Selected drying technologies and particle engineering for the future Biorefinery

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Abstract

This paper gives an overview of the drying technologies relevant to the biorefinery industry. The drying technologies are very diverse and besides economical considerations, the choice of drying method for a specific process depends on e.g. the feed type and the desired properties of the end product. To obtain a cost-effective drying process which gives a product of constant high quality it is critical to have detailed insight into the different elements of the drying technology chosen. Spray drying is one of the technologies where process understanding has moved significantly forward in recent years. This paper describes some of the new methods which are used for investigating spray drying. This includes a description of an apparatus for studying the single particle drying in detail and an explanation of how the experimental results from this apparatus are combined with advanced computer simulations to improve equipment design.

Introduction

The pulp and paper industry is heavily involved in developing new products from biomass and cellulosic material. In this context there is a constant search for appropriate production methods. One unit operation that comes into play is drying. The drying step in processing biomass and cellulosic material serves several purposes such as reducing transport and storage costs and extending shelf life. Also, in many cases the material needs to be dry in order to be processed further. In such cases the properties of the dry material is of paramount importance. Thus it is important to use the drying process that will give the dry material the right properties. Many different drying processes can come into play and a number of these are described below. This paper intends to give a brief overview of GEA Barr-Rosin and GEA Niro commercially available drying technologies, possible feed stocks and typical end products. On process of particular interest is spray drying that converts a slurry, suspension or solution directly into a powder. It is shown that by spray drying it is to a large extent possible to engineer the particle morphology and powder characteristics to fit specific needs. It is also shown that the spray drying process can be simulated with high accuracy. The purpose of presenting this development is to inspire whoever is stretching the technological borders of a biorefinery to look even further.

Table 1 below will give a quick overview over 9 different drying processes

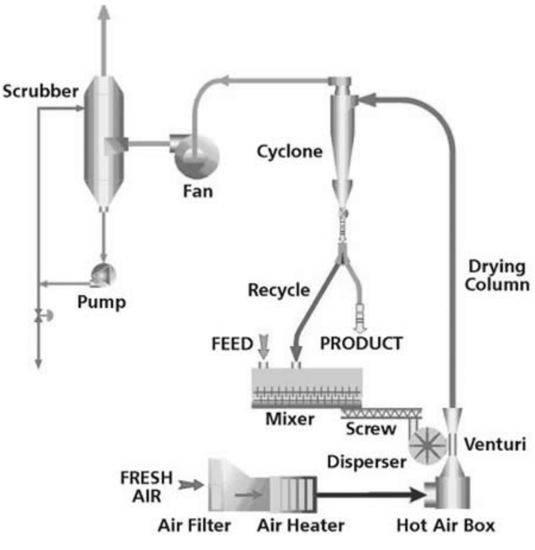
Table 1. *Overview of selected commercial drying technologies*

Type of dryer	Typical feed	Typical PSD* dried product	Comments	Retention time
Rotary dryer	Coarse particles, lumps, chips	As in the feed or reduced to >1mm		Several minutes
Tube Bundle dryer	Lumps or powder 1-5 mm	0,1-5 mm	Indirect heat transfer	Several minutes
Flash dryer	Friable solids or press cakes	0,01-10 mm	Lump degradation by flashing	10-30 sec
Ring dryer	Friable solids or press cakes	0,01-10 mm	Internal milling and product recirculation	30 sec- 3-5 minutes
Back mixing	High DS liquid	0,01-1 mm		
Superheated Steam Dryer	0,1-10 mm	As in the feed	Only cyclone possible	20-60 seconds
Fluid Bed	0,5-10 mm sticky	As in the feed	Sectionised for drying/cooling	1-10 minutes
Swirl Fluidizer	Cakes or pastes	< 50 micron	Internal milling	0.5-10 min
Spray Dryer	Pumpable liquid	10-100 micron		10-30 sec
Fluidized Spray Dryer	Pumpable liquid	50-250 micron Agglomerates	Fines recirculated	10-20 sec +1-5 min

