile compounds from the drying chamber. Generally the working temperature of superheated steam drying is 110 to 250 °C, but this can be increased.

Free choice of conveying techniques

Due to the difference in density between air and superheated steam, a boundary (stratification layer) between the atmosphere of superheated steam and the ambient air is created, thus preventing infiltration of air. In consequence, not only no sealing installations, e.g. airlocks or sluices, are necessary, but also any conveying system, which is best suitable for transport and handling of the material, can be chosen freely.

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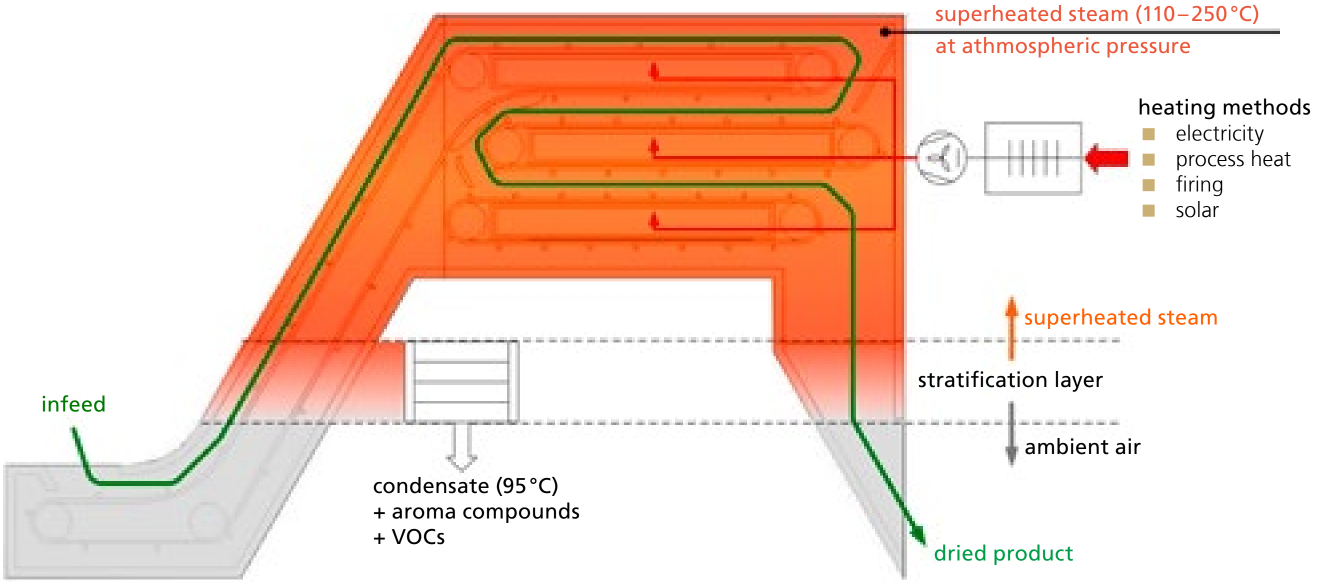
[3] *Desai, D. K. and Hoadley, A. F. A. (2009) Superheated Steam Drying of Brewer's Spent Grain in a Rotary Drum, Advanced Powder Technology, Vol. 20 (3), pp. 240–244*

[4] *Mujumdar, A. S. (1990) Superheated Steam Drying – Principles, Practice and Potential for Use of Electricity. Canadian Electrical Association Report 817 U 671: Montreal*

The system concept

The system is hermetically closed at the top, but is atmospherically open at the bottom. With a selectively regulated discharge of the excess steam, the boundary layer between the phases of superheated steam and ambient air is controlled to prevent the loss of recoverable energy to the environment. Generally, the excess steam at the temperature level above 100 °C, which contains virtually the quantity of the heat supplied for drying, can be utilized in other processes in the plant. This means that a higher overall energy efficiency of an industrial plant can be achieved.

Energy recovery can be conducted e.g. by means of condensation, which allows volatile organic compounds (VOCs) to be condensed out with the excess steam. These condensable organic substances can be further separated by simple decantation and the VOCs are made available as recovered material or value-added product. The use of superheated steam and thus the absence of oxygen permits an inert drying process. This prevents oxidation of the product and significantly reduces the risk of explosion. Moreover, the material to be dried can simultaneously be hygienized by specific adjustment of the temperature and the drying time.



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TEST EQUIPMENT

With several laboratory-scale and pilot-scale units, superheated steam drying processes for different materials can be tested, documented and demonstrated. We offer customers from many branches of industry a broad range of services and joint developments. The product – with its specific drying characteristics – determines the design and customization of the dryer. Through trials and practice-oriented approaches, scientists, engineers and technicians design and develop the right solution for individual clients.

