Model Stickiness in Spray Drying

The work presented in this thesis concerns wall deposits encountered in spray drying caused by products that exhibit so-called ‘stickiness’. The thesis delves into the understanding of the phenomenon of sticky wall deposits in spray drying and proposes a simple criterion for use in industrial design of spray dryers.

The experimental work centers around a new technique for measuring when, during drying, a particle becomes non-sticky based on a single droplet drying technique used to study drying kinetics. An acoustic levitator is used to dry a levitated droplet in conditions similar to those a droplet would encounter in a spray dryer. The droplet is recorded using a CCD-camera during drying and the subsequent stickiness test. After a user-specified drying time a piston strikes the partially dried particle at a user-specified velocity. After the impact the piston surface is inspected and if the particle was sticky it is seen adhering to the surface, while a clean piston signifies a non-sticky particle. The setup was designed specifically to test the stickiness of a particle produced by drying a droplet of the desired feed - something unlike methods of literature where dry particles have been humified before tests. The setup allowed for parameter variations in the temperature and humidity of the drying air, impact velocity, piston surface and more.

Results of measuring the stickiness of skim milk is reported for varying impact velocity, drying temperature and relative humidity. It is found that normalizing the critical drying time to get non-sticky particles with the initial diameter squared leads to a single value for a given set of parameters, if the initial diameter is in a limited range. The normalized critical drying time was found to increase linearly when increasing the relative humidity of the drying air. Furthermore, the dependency was the same independently of temperature. The drying time appeared to decrease linearly with increasing temperature, although with a smaller dependence. Measurements with increasing impact velocity showed that the required drying time increased linearly. This finding is opposite of what is typically reported in literature and it is an important part of the hypothesis for stickiness developed here. Finally, measurements with maltodextrin (with dextrose equivalent of 18) are reported for varying relative humidity and impact velocity and the same trends were shown as those found for skim milk.

Replacing the CCD-camera with a high-speed camera allows a user to produce videos of the impact of a sticky particle with a wall in a very high temporal resolution. This was done for skim milk powder for varying impact velocity, humidity and piston surface material. The results were mostly qualitative, with a little quantitative analysis where possible. The first observation was that there was very little dierence between a particle that just adhered (sticky) and one that just bounced (non-sticky). Both were forced to make some contact with the piston upon impact, deformed only slightly and then typically moved slightly away before either stopping with contact (sticky) or bouncing with no contact (non-sticky). Sticky particles had a large apparent contact angle, similar to what would be expected for a liquid with poor wetting properties. The velocity did not seem to change this much, although slight deformation was seen when the impact velocity was at the highest used values. The phenomenon did not appear to change noticeable when the droplet was dried in a high relative humidity environment. The qualitative difference observable between Teon and stainless steel was very limited. On Stainless steel the droplet seemed to wet slightly more after the initial impact while the contact area was constant for Teon. Modelling work was carried out to help understand the phenomenon, but also to investigate how the impact scaled for particle size. This was done using the Level Set Method implemented in the Finite Element based COMSOL Microwindics software. Using two level functions allowed for the denition of density and viscosity functions which were different throughout the particle and different from the surrounding air. This was used to model an in homogeneous droplet which consisted of a skin with high viscosity and a core with lower viscosity. The surrounding air had an even lower viscosity and a lower density. The droplet was modelled without elastic properties. The simulations were initiated with the condition that the droplet was moving towards the wall with a predened velocity. The simulation was run while individually varying initial droplet velocity, viscosity of skin, core and air, density of droplet and air, surface tension, droplet radius and the radius of the core relative to the droplet. A parameter analogous to the radius of the contact area was dened and the dependency of this parameter upon the ones listed above was mapped. The radius of spreading, normalized with the droplet radius, correlated with the square root of the Reynolds’ number (based on material properties of the skin) multiplied with the volume of the droplet divided by the volume of the skin. A simple analytical model was used to show that this dependence on the Reynolds’ number could be a result of viscous dissipation of kinetic energy in a zone near the movement of the triple line. The observations made in the experimental and modelling sections were combined to propose a simple criterion for use in conjunction with other tools for design or possible control of spray dryers. A single droplet drying technique is to be used to obtain a characteristic drying curve for the product of interest. The linear dependencies found is then used to reduce the necessary number of stickiness measurements to as little as three (although more measurements increase accuracy). These data are then used to produce a simple criterion which gives a critical residual moisture content under which a particle must be for it to be non-sticky as depending on the relative humidity in which it is dried, the initial radius of the droplet and the velocity with which it impacts the wall.

Finally, the hypothesis for stickiness that this work leads to is summarized as follows. Asa droplet is dried it forms a region near the surface in which the solvent concentration decreases and the viscosity increases. As it impacts a wall in the spray dryer it does sowith some kinetic energy. The kinetic energy forces the wet particle to deform and wet the surface, while energy is dissipated in the viscous ow. If the viscosity in the surface region is high enough and the region is large enough energy is dissipated with very little movement which means the contact area is small. A small contact area means a low energy of adhesion and the particle is easily removed by other ects. If the energy is not dissipated rapidly enough however a larger contact area is established and the particle will adhere strongly. This hypothesis suggests that the surface properties of the sticky particle are not the only effects that matter and therefore that measuringrehumied particles is not the same as dried droplets. Furthermore it has the important dierence from the established hypothesis that the contact is forced and not spontaneous.