*PSD= Particle Size Distribution

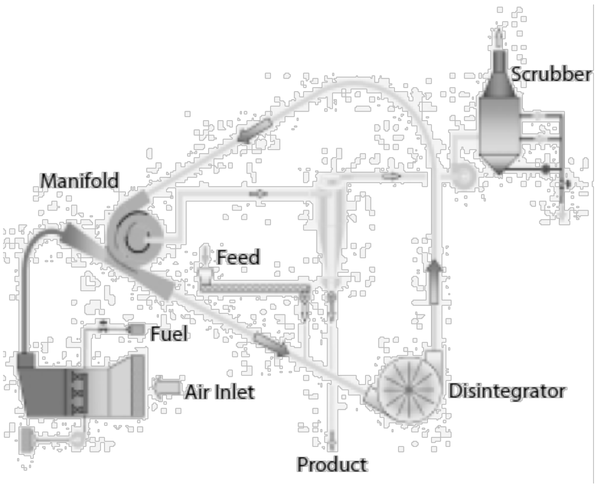
Flash Dryer

The GEA Barr-Rosin Flash Dryer is a pneumatic system primarily used to dry products which require removal of free moisture. Drying takes place in a matter of seconds. Wet material is dispersed into a stream of heated air (or gas) which conveys it through a drying duct. Using the heat from the airstream, the material dries as it is conveyed. Product is separated using cyclones, and/or bag filters. Typically, cyclones are followed by scrubbers or bag filters for final cleaning of the exhaust gases to meet current emission requirements. Elevated drying temperatures can be used with many products since the flashing off of surface moisture instantly cools the drying gas without appreciably increasing the product temperature. Flash dryers have been used to dry products in many industries including food, chemical, mineral and polymer. A broad range of feed materials including powders, cakes, granules, flakes, pastes, gels, and slurries can be processed. For slurries, pastes, or sticky materials, back-mixing of the wet feed with a portion of dry product to produce a suitable conditioned material is required.



Ring Dryer

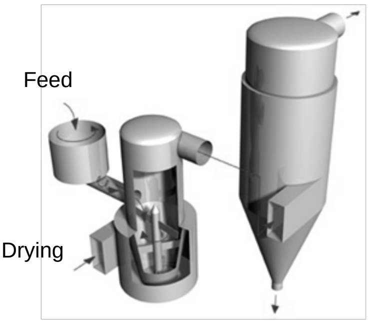
The GEA Barr-Rosin Ring Dryer is a pneumatic type system; in essence a modified flash dryer. The ring dryer was developed to increase the versatility of the flash drying technology and to overcome many of the limitations. The dispersion of feed into the drying gas stream in the venture and the subsequent drying is like the flash dryer. A disintegrator can be added to ensure breakdown of larger lumps of feed material. The



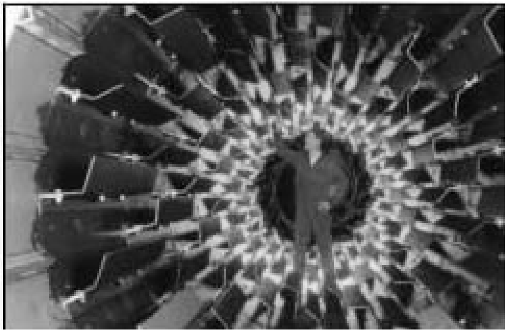
presence of a "manifold" or "internal classifier" in the ring drying system is what differentiates it from the flash dryer. The manifold uses the centrifugal effect of an air stream passing around a curve to concentrate the product into a moving layer. The adjustable splitter blades are used to return the heavier, semi-dried material back to the dryer for another pass through the system while the lighter, drier product exits the dryer and gets conveyed to the product collection system. In essence the ring dryer enables drying of same type of products as the flash dryer but with the selective extension of residence time enables the ring dryer to process many materials which are regarded as difficult to dry in a flash dryer. Lignin from the Lignoboost system is an example of a product which dries nicely in both flash and ring dryers, as well as in the following SWIRL FLUIDIZER™.

