What happens when droplets in a spray collide?

Spray drying is used in many process industries to produce powders from suspensions. The suspension is atomized (sprayed) in fine droplets that are dried in a hot air stream. The process involves complex interactions between drying air (gas), droplets (liquid), and solid or partially solidified particles. The quality of the final product depends on the way particles come together and break up during spray drying. I used experiments and modeling to learn more about these collision dynamics of droplets inside a spray dryer. My results improve the understanding, prediction and modeling of droplet dynamics and can help optimize powder quality.

Current theoretical models that describe the outcome of droplet collisions do not consider viscous dissipation – the fact that the speed of the droplets decreases – mostly because they look at water droplets where the viscous forces are not that relevant. I did add viscous dissipation energy in collisions to my model and studied droplets with different sizes and different physical properties. From these simulations, I propose a new general droplet collision model.

To extend the model and to detect all collision possibilities, I also did physical experiments. I forced two droplet streams to collide and recorded individual collisions with high-speed cameras. Through image analysis, I looked at the droplet positions, velocity, and shape after impact. I analyzed and compared collisions of glycerol-water mixtures and of milk solutions at three different concentrations. The resulting model is useful to improve the production of milk powder.

I also studied droplet-droplet collisions of xanthan solution to get insights into the collision dynamics of complex liquids. Unlike glycerol and milk, xanthan collisions hold together because of increased viscous energy dissipation.

I used the outcomes from my experiments to adapt the existing Direct Simulation Monte Carlo (DSMC) model of spray drying. I improved the treatment of the gas phase and liquid phase. I also introduced turbulence into the model to account for the turbulence that happens because of the high spraying velocity.

Another process that affects the evaporation of moisture from the spray, and therefore the final powder properties, is how much heat and mass is exchanged between the particles in suspension and the liquid they are suspended in. I updated the model to include these processes as well. Most heat and mass exchange occurs near the spray atomizer, because speeds are high there and the droplets are at their smallest because they have not collided with other droplets yet.

Until now, nobody had published a full characterization of the size and velocity distributions of drops inside a spray of viscous liquids. That is why I also performed experiments on a spray with liquids at different viscosity, measuring the size and velocity of droplets with a non-intrusive optical laser method that does not disturb the flow. The viscosity of the liquid had a strong influence on the size and velocity of the droplets, but not as much as the operating conditions of the sprayer. My detailed analysis of the optical system is a significant improvement and provides guidelines for future studies.
Title of PhD-thesis: Droplet collision dynamics in a spray dryer- Experiments and simulations.
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