Popular Science Summary

How Computers and Experiments Help Us Understand Spray Drying

What is spray drying and why is it important?

Have you ever wondered how instant coffee, powdered milk, or certain medicines are made? Many of these products start as liquid and end up as a fine powder. The process that makes this possible is called spray drying.

Imagine a tall glass cylinder where hot air blows downward while a liquid is sprayed in as tiny droplets. As the droplets fall, the water evaporates, leaving behind dry particles that are collected as powder. This is exactly how a spray dryer works. The Büchi B-290, the machine used in this project, is a small-scale version commonly found in research laboratories.

Spray drying is widely used in the food and pharmaceutical industries because it is fast, gentle on heat-sensitive ingredients, and can produce high-quality powders. However, one common problem is that some particles stick to the walls of the drying chamber instead of being collected. This reduces the amount of powder produced and can also cause the stuck particles to overheat and lose their quality.

Our approach: combining computer simulations with real experiments

To better understand why particles stick to the walls and how to prevent them, we used two complementary methods: computer simulations and laboratory experiments.

Computer simulations allow us to see inside the spray dryer in ways that are impossible with the naked eye. Using a software called ANSYS Fluent, we created a virtual model of the Büchi B-290. We then injected virtual particles (representing the liquid droplets) and tracked their movement, their speed, their temperature, and whether they escaped or stuck to the walls. The model was simplified into two dimensions (like a cross-section) to make the calculations faster while still capturing essential physics.

Laboratory experiments were conducted using a real Büchi B-290 spray dryer. We prepared a special solution containing glycerol (a common substance that prevents drying), trehalose dihydrate (a common excipient and stabilizer used in formulation development), and a colorant (to see where particles deposit). The solution was sprayed under controlled conditions while we varied the air flow rate and other parameters. After each experiment, we washed four different zones of the dryer (right wall, left wall, outlet tube, and conical section) and measured how much colorant had deposited in each zone using a spectrophotometer, a device that measures light absorption.

What did we discover?

Our experiments showed that the right wall of the drying chamber consistently captured most particles (up to 11% of the total colorant at the lowest air flow setting). When we reduced the air

flow rate, more particles stuck to the walls because they spent more time inside the chamber before being carried out. The total amount of particles stuck increased from about 11% at high air flow to about 20% at low air flow.
The computer simulations gave us even more detailed information. They revealed a fascinating pattern: particles that escape the chamber do so very quickly, within about 0.001 seconds, while particles that get stuck can recirculate inside the chamber for up to 0.08 seconds before finally depositing on a wall. This means that some particles travel in circles inside the dryer, passing through hot zones multiple times, before they eventually stick.
We also studied how particle size affects where they stick. When we simulated particles of different sizes (from 1 to 6 micrometers, which is about 50 to 100 times smaller than the diameter of a human's hair), we found a critical transition at 5 micrometers. Smaller particles tended to stick in the outlet tube, while larger particles penetrated deeper into the conical section before sticking. This is because larger particles have more inertia and are harder for the air flow to redirect.
The temperature analysis of 10,000 simulated particles showed that escaped particles warmed up only slightly (by about 9 degrees Kelvin), while some trapped particles heated up dramatically, reaching temperatures up to 87.2 degrees Kelvin above room temperature. This is important because excessive heat can damage heat-sensitive ingredients in food and medicine.

How do our simulations compare to reality?
We compared our simplified computer model with a much more detailed simulation from the scientific literature by Pralits and colleagues. Their model was three-dimensional and unsteady (meaning it captured the chaotic nature of turbulent flow), while ours was two-dimensional and steady (assuming the flow pattern doesn't change over time). Despite these simplifications, our model correctly identified the same main deposition zones: the right walls and the outlet tube. This gives us confidence that even simplified models can be useful for understanding spray drying, especially when computational resources are limited.

Why does this matter?
This research helps us understand why some particles stick to the walls of spray dryers and how to prevent it. By identifying the critical particle size of 5 micrometers, we can adjust the atomization process to produce particles either smaller or larger than this threshold, depending on where we want them to go. By understanding the relationship between air flow rate and particle deposition, we can optimize operating conditions to maximize product collection while minimizing overheating. By recognizing that particles that recirculate for longer periods heat up more, we can design drying chambers that minimize recirculation zones.

What's next?
This project opens several avenues for future research. A full three-dimensional model would capture the complex flow patterns more accurately. Including an evaporation model would make

the simulations more realistic by accounting for cooling as the droplets dry. Testing the critical particle size of 5 micrometers with different materials would confirm whether this threshold is universal or specific to our solution.

In summary, this project showed that combining computer simulations with laboratory experiments is a powerful way to understand and optimize spray drying. The insights gained can help manufacturers produce better quality powders with less waste, whether they are making instant coffee, powdered milk, or life-saving medicines.