One problem facing many processors today is accurately predicting how a major structural modification will affect a process machine’s performance. With the cost of high-speed computers dropping and software becoming more powerful, it’s more practical and cost-effective than ever to use computer modeling to solve such complex industrial problems. Using the example of a spray dryer that will be modified to produce an improved powder, this two-part article describes how you can use computational fluid dynamics modeling to predict the performance of modified equipment before you make hardware changes. This and similar computer modeling methods can be applied to predicting the performance of various bulk solids processing equipment. Part II will appear in the October issue.

Modifying your equipment to improve a final product’s quality or to handle a new product involves some risk. Downtime for the equipment changeover can eat up your profits, not only because of the days or weeks required to modify and install the equipment, but because field-testing the new configuration takes time too. Your profits can drop even more if the performance improvements you expect don’t materialize and you end up going back to your original equipment configuration or making further modifications.

You can minimize this risk and avoid unnecessary downtime by modeling the modified equipment’s performance with the aid of a computer. The modeling results can help you determine which equipment configuration and process settings will deliver the performance improvement you need and give you confidence that the proposed modification will work before you order capital equipment and schedule field tests in your plant.

How one form of computer modeling — computational fluid dynamics (CFD) — can be used to predict equipment performance is described in the following information, which outlines a recent application in a food processing plant.

Food processor wants to improve product

A food processor uses single-pass spray drying in several plants to make powders, including free-flowing, dust-free agglomerated milk-based powders (called instantized or instant powders) that will dissolve readily in water. In the spray-drying process, two feeds enter the dryer: a liquid feed, consisting of solids dissolved in a liquid, and dry fines returned from downstream cyclones. After the liquid feed is atomized by one (or more) spray nozzle into droplets that spray downward into the dryer, the droplets contact the returned fines (which enter in a stream at the dryer’s top), forming agglomerates. These are dried to the powder’s final moisture specification.

But spray drying milk products can be challenging. A common problem is that the high air temperatures in the spray dryer, as shown in Figure 1, can reduce the powder’s quality. The air temperature at the dryer chamber’s center...
core below the hot air inlet is particularly high, while the air temperature outside this core is much lower. To obtain high-quality powders, the food producer must agglomerate the milk powder in this cooler zone as well as control the process to provide the right combination of particle concentration, temperature, and moisture.

Recently the food producer decided to produce an improved version of an agglomerated, milk-based instant drink powder in one of its plants. As with all of its milk powders, the producer wanted to carefully control the process to obtain a high-quality product. But instead of buying a new spray dryer, the producer proposed modifying an existing spray dryer at the plant to handle the improved powder.

*Some background.* Two basic types of single-pass spray dryers are available — tall form and wide body — and both are used in the food producer’s plants. A tall-form dryer, as shown in Figure 2a, has a tall, narrow drying chamber and an axial air inlet at its top. The axial air inlet consists of a plenum chamber or circular inlet scroll and an air disperser with several holes in it. The hot air flows from the plenum or scroll through the air disperser’s holes into the dryer chamber in an axial pattern (that is, the air flows straight down the narrow chamber), as shown in Figure 2b.
A wide-body spray dryer has a shorter, wider vessel and a swirl air inlet at the dryer's top that consists of a circular inlet scroll with a swirl air disperser, as shown in Figures 3a and 3b. The swirl air disperser, which is conical and mounted with several rows of vanes, rotates the hot air as it passes through the disperser's vanes. As shown in Figure 4, this induces a helical or swirling, rather than axial, airflow pattern that creates a larger, cooler evaporation zone in the dryer chamber. In a tall-form vessel, such swirling airflow might cause moist powder to stick to the chamber walls, a problem called chamber fouling. But the wide-body dryer's wider chamber allows the powder to dry before it reaches the walls, making it ideal for an agglomerated powder. In the wide-body dryer, all the particles exit the bottom outlet with the airflow; fine particles are separated from the air by downstream cyclones and returned to the dryer.

Challenges in modifying the existing dryer. The food processor's experience with both dryer types in its plants demonstrated that the wide-body spray dryer's swirling airflow pattern not only didn't cause chamber fouling, but created a cooler evaporation zone that made it easier to adjust operating parameters when fine-tuning the powder quality. The producer knew these capabilities would be especially useful in producing the improved milk powder.

A spray-drying process — like any high-volume continuous process — has to run at capacity and without interruption for as long as possible between cleanings to control cost and maximize efficiency.

However, the existing dryer that the producer wanted to modify was a tall-form type. It was several stories high and represented an enormous capital investment. Rather than replace it with a wide-body model — which not only would have a high capital cost but entail extended down-
time for removing the old dryer and installing the new one — the food producer wanted to modify the tall-form dryer to include some wide-body dryer features.

In particular, the food producer wanted to replace the existing dryer’s axial air inlet with a swirl air inlet. The dryer, which currently produced nonagglomerated powders, already had a circular inlet scroll. By adding the swirl air disperser, the producer expected to produce a hybrid dryer that would have a tall-form chamber and a combination axial-swirling airflow pattern that would permit greater adjustments to the agglomeration process and produce the higher-quality milk powder. But would a swirling airflow pattern in the existing dryer’s narrow chamber result in chamber fouling? How could the dryer be modified or operated to prevent this problem? And would the planned modifications produce the expected product improvement?