SWIRL FLUIDIZER™

The GEA Niro SWIRL FLUIDIZER™ differentiates itself from the flash type dryers in having a fast rotating disintegrator that turns the feed into very fine particles as it is exposed to the drying gas. The high viscous feed material is mixed to a homogeneous feed in the feed tank by a vertical bottom driven agitator. A special designed horizontal auger transports the feed into the drying chamber where the disintegrator equipped with powerful and fast rotating chopper blades ensures increase of surface area from where the drying of the feed can occur. The fine particles are dried by heated process air which enters at the bottom of drying chamber through an air disperser with tangential inlet. The dried particles are carried out of the drying chamber by the air flow. The exhaust system is equipped with a bag filter to separate the powder product from the drying gas. Product is obtained through a rotary valve placed under the bag filter. As like other flash type dryers they are an economical choice for drying pastes and filter cakes. For these feeds, as well as suspensions, and highly viscous liquids, the SWIRL FLUIDIZER™ is able to produce a fine, homogeneous, non-agglomerated powder, all in one compact process step.

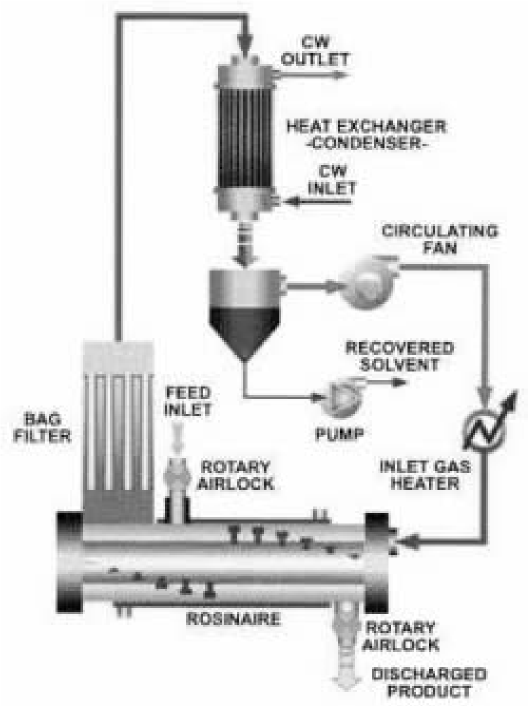


Rotary Dryer



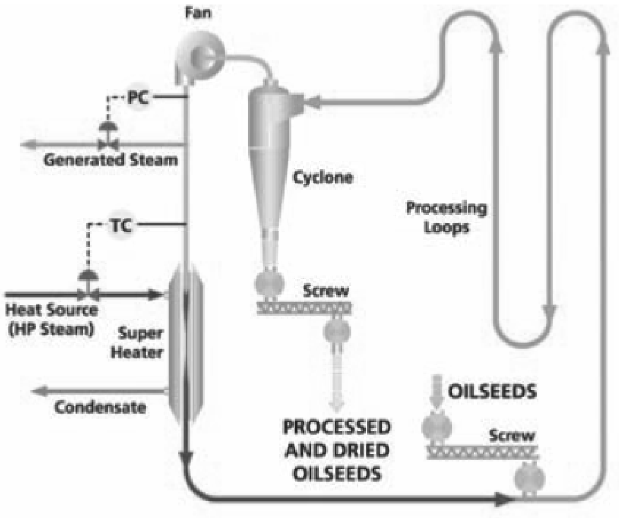
Rotary dryers operate on the principle of lifting and showering the product in a hot gas stream inside a rotating cylindrical drying chamber equipped with baffles. GEA Barr-Rosin produces two different types of rotary dryers; direct and indirect heated. Indirect heated rotary dryers are mainly heated from the outside, via a stationary jacket fitted on the dryer with only a minimal airflow through the drying chamber, making this solution suitable for dusty materials. For direct heated dryers the energy needed for the drying is supplied through the hot gas stream entering the dryer co- or counter-currently. For greater thermal efficiency and where inertisation is required, recycling of exhaust gases can be used. Rotary dryers are suitable for a wide variety of products, from granular, powdered and crystalline materials, to filter cakes and sludges for the food, chemical and mineral industries.

