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Reducing the deposition of fat and protein covered particles with low energy surfaces

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ABSTRACT

Deposition behavior of spray dried full cream milk, skim milk and whey particles were observed in a pilot scale dryer. Particle surface dominated with fats exhibit gradual decrease in deposition fluxes when transition from the initial adhesion to the subsequent cohesion mechanism. Whey protein, however, displayed significant differences in the adhesion and cohesion fluxes. Reduction of particle deposition on low energy chamber wall surface is more significant for the hydrophobic whey particles. Further analysis shows that the reduction in droplet–wall contact energy is larger for the more hydrophobic droplet, delineating weaker adhesion interaction. The results suggest that the hydrophobicity of the depositing particles in an important consideration when using lower chamber wall with lower surface energy. This is in addition to the effect of particle rigidity and deposition strength as reported previously.

1. Introduction

Spray drying is common process used in the dairy industry to process instant powders by the dehydration of individual atomized liquid milk droplets. As particles (or droplets) get transported within the drying chamber, they may come into contact with the chamber wall. A common industrial practice is to use pneumatic wall hammers which aims at dislodging the deposited particles throughout the spray drying process. While this approach minimizes the already deposited particles, there are numerous research efforts focusing on preventing this deposition of particle in the first place.

There are several factors that impact on this particle–wall deposition problem. The dispersion of the particles within the chamber had been identified as one factor affecting the amount of particle coming in contact with the wall. Experimental observations have shown that the reduction of inlet induced swirls improved the stability of the internal flow field and thus reduced the dispersion of the particles onto the internal wall (Kieviet et al., 1997; Oakley and Bahu, 1991; Ozmen and Langrish, 2003; Southwell and Langrish, 2001). Along this line, numerical studies are reported focusing on minimizing the deposition of particles by manipulating the airflow pattern within the drying chamber. The potential in this approach has led to the development of numerical deposition models particularly for incorporation into Computational Fluid Dynamics (CFD) simulations (Jin and Chen, 2010; Harvie et al., 2002).

Another method extensively studied in controlling the rigidity of the particles. Depending on the degree of plasticization of the particle, due to moisture contained or at elevated temperature, the particle may form deposits on the wall (Bhandari and Howes, 2005; Chen et al., 1993; Keshani et al., 2012). The idea is to increase the rigidity of the particles, which inevitably reaches the wall to certain extents, so that the particles will not adhere upon impact. For sugars and food powders, the stickiness of the particle is often associated with the glass transition temperature (Bhandari and Howes, 2005). For dairy particles Ozmen and Langrish (2003), suggested the use of a sticky point temperature. The air inlet and outlet temperatures are two important parameters to control the degree of dryness and the plasticization of the particle (Keshani et al., 2012; Woo et al., 2008a). Incorporation of high molecular weight additives or proteins was also aimed at increasing the rigidity of the particle, thus lowering the stickiness of the particle–wall contact (Bhandari et al., 1997).

As aspect of particle deposition in spray drying which received very little attention is the effect of electrostatics forces on particle adhesion. In spray drying, dry particles may become charged by friction with the walls of the equipment. Charged particles may stay and adhere to the walls of spray dryers by electrostatic forces

