An introduction to steam-atmosphere drying

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Steam-atmosphere drying is much more efficient than the most common drying technique, convection drying. But is it right for your application? Information here explains how steam-atmosphere drying works, outlines the method's benefits and limitations, and details how to determine if this drying technique is right for your product.

Steam-atmosphere drying recirculates rather than vents the exhaust stream and provides free heat for other processes in your plant, making the method significantly more efficient than convection drying. It offers other advantages over convection drying, too, including providing better control of particulate emissions and odors and providing an inert drying atmosphere that eliminates fire and explosion risks.

Several products are suitable for steam-atmosphere drying, including organic waste, such as spent grains; flour and other food products; tobacco; wood chips; and many organic and inorganic chemicals. Determining whether steam-atmosphere drying is right for your product requires an understanding of how this drying method differs from convection drying and how this can affect your product's characteristics.

Comparing convection and steam-atmosphere drying

The essential difference between convection drying and steam-atmosphere drying is that convection drying *vents* the exhaust stream (called *open-circuit* operation), while steam-atmosphere drying *recycles* it (*closed-circuit* operation).

Convection drying. In a convection dryer, heated air flows through the dryer, contacting the wet feed. The water from the feed evaporates into the air, which cools the air while increasing its humidity. After the dried product — often a powder — is separated from the air, the moist air is exhausted to the atmosphere along with some of the energy used during drying.

The convection dryer's efficiency can be improved by recycling some of the moist exhaust air — together with its energy (in the form of waste heat) — back to the dryer inlet. Recycling the exhaust air increases the humidity in the dryer. This, in turn, requires a higher operating temperature and results in a higher final product temperature than in a completely open-circuit convection-drying operation.

Some of the convection dryer's waste heat can be recovered by passing the hot exhaust air through a heat-recovery system to warm the dryer's fresh makeup air. This can be an indirect system, such as an air-to-air heat exchanger or a coil system with two recirculating-fluid-filled coils that transfer heat to the makeup air passing between them. Or the heat-recovery system can be a direct system, in which the makeup air is passed through a scrubber system that sprays it with hot water condensed from the dryer's recirculated exhaust air. This water runs very close to the exhaust air's saturation temperature (the dew point), frequently in the range of 130°F to 150°F (55°C to 65°C). However, this temperature is limited by the amount of air present in the dryer exhaust: the more air in the exhaust, the lower the saturation temperature.

Steam-atmosphere drying. Steam-atmosphere drying takes waste-heat recovery to another level, increasing the temperature of the heat recovered from the dryer's exhaust by reducing the amount of air (more correctly, the quantity of *noncondensible gases*) in it. To achieve this, heat must be transferred to the dryer indirectly, using a fired heat exchanger, rather than directly, such as by using a burner that directly heats the air. Indirect heat transfer allows the recirculated exhaust stream to be reheated without introducing any more noncondensible gases. Tightly sealing the dryer circuit to prevent leaks into or out of the dryer and operating the dryer at a slightly positive pressure allows the dryer to purge the air atmosphere (that is, the *primary air* that originally fills the dryer) with evaporated vapor (typically water) to form an atmosphere of superheated vapor, or *superheated steam*. Now you have a steam-atmosphere dryer, in which all the vapor formed during evaporation from the feed is vented as steam. As with a conventional boiler, the temperature of this vapor — and, hence, the heat recovery — depends solely on the dryer's operating pressure.

As a result, the steam-atmosphere dryer has a higher operating temperature and a higher product temperature than a typical convection dryer. For drying most food products, for example, the operating temperature in a convection dryer typically ranges from about 180°F to 250°F (80°C to 120°C) and in a steam-atmosphere dryer ranges from about 250°F to 300°F (120°C to 150°C). A typical steam-atmosphere drying system is shown in Figure 1.