Paddle Dryer



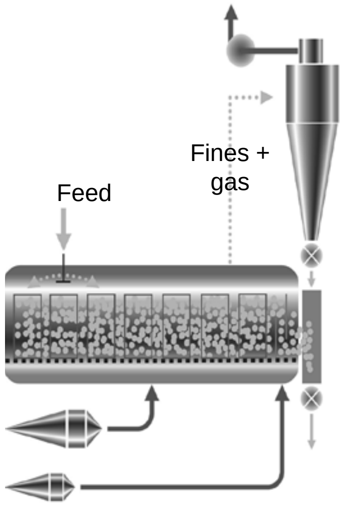
The GEA Barr-Rosin ROSINAIRE™ is a high-speed, thin-layer, indirect-contact, paddle dryer. It consists of a horizontal, cylindrical vessel containing a longitudinal rotor / paddle assembly. The vessel body is fabricated with external jacket sections enabling heating of the dryer surface. Paddle orientation is adjustable enabling adjustment of the residence time of the solids within the vessel. Feed material is either pumped or conveyed into the ROSINAIRE™ vessel. The centrifugal action of the high-speed rotor / paddle assembly delumps and conveys the product material through the ROSINAIRE™ as a thin-layer of solids in a helical flowpath along the jacketed wall resulting in very high heat transfer coefficients. Moisture is vaporized into the annular vapor space, and a small counter-current flow of sweep air or inert gas is used to convey the vapour out of the ROSINAIRE™ at the feed end. The product material is discharged tangentially as free flowing solids. The ROSINAIRE™ is often employed to operate in closed cycle mode, using a small flow of recirculating inert gas to sweep away the evaporated volatiles to the condenser, eliminating any potential air pollution discharge to the atmosphere. This method is ideal for evaporating organic solvents or for processing toxic substances. The ROSINAIRE™ is well suited to process polymers, organic chemicals, inorganics, and foods. The ROSINAIRE™ can handle pumpable feedstocks (slurries, pastes, gels), as well as non-pumpable feeds in the forms of centrifuge or filter cakes, crumbs, granules, beads, pellets, powders, flakes, or short fibers.

Super heated steam dryer



GEA Barr-Rosin Superheated Steam Dryer (SSD)™ is a closed loop pneumatic conveying type dryer. The wet solids are fed into the flow of pressurized superheated transport steam by means of a pressure tight rotary valve, plug screw or similar. The transport steam is superheated indirectly via a tubular heat exchanger using different heating sources or alternatively by using a mechanical vapour recompressor. In the subsequent drying ducts, moisture is vaporized from the product, forming excess transport steam and lowering its degree of superheat. Normally, the residence time in the system is only 5-60 seconds. Transport steam and the dried material are separated in a high efficiency cyclone and the product is discharged from the dryer by means of another pressure tight rotary valve. The generated excess steam is normally at a pressure of 0-4 bar and its reuse make the energy efficiency of the drying process very high. The super heated steam dryer is suited for drying a range of different product e.g. cellulose derivatives, wood chips, biomass, bagasse etc.