Laboratory dryer for comparative tests: hot air vs. superheated steam

The transportable laboratory dryer was developed specially to dry a very wide range of products with hot air or superheated steam and to determine the differences in energy consumption and product quality. The laboratory dryer is designed exclusively as a semi-technical pilot plant with modular components, thus allowing it to be easily transported.

In this unit, the process peripheries are separated from the product chamber. This has the advantage that the drying chamber and conveyor technology can be adapted individually to each product. Two different drying chambers are available for the various fields of application; the chambers can be exchanged as required in just a few simple steps.

Technical data

- Evaporative capacity: up to 45 kg/h at a working temperature of up to 300 °C

Continuous belt dryer

The laboratory-scale belt dryer represents the function of an industrial equipment on a smaller scale. The unit is operated as a continuous convective dryer. The product to be dried is conveyed through the dryer on a perforated steel belt (apron), where a flow of superheated steam is passed through. It has four drying sections that can be controlled independently of one another. Parameters such as residence time, temperatures and flow velocity can be adjusted individually to suit the product.

Drying trials can be carried out with this unit, simulating the full-scale production in smaller quantities. The achievable throughput rates depend to a large extent on the characteristics of the product to be dried.

Technical data

- Evaporative capacity: up to 50 kg/h at a working temperature of up to 250 °C
- Product transport: an apron conveyor is standard, but other belts can be installed upon the customer's specific requirements


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1 *Laboratory dryer.*
2 *Belt dryer.*
3 *Vibration fluid-bed dryer.*
4 *Mill dryer.*

Vibrating fluid-bed dryer

The vibrating fluid-bed dryer is designed as a freely-oscillating system with a vibration motor. The machine is mounted on a frame with elastic springs and the actuator (vibration motor) is located directly below the drying chamber. The advantage of a freely-oscillating unit is the possibility to control the conveying speed by means of a frequency converter and thus a variable adjustment of the residence time of the product in the drying chamber.

The product is fed into the dryer e.g. via a screw conveyor. From infeed to discharge, the product is continuously swirled by an intensive flow of superheated steam in the vibrating fluid-bed chamber. The flow of steam can be introduced from the bottom through the perforated plate or from the top via jet nozzles. For particular applications, e.g. roasting of coffee and cocoa beans, a downstream equipment for quenching and cooling can be integrated.

Technical data

- Evaporative capacity: up to 45 kg/h at a working temperature of up to 300 °C

Mill dryer for simultaneous drying and grinding

Superheated steam passing through the heater is directed into the mill drying chamber, where not only the effective evaporation surface area is increased through grinding, thus reducing in the diffusion distance for the evaporated moisture, but as well the drying operation is complimented by thermal energy converted from the mechanical work. The dried product particles are discharged from the mill together with superheated steam pneumatically and passed further to the cyclone and the filter, where the fine particulates are separated out.

The product is enclosed by the flow of superheated steam, subjected to extreme turbulence and crushed by the impact of particles against one another and also on the grinding plates. Potentially explosive products can be ground and dried using a superheated steam atmosphere. Moreover, with the deployed rotary mill, sticky or pasty products can be processed.

Technical data

- Evaporative capacity: up to 200 kg/h at a working temperature of up to 300 °C
- Speed of the rotary mill up to 3500 rpm


APPLICATIONS

REFERENCE DATA

Foodstuffs

Considerable reductions in time have been achieved in the field of foodstuff drying. For example, in the drying of apple chips, the retention time was reduced by 90 percent from 8 hours to 50 minutes without any loss of product quality. Also in the case of pre-processed food products for potato-based snacks, the drying time was reduced by more than 90 percent (from 7 hours to 30 minutes).

Hygienization

Based on systematic test trials we were able to show that superheated steam drying is also suitable for the hygienisation of foodstuffs. The microbial load of mushrooms and bell pepper artificially contaminated with *E. coli* cells and *Bacillus* endospores was reduced by 7-log stages. Other products that have been tested and studied are tea ingredients (e.g. ginger and juniper berries), bananas, coffee and cocoa beans, fish and shrimps, onions, orange peels, dough for noodles and bread crumbs.

Fodder and pet food

The retention time for various types of fodders and pet foods has been reduced from 35 to 10 minutes. In this study, the superheated steam drying was operated at a temperature 10 °C lower than the currently employed hot-air drying process. The process optimization also results in a lower specific energy consumption.

