Effervescent atomization

A new atomizing technique for the energy-efficient spray drying of food liquids with high viscosity

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Spray drying is widely used for the production of food powders. Prior to the drying itself, the liquid feed has to be atomized into fine spray droplets. The smaller the droplets, the bigger the surface of the liquid and thus the drying can be accomplished in a shorter time [1]. Unfortunately, it is very hard to create spray droplets with a uniform size. As a result, there are always particles which are either exposed to unfavorably high temperatures (smaller droplets) or are not completely dried (bigger droplets). The latter may lead to serious sticking with consequent problems in the handling of the particles. Additionally, the width of the spray droplet size distribution influences other important powder properties such as its bulk density, flowability, dusting characteristics and instant properties (wettability, sinkability, dispersibility, solubility). To achieve a high bulk density a broad droplet size distribution is favorable. Small particles tend to dust and to float on the water surface when reconstituted by the consumer.

The energy consumption of spray drying

Concerning its energy consumption spray drying is a very expensive process. Published data of spray drying plants in the U.K. indicate a consumption of 4.88 GJ per ton of evaporated water [2]. Unfortunately, there are not many possibilities to save or regain energy. Regarding a typical milk production line, calculations show that it is not possible to save more than 20 % of the energy used via heat exchanger devices [3]. A heat flow balance highlights the dry matter content of the feed as a parameter of outstanding importance

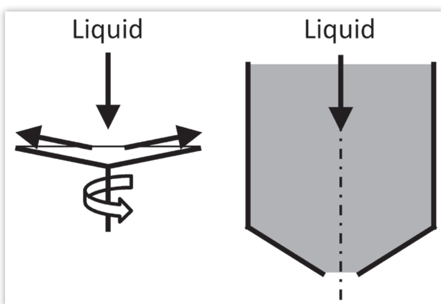

Figure 1: Schematic drawing of a rotary atomizer (left) and a pressure nozzle (right).

regarding the energy consumption of a spray drying plant [4]. However, the practical implementation is limited as a reduction of the water content is normally linked to a higher feed viscosity and consequently to a worse atomization. In general, different atomization techniques exist [1]. To meet the economical interests, the best atomizer should be able to atomize a feed liquid with elevated viscosity into fine spray droplets with an energy input as low as possible.

Atomizing techniques and their applicability in saving spray drying energy

The easiest way to distinguish the different atomizing techniques is to look at the energy used for atomization:

- Kinetic energy transferred via centrifugation ➡ Rotary atomizers
- Energy of pressurized liquid ➡ Pressure nozzles
- Kinetic energy transferred via a gaseous phase ➡ Two fluid or pneumatic nozzles

The following statements are valid for all types of atomizers: With a higher energy input the spray droplet size decreases as well as the size of the dried particles. Furthermore, with increasing liquid viscosity and surface tension, the spray droplet size increases.

In **rotary atomizers** (Figure 1, left side) the liquid is centrally distributed on a fast rotating disc. Because of the high rotational speed the liquid is accelerated to velocities up to 180 m/s. The liquid spreads into a thin film and is atomized at the edge of the disc. One may use guide grooves or increase the friction between the liquid and the rotating disc in order to minimize the slip between the liquid and the geometry. Rotary atomizers are suitable to atomize abrasive as well as particle loaded fluids and do not tend to become blocked. The average spray droplet size is usually within the range of 20 to 200 microns whereas the spray shows an intermediate size distribution [1]. To ensure a satisfying atomization with rotary atomizers the liquid viscosity must be in a low to moderate range. Thus, they are not suitable to save drying en-

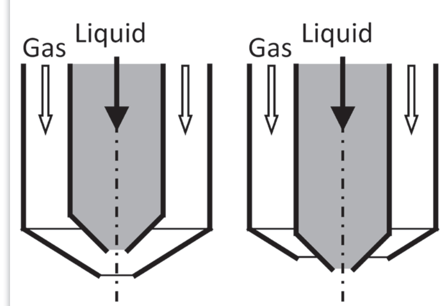

Figure 2: Schematic drawing of a pneumatic nozzle with internal (left) and external (right) mixing.

ergy when drying highly viscous liquids.

In **pressure nozzles** (Figure 1, right side) the liquid is pumped under pressurized conditions (2 to 30 MPa) to an exit orifice with a small diameter. Here, the pressure energy is transformed into kinetic energy. A thin liquid film is formed which is subsequently atomized into fine spray droplets. Additionally, the liquid can be set into rotary motion upstream the exit orifice to enhance the atomization. With a pressure nozzle average spray droplet sizes of 50 to 400 microns and an intermediate size distribution width is achievable [1]. Because of the small diameter of the exit orifice, pressure nozzles are of limited use for the atomization of abrasive and particle loaded liquids. In addition, they are prone to clogging. The atomization pressure is directly linked to the liquid viscosity which must consequently be in a low to moderate range. Again, with pressure nozzles it is also hard to save spray drying energy when drying highly viscous liquids.