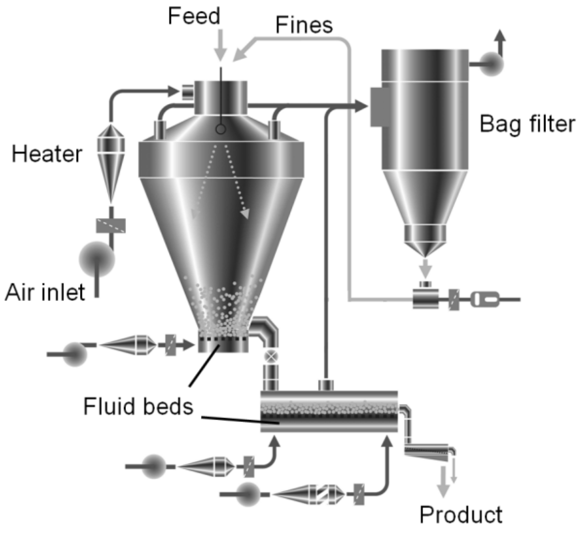
Fluid Bed Drying



GEA Niro fluid bed dryers are designed to dry powder dispersed in gas. The process gas is supplied to the bed through a special perforated distributor plate and flows through the bed of solids at a velocity sufficient to support the weight of particles in a fluidized state. Large gas bubbles form and collapse within the fluidized bed of material, promoting intense particle movement. In this state, the solids behave like a free flowing boiling liquid. Very high heat and mass transfer values are obtained as a result of the differential velocities between individual particles and the fluidizing gas. Contact heating panels can be incorporated, resulting in a significant reduction in airflow compared with the typical standard fluid bed. Many materials begin at or pass through a sticky, softening or cohesive phase during processing. Vibrating beds are extremely effective in keeping the material in a live fluidized state during this transitionary phase. A broad range of feed materials including powders, crystals, granules and prills can be processed.

Spray Drying

In spray drying the liquid feed is atomized to droplets and contacted with a hot gas which causes the solvent of the droplets to evaporate, leaving dried particles. The particles are subsequently separated from the drying gas in a cyclone or a bag filter. Spray drying is the most widely used industrial process for particle formation and drying. It is extremely well suited to the continuous production of dry solids as either powder, granulates or agglomerates from liquid feeds. Feeds include solutions, emulsions and pumpable suspensions.



Spray drying is a versatile process and therefore it provides good control over the final powder properties such as flowability, particle size, redissolution rate, bulk density and mechanical strength. For example different atomization methods may be chosen to obtain a specific particle size or atomize high viscosity feeds. The most commonly used atomization methods are rotary (wheel) atomizers, pressure and two-fluid nozzles. Also, spray dryers are often equipped with one or more fluid beds for further drying, agglomeration, dust removal and/or cooling. GEA Niro produces spray dryers in many types to facilitate drying of many different products. The dryer shown in the enclosed figure is the GEA Niro MSD™ (Multi-Stage Dryer) which separates the drying into different stages making the drying operation more efficient and at the same time more gentle.

Fluidized Spray Dryer

As mentioned above spray dryers are often followed by a fluid bed dryer for further drying, agglomeration, dust removal and/or cooling. To make the plant more compact and the fines circulation better integrated in the spray drying there is also the possibility to integrate the fluid bed in the bottom of the spray dryer chamber. The fluid bed can still have different sections, and the integration into the spray drying chamber enables one combined exhaust line.

In the fluidized spray dryer it is possible to extend the retention time of particles in the dryer, and also to recirculate the finer fraction. By having slightly more moisture in the particles when entering the fluidized bed section, agglomerates can be built up. Agglomerates enable the penetration of water into the particle and increase a fast dissolving of the powder.