Mineral raw materials

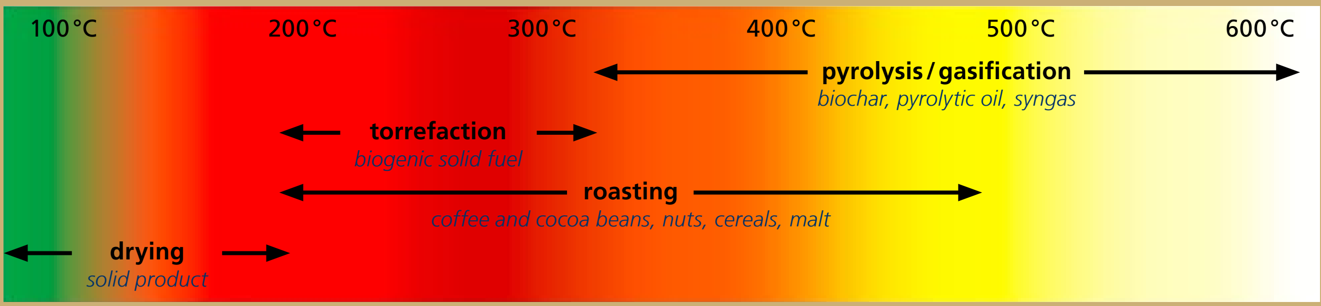
When drying bulky minerals, a reduction in retention time of 30 percent and energy savings of 40 percent were achieved compared to the existing hot-air dryers. This permitted a reduction of the overall size of the dryer by one third or a corresponding increase of the throughput capacity.

Construction materials

In an initial series of trials on a laboratory-scale belt dryer, the retention time was reduced from 4 to 6 hours to less than 3 hours. This resulted in a time reduction of 25 to 50 percent.

Biogenic waste products

In addition to reducing the energy consumption by over 30 percent, superheated steam was successfully used at laboratory scale to decrease greenhouse gas emissions during drying of sewage sludge. Ammonia and volatile organic acids were identified in the condensate and recovered as secondary raw materials for the production of the mineral fertilizer (e.g. ammonium sulphate). Also, investigations of fermented residues (e.g. anaerobic digestate), manure and algae were carried out by drying with superheated steam with the aim of recovering recyclable materials.



OUTLOOK – FURTHER NEW APPLICATIONS

Together with industrial partners, the Fraunhofer IGB is developing the process further to extend the use of superheated steam beyond the drying process, enhancing its application in other thermal and thermo-chemical process. Due to the many advantages of the superheated steam technology, significant progress has already been made as follows:

Roasting

Roasting is the heat treatment of plant-based foodstuffs such as nuts, coffee and cocoa beans, cereals and grains, in which fundamental physical and chemical changes take place in the structure and the composition. These result in browning and the development of aromas and flavors.

Superheated steam has already been used and tested as roasting gas for roasting coffee beans at the laboratory scale on the vibrating fluid-bed dryer. The exhaust gas flow was recirculated and reduced to the technologically possible minimum (50 times less exhaust gas flow compared to hot-air roasting), thus only the gas released from the coffee beans during roasting leaves the closed cycle and is condensed out. The condensate was used to cool the roasted coffee beans, preventing an uncontrolled post-roasting. Since valuable aromatic substances including essential oils were identified in the condensate, we are currently working on extracting these individual substances. On the basis of mathematical calculations 245 W thermal energy is required to roast 1 kg of coffee beans. Roasting with superheated steam almost achieves this theoretical minimum value. The process of roasting coffee beans with superheated steam has been patented and successfully implemented using the vibrating fluid-bed dryer.

Torrefaction

In the superheated steam atmosphere, and thus with the exclusion of oxygen, the woody material is treated at temperatures of 250–300 °C. After the water present in the material is evaporated, decomposition of lignocellulosic compounds takes place; firstly hemicellulose and then a part of cellulose and lignin. The aim of the torrefaction is to enhance the mass-related energy density and thus the heating value of the raw material, to increase the transport capability and storage stability, and to reduce the mechanical works required for subsequent grinding or pelletizing. The resulting product is considered to be an ideal additional fuel for power stations using coal dust firing as well as raw material for biotechnical refinery for the production of chemical products. Volatile compounds evolving during torrefaction can be pre-separated and further used as feedstock for the production of chemical building blocks.

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OUR SERVICES

- Scientific assessments, consultations, investigations for tasks related to drying and thermal processes
- Development of specific plant concepts according to the needs of individual clients
- Process layout and specification by an interdisciplinary team with a background of process engineering, plant construction, chemistry, microbiology and electrical engineering
- Laboratory, technical and pilot plants for test trials
- Product-related evaluation of the drying process using a wide range of analytical equipment and expertise
- Design and specification of the process unit and components, e.g. by integrated combination of 3D CAD design and numerical modeling of e.g. fluid dynamics and heat transfer with the latest software
- Supporting our clients from the first drying trial to realization of the concept and commissioning of a plant

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