Process intensified spray drying of milk in a counter flow dryer: experimental investigation of evaporation and deposition zones

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Abstract

Conventional spray dryers are known for their high capital costs and low thermal efficiencies. An intensified spray drying technology requires the combination of high inlet temperatures- reduces required volumetric flow rates of air- and reduced droplet/particle residence times to avoid product degradation. Radial Multizone dryer (RMD) [1]–[3] offers a promising solution in two step drying process. In the first step, droplets are sprayed in the radially central region of the chamber wherein air temperatures of 350-400 °C can be employed due to the very short droplet/particle residence time (order of milliseconds), and the produced particles, under the action of the strong centrifugal forces, are rapidly evacuated to the rotating peripheral zone of the VC where mild air temperature (≈100 °C) is utilized for cooling and after drying of particles and hence, product quality is maintained. In addition, the high-G operation in the periphery of vortex chamber(s) further intensifies the heat, mass and momentum transfer between the particles [4] together with efficient particle separation [5], [6]. This way, two drying zones are established: an initial fast drying zone and a final slow drying zone.

In this research, an experimental setup has been designed to study the fast drying zone i.e. the interaction of droplets and counter flowing hot air. Therefore, only hot air injection is considered without including the effects of cold vortex zone. The designed setup is based on the dimensions of earlier multi-zone vortex chamber studies [7], [8] and is modular, such that vortex chamber(s) can be added at a later stage at the desired location(s). The focus of this experimental study is to investigate the evaporation zones and areas prone to milk sticking and deposition.

In this paper, we are presenting results of water and skim milk sprays using hollow cone pressure nozzles. Influence of various process conditions such as air temperature (280-380 °C), air flow rate (300-500 kg/h), feed flow rate (15-30 kg/h) and initial droplet size are investigated. The experiments are run in three phases: i) dry tests ii) water tests and iii) milk tests. The analysis of the experiments was carried out using a total of 15 thermocouples - radial and axial locations- inside the dryer and 4 thermocouples at the inlets and outlets of the dryer. The temperature measurements provides data on the symmetry of the spray pattern and the evaporation zones in the dryer. Further, the powder collected in the cyclone and wall deposition were analyzed. Finally, an important aspect of the experiments was to see the possibility of spray drying of sticky feeds such that, nozzle is not clogged by the counter flowing hot air.

The experimental results showed that atomization plays a key role. At low atomization pressures, droplets were instantly deflected to the gas outlets whereas at higher pressures, due to higher injection velocities, droplets impinged the hot air inlet. Milk tests were conducted using optimum process conditions from the water tests. The results show that it is possible to

obtain an efficient hot air and spray contact without the risks of nozzle clogging. The droplet size, spray angle and the balance between feed rate and hot air were found to be the key parameters controlling the first step of drying process in RMD.

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References

[1] A. de Broqueville, J. De Wilde, and T. Tourneur, "DEVICE FOR TREATING PARTICLES IN A ROTATING FLUIDIZED BED," WO/2018/203745, 2018.

[2] T. Tourneur, A. De Broqueville, A. Sweere, A. Poortinga, A. Wemmers, U. Jamil Ur Rahman, A. Pozarlik, and J. De Wilde, "Experimental and numerical study of a radial multi-zone vortex chamber spray dryer," in *12th European Congress of Chemical Engineering*, 2019.

[3] U. J. U. Rahman, A. K. Pozarlik, I. Baiazitov, T. Tourneur, A. De Broqueville, J. De Wilde, and G. Brem, "STATIONARY AND TRANSIENT ASPECTS OF AIR FLOW IN A NOVEL RADIAL MULTI-ZONE DRYER," in *Euro Drying*, 2019.

[4] A. de Broqueville and J. De Wilde, "Numerical investigation of gas-solid heat transfer in rotating fluidized beds in a static geometry," *Chem. Eng. Sci.*, vol. 64, no. 6, pp. 1232–1248, 2009, doi: 10.1016/j.ces.2008.11.009.

[5] J. M. Weber, R. C. Stehle, R. W. Breault, and J. De Wilde, "Experimental study of the application of rotating fluidized beds to particle separation," *Powder Technol.*, vol. 316, pp. 123–130, 2017, doi: 10.1016/j.powtec.2016.12.076.

[6] J. De Wilde, G. Richards, and S. Benyahia, "Qualitative numerical study of simultaneous high-G-intensified gas–solids contact, separation and segregation in a bi-disperse rotating fluidized bed in a vortex chamber," *Adv. Powder Technol.*, vol. 27, no. 4, pp. 1453–1463, 2016, doi: 10.1016/j.apt.2016.05.005.

[7] U. J. U. Rahman, I. Baiazitov, A. K. Pozarlik, and G. Brem, "CFD study of air flow patterns and droplet trajectories in a vortex chamber spray dryer," in *21st International Drying Symposium*, 2018.

[8] T. Tourneur, A. De Broqueville, and J. De Wilde, "Experimental and CFD study of multi-zone vortex chamber spray dryers," in *International Symposium on Chemical Reactor Engineering-ISCRE 25*, 2018, [Online]. Available: www.aidic.it/iscre25.