Applications for steam-atmosphere drying

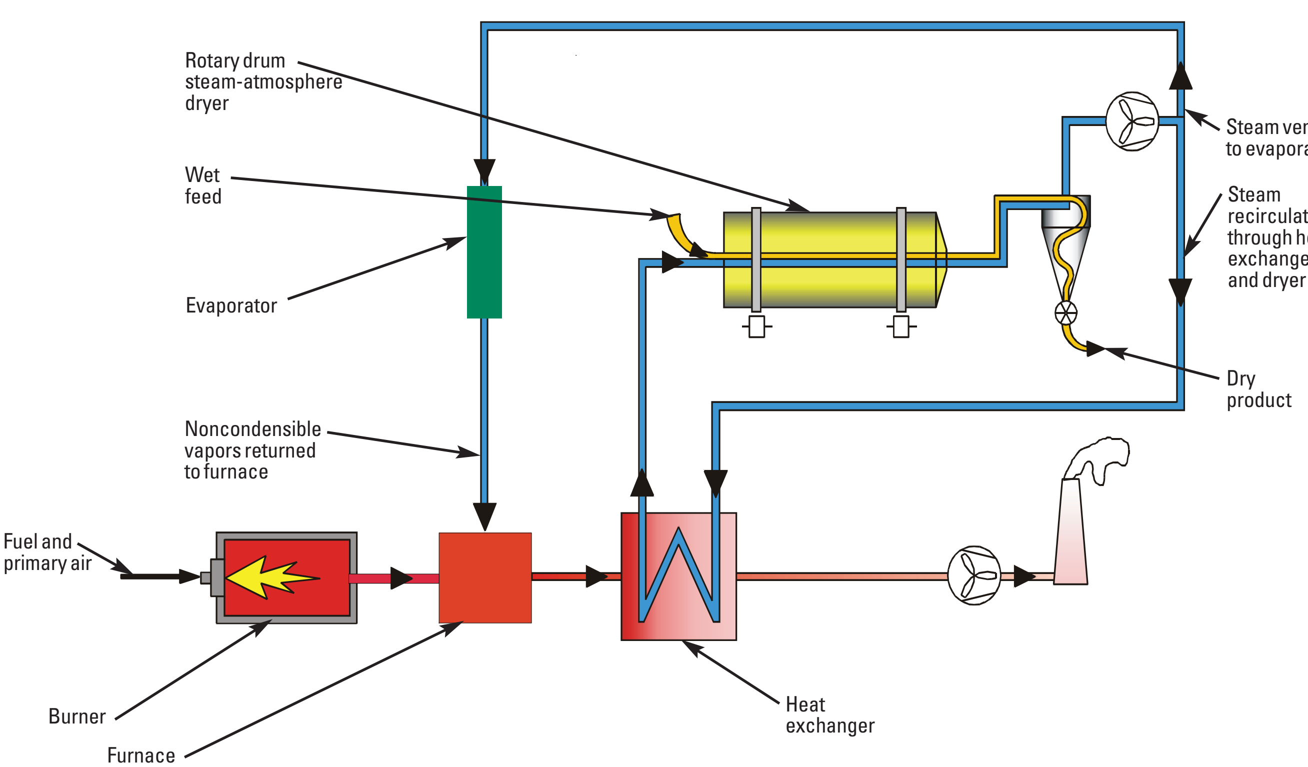
A steam-atmosphere dryer is suitable for applications in which the plant has a secondary use for the steam produced by the dryer. Evaporators such as those used in ethanol plants and corn wet-milling plants are a common example of equipment that can use waste steam from this dryer.

The steam-atmosphere dryer is also suitable for drying products that benefit from the conditions provided by the unit's superheated-steam atmosphere. For instance, this atmosphere allows the dryer to process organic waste materials without producing offensive odors. Depending on the waste material's composition, the dried waste may also have a secondary use, converting the waste into a usable by-product. The dryer can reduce the residual bioactivity levels of some organic materials, extending their storage life.

The dryer can also process many organic and inorganic chemicals as long as they can't be damaged by the dryer's higher operating temperatures.

Figure 1

Closed-circuit steam-atmosphere drying system



Courtesy SWISS COMBI, Dintikon, Switzerland.

