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Spray drying of high viscous food concentrates: Investigations on the applicability of an Air-Core-Liquid-Ring (ACLR) nozzle for liquid atomization

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Abstract

Spray drying is widely used for powder production from liquid concentrates. Often low input temperatures are desired, as many materials, like proteins, are sensitive to heat. However, this demand leads to increased concentrate viscosities. Commonly used pressure swirl atomizers are limited concerning maximum processible viscosity. In this study, a so called Air-Core-Liquid-Ring Atomizer is used for pilot scale spray drying of whey protein concentrate (WPC80) at 40 °C and hence a viscosity of 0.09 Pa s. The produced powder was compared to an industrially produced reference. As a result, no significant differences in particle size distribution and particle morphology were observed.

Keywords: *spray drying, atomization, ACLR, high viscous feeds, whey protein concentrate.*

1. Introduction

Spray drying is an important and widely used processing technique for powder production form liquid concentrates[1]. The process consists of three main steps: atomization, drying and powder separation. In the atomization step, the bulk concentrate is disintegrated into small droplets, in order to accelerate convective drying. For sufficient drying, all droplets have to be small enough to dry within the given residence time inside the spray dryer[2]. Consequently, mean droplet size and distribution width, generated in the atomization step, are of high importance for the subsequent processing steps. Generally, spray dryers should be operated at the highest possible input dry matter content, in order to insure economic operation[3]. Moreover, low input temperatures are desired, as many spray dried materials are sensitive to heat. Both demands lead to high concentrate viscosities[4] which complicates atomization for all known atomizer techniques[5]. On industrial scale, mainly pressure swirl atomizers are used. In this type of atomizer, high liquid pressures are used to deliver the required atomization energy. This type of atomization is very energy efficient, but the maximum processible viscosity is comparably low[5]. In laboratory or pilot scale spray dryers, often external mixing pneumatic atomizers are used. In this type of atomizer, the kinetic energy of compressed gas is used for droplet disintegration. In contrast to pressure swirl atomizers, the applied disintegration energy can be increased independently of the liquid flow. This allows the production of very small droplet sizes, even at high concentrate viscosity. However, high gas consumption rates of these atomizers do not allow economic operation on larger scales[3].

Internal mixing pneumatic atomizers (IMPA) offer the possibility to atomize high viscous concentrates at low gas consumption rates[6–11]. One specific IMPA, proposed for spray drying purposes, is the so called Air-Core-Liquid-Ring (ACLR)[12] atomizer (see Fig. 1). In this atomizer, liquid concentrate and atomization gas are brought into contact with each other in a mixing chamber, shortly before the exit orifice. The specific gas injection geometry induces a continuous core of compressed gas in the middle of the liquid stream, leading to an enforced annular two phase flow inside the exit orifice. This kind of flow pattern is known to deliver constant spray droplet distributions at high viscosities[12,13].

In the here presented study, a fresh liquid whey protein concentrate WPC 80, delivered by a dairy company, was processed in a pilot scale spray dryer, equipped with an ACLR atomizer. In order to investigate the potential of the ACLR atomizer to process high viscous concentrates, the input temperature before atomization was lowered (40 °C) in comparison to the corresponding industrial process (60 °C) of the supplier, leading to an increase of the viscosity by 50 % up to 0.09 Pa s. The produced powder was compared to the industrially produced reference by means of particle size distribution, water activity, moisture content and particle morphology.

2. Materials and Methods

2.1 Whey protein concentrate WPC 80

For the performed investigation, a fresh whey protein concentrate WPC 80 was used. The concentrate was delivered by Sachsenmilch GmbH, Leppersdorf, Germany. The concentration was executed in a membrane process. The dry matter content was given by the supplier as 36.1 %.

As reference, an industrially spray dried WPC 80 powder of the same supplier was analyzed for comparison to the powder, produced in the pilot scale spray drying process using the ACLR atomizer (See section 2.4).

2.2 Rheological characterization of liquid concentrates

The rheological characterization of the liquid concentrate was performed in a rotary rheometer (MCR 101, Anton Paar GmbH, Graz, Austria), equipped with a coaxial cylinder geometry (CC 27). The measurements were conducted at temperatures of 25, 40 and 60 °C and shear rates between 1 and 1000 s^{-1}.

2.3 Process equipment

2.3.1 ACLR Atomizer

A scheme of the used ACLR atomizer is given in Fig. 1. All parts are produced from stainless steel. The atomization gas is injected into the liquid stream, shortly before the exit orifice. For this purpose, a gas capillary with a diameter of 1.5 mm is used, leading to gas injection area of 1.76 mm^2. The mixing chamber length is 2.4 mm. Diameter and length of the exit orifice are 1.5 mm each.