Examples of dryer installations for cellulose based powder products

Below a selection of dryers related to products derived from cellulose based raw material

1. Domsjö Fabriker operates one spray dryer since 2009 and is installing the second one for lignosulponate during 2011. (www.domsjoe.com)
2. Xylophane in Gothenburg is running their pilot production for Xylane based packaging film material with a fluidized spray dryer since 2009. (www.xylophane.se)
3. Lignin from the Lignoboost process has successfully been tested on pilot plants for flash dryer, ring dryer and the SWIRL FLUIDIZER™. The main difference is the smaller and more homogenous particle size distribution achieved by the SWIRL FLUIDIZER™. (www.lignoboost.se or www.innventia.com)
4. AkzoNobel in Örnsköldsvik is running since 1995 a ring dryer for its modified cellulose called Bermocoll. (www.akzonobel.com/cs)

Particle engineering by single droplet drying analysis

The powder properties of a spray dried product such as mechanical strength, flowability, density, redispersion rate are very important. These properties are determined by the final morphology of the individual particles in the powder. Both the feed formulation and the process parameters (e.g. drying gas temperature and humidity) determine the particle morphology. To investigate the morphology formation during drying of a single droplet, GEA Niro has developed an experimental apparatus named the DRYING KINETICS ANALYZER™ (DKA).

The DKA is based on the principle of ultrasonic levitation as illustrated in Figure 1. An ultrasonic field is generated between the transmitter and reflector. Due to the forces of this ultrasonic field it is possible to hold a small droplet constant against gravity. While the droplet is drying it is monitored by a CCD-camera and an infrared thermometer. The former is used to record a video file of the drying process while the latter is used to measure the development in droplet surface temperature during drying. The levitation unit is encapsulated in a small drying chamber (not shown in Figure 1) so that the air temperature and humidity may be set to match the conditions in a spray dryer.

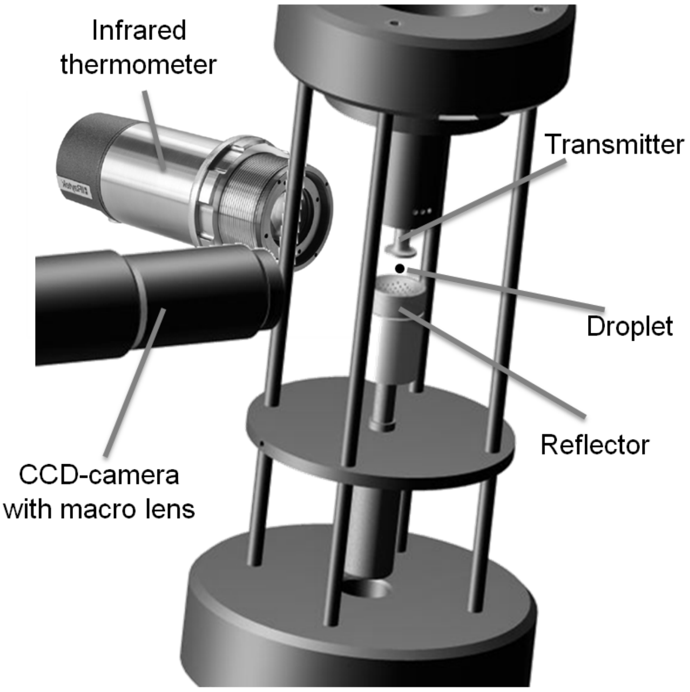


***Figure 1**. The DRYING KINETICS ANALYZER™ where a droplet is suspended in an ultrasonic field. The droplet drying process is recorded with a CCD-camera and monitored with an infrared thermometer.*

Using the DKA the morphology formation may be investigated in different ways. Firstly, it is possible to review the video recorded during an experiment – an example is given in Figure 2. Investigations of this kind may be conducted at, for example, different drying air temperatures to map the effect of this parameter. When the particle has dried completely it is possible to recover it from the ultrasonic field. The particle may then be subjected to analysis by optical or scanning electron microscopy. It is also possible to conduct different kinds of analyses such as XPS (X-ray photoelectron spectroscopy) or Raman spectroscopy to measure the distribution of different compounds inside the dried particles.