Dryer configurations

Several equipment manufacturers have adapted common dryer configurations for steam-atmosphere drying to take advantage of their benefits for particular applications.

Rotary drum dryer. In a rotary drum steam-atmosphere dryer, steam and wet feed flow through a rotating drum. Rotary drum dryer applications include processing distillers spent grain from ethanol production, corn wet-milling by-products, wood chips, alfalfa grass, and slaughterhouse (abattoir) by-products.

Flash dryer. A flash steam-atmosphere dryer is essentially a pneumatic conveying dryer in which the conveying medium is steam. Applications include drying biomass fuel, wood chips, corn wet-milling by-products, flour, and tobacco.

Deep-bed (or mass-flow) dryer. This specialized steam-atmosphere dryer consists of a vertical cylindrical housing containing several wedge-shaped compartments that are filled with wet feed and revolve around a center axis. Steam flows upward through the compartments to dry the feed. The deep-bed steam-atmosphere dryer is used in sugar mills, where it dries sugar cane fiber (bagasse) after sugar removal.

Others. Other dryers have recently been configured for steam-atmosphere drying in various applications. These include a spray dryer (in which an atomized wet feed is sprayed into steam flowing through a tower-like chamber), spin-flash dryer (a compact version of a flash dryer, but with a rotor at the dryer center that agitates the wet feed and forces it to contact the steam), and fluid-bed dryer (in which the steam flows upward through a bed of wet feed).

Weighing the pros and cons

Pros. Steam-atmosphere drying provides the following benefits when compared with convection drying.

Efficiency: The steam-atmosphere dryer is roughly 15 percent more efficient than an open-circuit convection dryer operating over the same temperature range. This is because the steam-atmosphere dryer completely recirculates the exhaust vapors, at the dryer's outlet temperature, back to the heat exchanger inlet. In an open-circuit convection dryer, these exhaust vapors are vented out the plant exhaust stack along with the inlet air and are lost to the atmosphere.

Secondary steam use: The steam resulting from water evaporation in the steam-atmosphere dryer can provide free heat — via *condensing heat recovery* — for secondary processes. The most common example is using the steam to heat an evaporator, which normally uses steam produced by a boiler. Reusing the dryer's steam this way allows twice the use of the dryer's original energy input. By using a multiple-effect evaporator, it's possible to use this recovered energy two or even three times, providing additional savings. The steam's heat energy can also be recycled by other condensing heat-recovery methods.

Emissions control: When a condensing heat-recovery system is used to recover heat from the steam-atmosphere dryer's exhaust, the dryer's particle emissions collect in the heat-recovery system instead of venting to the atmosphere. In a carefully designed condensing heat-recovery system, these particles will be flushed out with the condensate to the system's wastewater control system. This leaves only the noncondensible vapors. If these vapors are returned to the heat exchanger's furnace, they can be oxidized and any organic content in them can be converted to heat for the drying process, reducing the dryer's fossil fuel use. For instance, in the case of a steam-atmosphere dryer that processes distillers spent grain in an ethanol plant, returning the noncondensible vapors to the heat exchanger's furnace helps reduce the dryer's fuel consumption by 2 to 3 percent.

Inerting: Since the air has been purged from a steam-atmosphere dryer, the steam forms an inert atmosphere. This means that the dryer can't catch fire or explode during normal operating conditions. However, during dryer startup and shutdown, fire and explosion risks still affect the dryer, so it must be carefully operated during these phases and during any upset conditions.

Heat treating: The steam-atmosphere dryer's major heat-transfer mechanism is localized steam condensation on each moist particle's surface. This mechanism results in rapid heat transfer and surface heating of each particle to the steam's saturation temperature. In some cases this "heat treatment" is an advantage: For instance, when a steam-atmosphere dryer processes digester sludge, the heat treatment sterilizes the sludge, producing material with less residual odor. Drying soy fiber (also called *okara*) in a steam-atmosphere dryer produces dried material with low residual bioactivity, which gives it a longer storage life. In some applications, the dryer's heat treatment may even eliminate a unit operation preceding the dryer, such as a boiling step in a vegetable processing line. However, the heat treatment provided by localized steam condensation may be a disadvantage when drying some protein-rich products, such as oatmeal, because the heat will denature some of the protein, reducing the product's nutritive properties and ability to be reconstituted in water.