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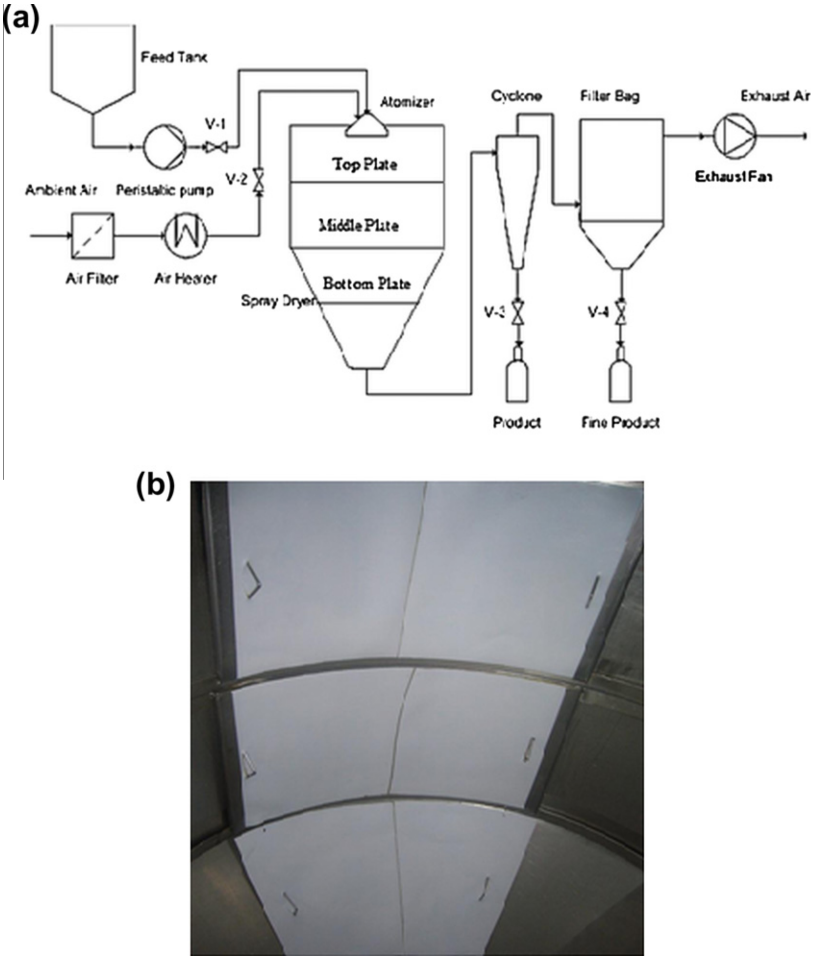

Fig. 1. (a) Schematic diagrams the spray dryer unit and (b) picture showing deposition Teflon plates.

Table 1
Compositional information of the powders.

Powders	Fat (%)	Protein (%)	Lactose (%)	Moisture (%)
Full cream milk	26 [29] (98)	22.8 [31] (0)	42.4 [40] (2)	4
Skim milk	0.8 [1] (18)	34.5 [41] (46)	33.3 [40] (36)	3.5
Whey protein	7.2 [6] (53)	80 [86] (41)	6.1 [8] (6)	4.1

*Values in square brackets [] are the bulk composition while the rounded brackets () are the surface composition of the industrial powder from Kim et al. (2005) and un-bracketed are representing the actual composition.

Table 2
Properties of the Teflon and stainless steel plates.

Properties	Stainless steel	Teflon
[a]Surface energy (m N m^{-1})	40.1	23.6
[b]Average roughness, Ra (nm)	77.89	35.849
[c]Specific heat capacity (J °C kg^{-1})	0.04	1.04
Dielectric property	Conductor	Dielectric

[a] Taken from Michalski et al. (1999).
[b] Measured using Atomic force microscopy (AFM) with an Agilent 5500 PicoPlus microscope (Agilent Technologies Inc., Santa Clara, USA).
[c] Estimated from Bejan and Kraus (2003).

(Ozmen and Langrish, 2003). Chen et al. (1993) found that electrostatic or van der Waals forces maybe partly responsible for wall deposition of milk in spray dryers. However at room temperature, fine milk particles adhered to the surface of the ceiling of a spray dryer, suggesting that electrostatic forces might be important. Later work by Chen et al. (1994), found that earthing or charging the plates for a deposition study of milk powders had no effect on the amount of deposit.

Complementing these different methods, another approach was introduced by Bhandari and Howes (2005) focusing on the properties on the chamber wall. The use of low surface energy was found to be useful in reducing the fouling of equipment surfaces processing liquid or soft bulky food materials. It was suggested that the same principle can be applied for particles. The rationale was that amorphous particles in spray drying tend to be rubbery and the particle surface–wall interaction resembles those of bulk liquid food-wall contact. Kota and Langrish (2006) showed that nylon which has lower surface energy exhibited lesser deposition of skim milk particles when compared to stainless steel. Detailed mechanism on such reduction in deposition flux was further experimentally elucidated by Woo et al. (2008a, 2009). It was found that the reduction in deposition was more significant at higher temperatures when the particles become rubbery supporting the initial rationale for this approach. In that previous work, however, the particle tested was mainly carbohydrates (sucrose and maltodextrin).

For carbohydrate particles, it is expected that only the degree of plasticization is involved in determining if a particle sticks or bounce off upon impact with the wall. For dairy products, the particle surface can be encapsulated with fats (full cream milk powder) or proteins (skim milk or whey powder). This is because