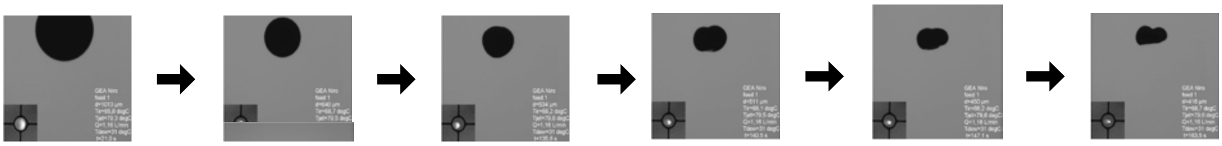


***Figure 2**. Course of drying for a levitated droplet consisting of a 10 wt% TiO2 suspension. The drying air temperature is 79.5°C. The initial droplet size is about 1000 µm whereas the final droplet size is about 400 µm.*

Investigations of the particle morphology are one part of the so-called DRYNETICS™ concept. The other part is the use of the results of the DKA experiments in computer simulations. Based on the measurements conducted during a DKA experiment it is possible to calculate the drying kinetics through advanced mathematical modelling. This is very important since the spray drying process has become a frequent subject for Computational Fluid Dynamics (CFD) modelling. In CFD a three-dimensional model of the spray dryer is drawn by a computer. Using this model, commercially available CFD software like FLUENT™ allows the calculation of temperatures, gas velocities, particle trajectories, etc. inside the spray dryer.

To obtain useful results from the CFD simulations it is necessary to include calculations of the evaporation process occurring within the drying droplets. Using the FLUENT™ CFD software it is possible to include the evaporation process by applying a simple drying model which assumes that the feed droplets are drying like pure liquid droplets. But this assumption leads to a too optimistic drying rate as any solid material in the droplets will retard the drying. To overcome this problem a user-defined function has been developed as part of the DRYNETICS™ method. This user-defined function couples the results of the drying kinetics based on the DKA measurements with the commercial FLUENT™ CFD software. Consequently, very accurate results from the CFD software are obtained because the unique drying properties of the feed in question are included in the simulations.

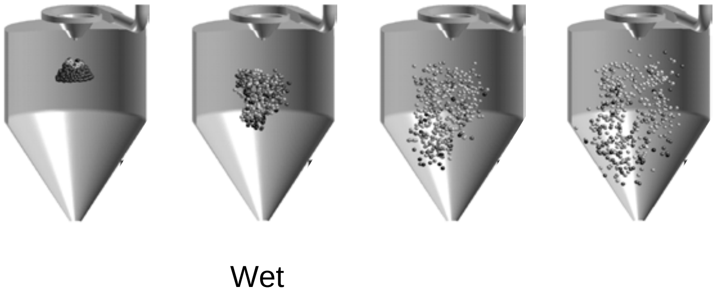


***Figure 3**. Drying particles tracked during the CFD simulation. Dark: high moisture content. Light: Particles close to dry. The drying rate is found from experiments using the DRYING KINETICS ANALYZER™.*

The DRYNETICS™ coupling between DKA experiments and CFD simulations is shown in Figure 3. The figure shows a result of a simulation of a full-scale spray dryer where a few hundred particles have been tracked during drying. The colours of the particles illustrate the residual moisture content in each particle – based on the input from the DKA experiments (though difficult to seen in Figure 3 since it is in black and white). The results of a simulation gives a very detailed insight into the spray drying process and are well suitable for the troubleshooting of existing plants, for designing new plants as well as developing better components for spray dryers.

Summary

Drying technologies are very diverse and besides economical considerations, the choice of drying method for a specific process depends on e.g. the feed type and the desired properties of the end product. To obtain a cost-effective drying process which gives a product of constant high quality it is critical to have detailed insight into the different elements of the drying technology chosen.

Spray drying is one of the technologies where process understanding has moved significantly forward in recent years. Newly developed methods of analyzing the drying process for a single droplet and CFD simulations for scale up the results has enhanced real particle engineering. By engineering the particles properly the new products derived from the future biorefineries can be given the desired powder characteristics and superior quality.