**Downtime concerns.** Even with modifying rather than replacing the tall-form dryer, the food producer knew the spray-drying operation would be down for a few weeks. Minimizing this downtime was another major concern.

A spray-drying process — like any high-volume continuous process — has to run at capacity and without interruption for as long as possible between cleanings to control cost and maximize efficiency. Not only is the process not profitable when the dryer is shut down, but starting the dryer up again uses raw materials and energy without producing any salable product until heat and airflow in the dryer stabilize.

The CFD engineer needed the process engineers’ practical knowledge of the spray-drying process throughout the project to develop accurate models.³ So at the start of what would become a close working partnership, the food producer’s process engineers met with the CFD engineer to explain several spray-drying and agglomeration details and describe results of some preliminary dryer testing.

To validate the baseline models, the process engineers compared the CFD modeling results with the actual dryers in as many ways as possible.

The process engineers explained that in any agglomeration process, dry returned fines must be combined with the atomized liquid feed. In the food producer’s application, the dryer’s high temperatures must also be prevented from degrading the agglomerated powder — specifically, by denaturing its milk protein. To achieve these goals, the modified dryer must maintain the proper combination of particle concentration, particle temperature, and particle moisture content. In fact, the process engineers had tested the improved milk powder in the existing tall-form dryer and in a wide-body dryer at another plant. In the tall-form dryer, the agglomeration process worked well but produced a final powder with excessive protein denaturation, while the wide-body unit produced excellent agglomerated powder with no protein defects. Now they needed to investigate the dryers’ operating differences, focusing on airflow patterns, temperature, and humidity, before they could determine how to modify the tall-form dryer to produce the improved milk powder.

Choosing CFD modeling

To address these performance and downtime concerns before going ahead with the dryer modification, and since no pilot- or production-scale hybrid dryer existed for testing, the food producer contracted an engineering consulting service to model the proposed dryer modifications with CFD. The computer modeling would allow the producer to see how various modifications would affect the dryer’s performance and agglomeration process and whether the changes would produce the improved milk powder.

For the spray dryer application, the consulting service’s CFD engineer used a high-speed UNIX computer workstation and commercially available CFD modeling software called FLUENT.¹ The software solves fundamental fluid mechanics equations, called the Navier-Stokes partial differential equations, for a particular process. [Editor’s note: A detailed description of CFD theory is beyond this article’s scope; for more information, see endnote 2.]

**Establishing the modeling goals**

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body spray-drying processes, and 2) to help determine what modifications the tall-form dryer would require and how to control the modified dryer's operating parameters.

**Modeling the baseline processes**

Creating baseline models of the food producer's existing tall-form and wide-body spray-drying processes, which had known operating parameters and process variations, allowed the team to calibrate the models and see how the modeling outputs compared with physical effects in the actual dryers. Providing such insight was important because current CFD technology can't determine if the dryer's atomized liquid feed mixes with the returned fines and agglomerates into larger particles, nor can it determine whether a particle with a given temperature, mass, and moisture content will stick to the wall and cause chamber fouling. These modeling limitations weren't serious obstacles to the team because the process engineers' spray-drying expertise enabled them to make conclusions about agglomeration and chamber fouling based on what the models did tell them about airflow pattern, particle concentration, particle temperature, and particle moisture content during drying. Only CFD modeling could provide this data for them.

To validate the baseline models, the process engineers compared the CFD modeling results with the actual dryers in as many ways as possible. For instance, they compared the mass flowrates for the air and particles, particle concentrations, air and particle temperatures, humidity levels, and pressure drops in the models and the actual dryers. This demonstrates CFD's ability to "look inside" enclosed process vessels like spray dryers and see what's going on. While installing instruments on the dryers to measure all of these variables would have been impractical, some instruments were installed at inlets and outlets to measure actual conditions. These allowed the team to input the same inlet conditions in each CFD model and actual dryer and compare the outlet conditions in both to see whether the model was able to correctly predict the outlet conditions, thus validating the model.

**Endnotes**

1. FLUENT CFD software, FLUENT Inc., Lebanon, N.H. CFD software has also been developed by others for proprietary, academic, and special-purpose applications.


3. Be aware that with complex equipment such as a spray dryer, CFD modeling results shouldn't be the only basis for your decision to modify the equipment. In the food producer's case, CFD modeling was applied because strong evidence suggested that this form of computer modeling could help the producer's process engineers make more informed decisions and avoid costly mistakes and prolonged field trials. When combined with the process engineers' practical knowledge of the spray-drying process, the CFD modeling results helped predict the proposed modification's impact on dryer performance.

**For further reading**

Find more information on equipment design in articles listed under "System or equipment design, fabrication" and "Software tools" in *Powder and Bulk Engineering's* comprehensive "Index to articles" (in the December 2000 issue and at www.powderbulk.com).

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**Next month:** Part II describes how the spray dryer modifications were modeled and field-tested, then explains how to apply computer modeling in modifying your own equipment.