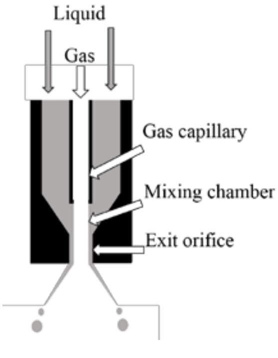

Fig. 1: Scheme of the used ACLR atomizer. ($l_{mixing\ chamber}$ = 2.4 mm, $l_{exit\ orifice}$ = 1.5 mm, $d_{exit\ orifice}$ = 1.5 mm)

2.3.2 Media supplies

The concentrate was supplied by an eccentric screw pump (MD 006-12, seepex GmbH, Bottrop, Germany). The flow rate was adjusted to 15.7 L/h and measured by a flow meter (VSI 044/16, VSE GmbH, Neuenrade, Germany). The concentrate was preheated before atomization to 40 °C in a tube heat exchanger. As atomization gas, compressed air, supplied by a compressor (Renner RSF-Top 7.5, Renner GmbH, Güglingen, Germany), was used. Air pressure was adjusted to 0.55 MPa by a pressure regulator. The gas volume flow through the atomizer's mixing chamber, resulting from gas pressure and liquid flow rate, was measured by a gas flow meter (ifm SD6000, ifm electronic, Essen, Germany) as 3.7 Nm^3/h. The resulting gas to liquid ratio by mass (GLR) was 0.28.

2.3.3 Pilot scale spray drying process

A pilot scale spray dryer (Werco SD20, Hans G. Werner Industrietechnik GmbH, Reutlingen, Germany) with a maximum water evaporation capacity of 20 kg/h was used. The dryer was operated at an inlet temperature of 180 °C, an outlet temperature of 95 °C and a drying air flow of 470 kg/h.

2.4 Powder characterization

The powders were characterized by measurement of particle size distribution, moisture content, water activity and morphology. Particle size distributions where measured by a laser diffraction spectroscope with powder dispersion unit (Horiba LA950, Retsch Technology GmbH, Haan, Germany). Moisture contents were calculated by weight loss after oven drying at 105 °C to constant mass. Water activities were measured by a dedicated measuring instrument (AW Sprint, Novasina, Lachen, Switzerland). Investigations on particle morphology were performed with an environmental scanning electron microscope (FEI Quanta 650 ESEM) at the Laboratory of Electron Microscopy of KIT, Karlsruhe.

3. Results and Discussion

3.1. Rheological characterization of liquid concentrates

In the first step, the shear rate dependent viscosity of the fresh whey protein concentrate WPC 80 was investigated at different temperatures of 25, 40 and 60 °C. All investigations were performed in triplicate. The concentrates showed shear thinning behavior with increasing shear rate at all investigated temperatures. However, the decrease of viscosity between shear rates of 1 and 1000 s^{-1} was pronounced with increasing temperature level. Moreover, the viscosity decreases with decreasing temperature at constant shear rate. (data not shown)

As high shear rates are expected in the atomization process, the viscosity at the highest shear rate, applicable in the used rheometer (1000 s^{-1}) are given in Table 1.

Table 1. Concentrate viscosity at a dry matter content of 36.1 % at a shear rate of 1000 s^{-1} and different temperatures.

Temp. / °C	**Viscosity / Pa·s**	
	mean	std
25	0.15	0.001
40	0.09	0.001
60	0.06	0.001

In the industrial process the concentrate is preheated to 60 °C before atomization. According to the here presented data, the viscosity in the moment of atomization is 0.6 Pa·s in this case. However, it is reported in literature, that the viscosity of whey protein concentrates might increase in the first hours of storage[14]. As the concentrate had to be transported from the production plant of the supplier to our pilot plant, the viscosities in the industrial process might be lower than the here presented values. In order to observe the viscosity increase over time, rheological measurements were performed directly after receiving the concentrate, as well as one and two days later, though no changes in viscosity were observed (data not shown).

In order to investigate the potential of the used ACLR atomizer to process concentrates at lower preheating temperatures and therefore higher viscosities, the preheating temperature was lowered by 20 K to 40 °C in the performed pilot scale trial. This procedure led to an increase of the viscosity by 50 % up to 0.09 Pa·s in comparison to the industrial process.