In **twin fluid nozzles** the liquid is fed under ambient conditions to the atomizer. Subsequently, it is mixed with a fast moving gaseous phase either inside or outside the nozzle (see Figure 2). The required kinetic energy is applied by the compression and subsequent relaxation of the gaseous phase. If air is used as gaseous phase the atomizer is called pneumatic nozzle. Since there is a huge difference between the velocity of the air and the liquid, large shear and elongational forces act on the liquid`s surface. As a result, the liquid is atomized into fine droplets. The used amount of air for atomization is expressed in relation to the amount of the liquid by mass via the Air-to-Liquid-Mass-Ratio (ALR) as in Equation 1:

$$\mathrm{ARL} = \frac{\text{massflow of air}}{\text{massflow of liquid}}$$

Equation 1

The mean spray droplet size decreases with increasing ALR. Compared to pressure nozzles, twin fluid nozzles are equipped with exit orifices of larger diameters. Thus, they show a decreased susceptibility to clogging and are also suitable for the atomization of particle loaded and abrasive liquids. With this technique it is possible to atomize a liquid with high viscosity into spray droplets with an average diameter of 5 to 75 microns. However, the main drawback of this technique is the huge amount of compressed air which is needed for the atomization. Because of the high energy consumption of the air compressors, the atomizing technique of the twin fluid nozzle becomes uneconomic at a point.

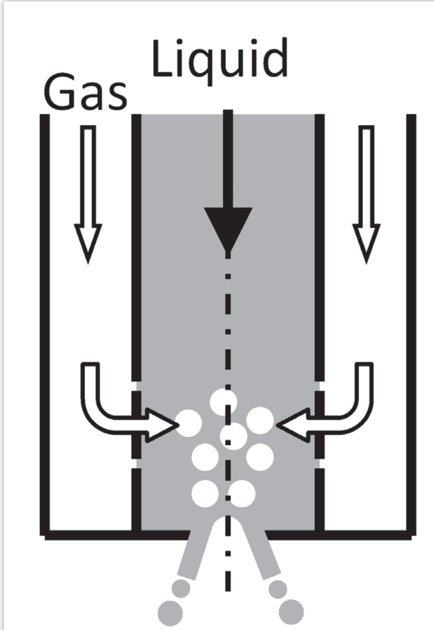

Figure 3: Schematic drawing of an effervescent atomizer (according to [5])

An approach to solving this problem is to change the way in which the atomizing air and the liquid are brought in contact e.g. by effervescent atomization.

Effervescent atomization

Figure 3 shows a schematic drawing of an effervescent nozzle. A targeted mixing of the air into the liquid in a mixing chamber upstream the exit orifice distinguishes this nozzle from conventional pneumatic nozzles. A two fluid flow of air bubbles and liquid is formed. At suitable process parameters the liquid forms a thin sheet at the wall of the exit orifice with air occupying the core. The liquid leaves the exit orifice in this shape and disintegrates into fine spray droplets [5]. The main benefits of that atomizing technique are: Good atomization even at an elevated viscosity, small gas flow rates, low air and liquid pressures and alleviated clogging problems.

Figure 4 shows the Sauter mean diameter $x_{1,2}$ of the spray droplets produced by an effervescent and a conventional external mixing pneumatic nozzle in relation to the ALR [6]. The Sauter mean diameter represents the diameter of a droplet whose ratio of volume to surface area is equal to that of the spray as a whole. With decreasing $x_{1,2}$ the specific surface area is increased and thus the drying time is reduced.

From the data in Figure 4 it is evident that the effervescent atomization technique requires only 30 to 50 % of the gas mass of the conventional pneumatic technique to achieve alike Sauter mean diameters [6]. Thus, with an effervescent atomizer it is possible to decrease the main drawback of the pneumatic nozzles: Even for liquids with elevated viscosities, a good atomization can be achieved at a relatively low energy consumption of the air compressors. In comparison to pressure nozzles, the much lower liquid pressures are also worth mentioning.

In addition, if a liquid feed based on an oil-in-water-type emulsion such as milk or other dairy educts is to be spray dried, the effervescent atomization technique can save homogenizing energy [7, 8]. Because of the effervescent atomization process a breakup of the dispersed oil droplets can occur (Figure 5). With an increasing energy input (ALR) of the atomization process the resulting oil droplet size decreases. This indicates that the energy used for the atomization process not only results in the breakup of the liquid bulk volume into spray droplets, but can also result in a change of the inner structure of the feed.

Our research currently deals with the potential application of the effervescent atomization technique in the spray drying of food based products. The dried products are extensively characterized with respect to important product properties by consideration of particle size, particle density, bulk density, amount of free fat, oxidation stability and instant properties.

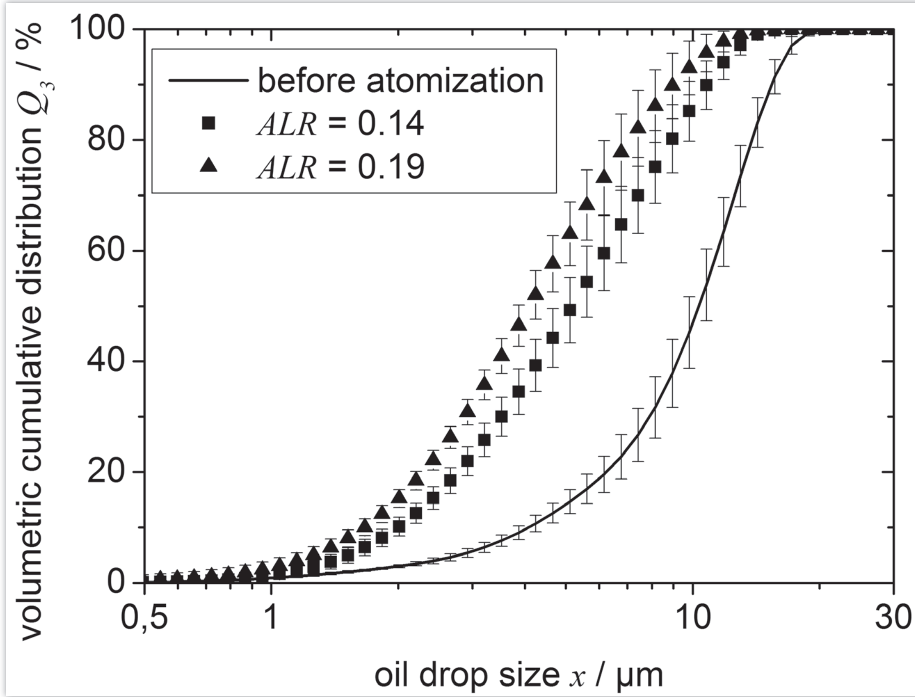

Figure 5: Oil drop size distribution of an oil in water emulsion before (continuous line) and after atomization (discrete data points) by an effervescent atomizer at two different ALR [7].

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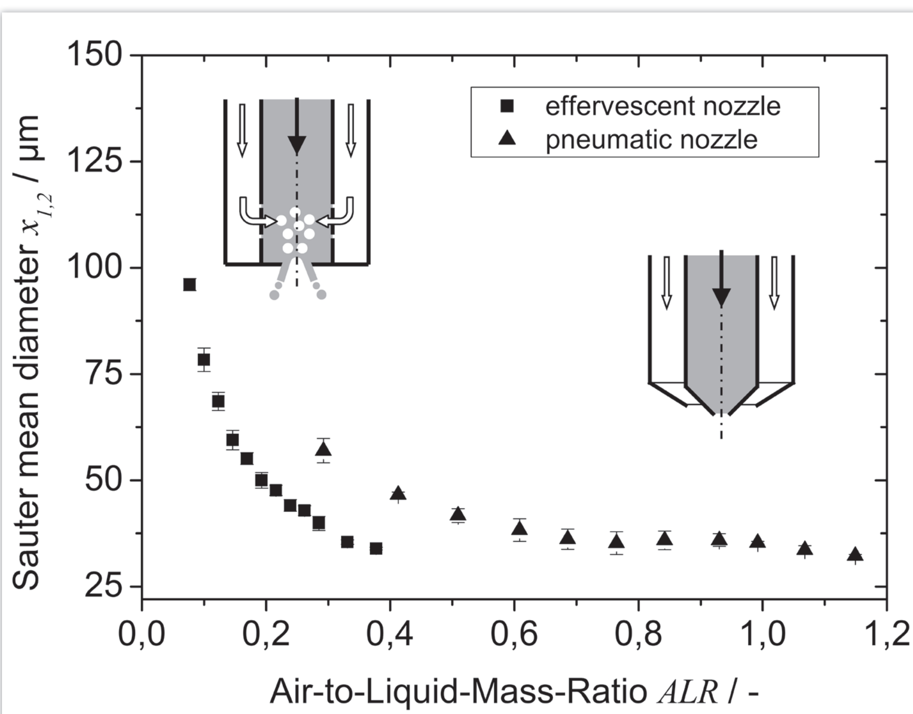

Figure 4: Impact of ALR on the Sauter mean diameter of the spray droplets atomized by an external mixing pneumatic nozzle and an effervescent atomizer at constant liquid flow (liquid viscosity: 25.5 mPas) [6]