3.2. Spray drying process and powder characterization

The spray drying process with an ACLR atomizer was undisturbed during the whole trial time of 83 min. No sticky deposits in consequence of insufficiently dried particles were found inside the drying chamber after the trial. In Fig. 2 cumulative volume distributions of the powder particle sizes produced in the pilot scale spray dryer, as well as of the reference powder, are shown. The particle size measurements were performed fivefold. Both particle size distributions are similar. Small differences were found in fine particles, as well as in particles with sizes lager than 100 µm. The latter can most probably be traced back to agglomeration of primary particles, as the moisture content of the powder, produced in the pilot scale dryer, was significantly higher (9.1 %) than the one of the reference powder (5.4 %). Powders with increased moisture content are known to show increased stickiness an tension to build agglomerates[3]. However, it can be assumed, that the moisture content of powder can be reduced to the value of the reference powder, when the dryer height, and therefore the residence time inside the drying chamber, is increased to industrial level.

Nevertheless, water activity values of 0.20 (ACLR) and 0.12 (reference) show, that microbial stability is insured in both cases.

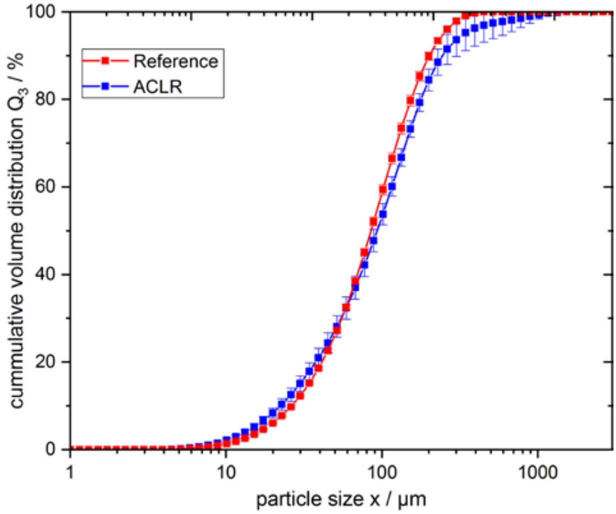

Fig. 2: Cumulative volume distributions Q_3 of powder particles, using ACLR atomization based processes (preheating temperature = 40 °C), as well as of an industrially produced reference powder.

In Fig. 3, overview images of the industrially produced reference powder (left) and of the powder produced in the pilot scale process with ACLR atomizer (right) are shown. Regarding particle morphology, no significant differences between the powder samples were observed. Although, in the reference powder more wrinkled and irregularly shaped particles were found. This fact might be also based on the more progressed drying process, indicated by a lower moisture content.

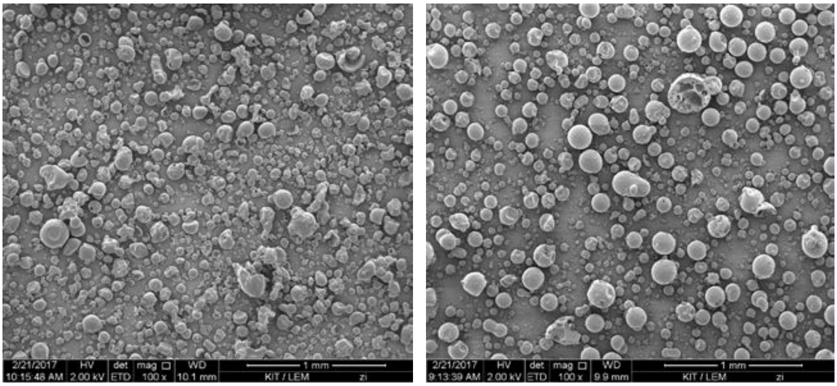

Fig. 3: Scanning electron microscope images of the industrially produced reference powder (left) and of the powder produced in the pilot scale process with ACLR atomizer (right)[15].

4. Conclusions and Outlook

In the presented study, the potential for use of an ACLR atomizer in pilot scale spray drying of a high viscous whey protein concentrate was shown. By decreasing the preheating temperature in comparison to the industrial reference process, the concentrate viscosity was increased by 50 % to a value of 0.09 Pa·s. The produced powder showed similar particle size distribution and particle morphology as the industrially produced reference powder. The moisture content was significantly higher (9.1 %) than the reference value (5.4 %). This is based on the comparably short residence time inside the pilot scale dryer. Increasing the dryer height, and therefore the residence time in the drying chamber, to industrial level, should lead to similar moisture contents. Nevertheless, a microbial stable product was produced in the pilot scale process, according to the water activity value of 0.2.

Further research will be performed in order to use the ability of the ACLR atomizer to atomize high viscous concentrates in spray drying processes. Besides the application of lower preheating temperatures this ability could also be used to atomize concentrates with higher initial dry matter contents, compared to currently used pressure swirl nozzles. Hence, the use of the ACLR atomizer offers the opportunity of energy savings and capacity increases in spray drying processes[16].

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