Steam stripping of hydrocarbons: Another benefit of steam-atmosphere drying is that it provides *steam stripping,* a process that removes volatile hydrocarbon fractions from the product. The hydrocarbons are given off by residual oils in the feed, and steam-atmosphere drying transfers more of the hydrocarbons into the vapor phase than convection drying can. The steam-atmosphere drying system can then recover these hydrocarbons after condensing heat recovery so they can be used in other processes or transferred to the heat exchanger's furnace and burned to reduce the dryer's fuel consumption. In some cases, however, the dryer's hydrocarbon-stripping capability may be a disadvantage. For instance, a processor drying spent grains that will be used in animal feed may prefer to maximize the grains' oil content to boost the product's nutritional value rather than strip its hydrocarbon fractions.

Cons. Leaks and condensation problems are the steam-atmosphere dryer's chief limitations.

Leaks: The higher the dryer's system pressure, the more value the dryer's vented steam will have. In fact, it would be ideal to operate the dryer at a pressure of several bar so the dryer's vent steam could be expanded through a turbine to generate power before the steam was condensed for its heat value. However, increasing the dryer's system pressure also increases its susceptibility to leaks.

Leaks can be a problem whether the dryer is operating above or below atmospheric pressure. A leak in a dryer operating slightly under atmospheric pressure will draw air into the dryer. A symptom of such a leak is a drop in the recovered steam heat's temperature. A leak in a dryer operating above atmospheric pressure will draw steam out of the dryer. When hydrocarbons are present in the feed, the steam leak will produce an obvious mark on the dryer housing caused by the steam and oils condensing in or just outside the dryer's insulation.

Leaks can occur at any of several points in the steam-atmosphere drying system. Leaks are common at the feed inlet to the dryer, making the feed device a critical component of the drying system. For a positive-pressure dryer, some form of plug-flow screw feeder is typically best for preventing leakage. For a negative-pressure dryer, any screw feeder or other feed device that restricts the amount of air ingress will work.

The dryer's product discharge is also prone to leakage. If the dryer uses a rotary valve outlet, the valve should typically have an 8- or 10-vane rotor, which provides better vane-to-housing sealing to minimize air leakage through the valve. A modified or custom-designed discharge valve can also minimize leakage.

The dryer's flange connections to other equipment in the process are also subject to leakage. To avoid this, the dryer should have as few flange connections as possible. The connections should be designed for easy removal, including having machined faces mounted with gaskets and bolts with appropriate tension to handle the dryer's operating temperature and pressure.

Two rotary drum steam-atmosphere dryers (arrows) process distillers spent grain in an ethanol plant. Heat energy from their exhaust is used in evaporators and the noncondensible vapor is recirculated to the furnace to reduce the dryers' fuel consumption.

Leaks can also result from stress or fatigue cracks at weld points between the dryer's stiffening or structural elements and the inner shell. Such cracks tend to develop over time, particularly if the dryer hasn't been properly designed to handle the effects of differential expansion and thermal cycling.

Condensation problems: Poorly insulated areas in the steam-atmosphere dryer system will become cold spots. These cold spots create continuous condensation that will cause moist product to accumulate, and eventually the accumulated product will fall into the process, resulting in off-spec product. This problem can be prevented by ensuring that the dryer is well-insulated, particularly in areas that tend to have less insulation, including dryer and duct support points, flange connections, cleanout ports, access doors, sight glasses, and instrument connections.

How steam-atmosphere drying can affect product properties

The steam-atmosphere dryer may change a product's characteristics, which may or may not be desirable. For one thing, the dryer's inert steam atmosphere reduces or eliminates product oxidation. This may make the dryer unsuitable for drying a product like an iron-oxide pigment, which must be oxidized to turn it a darker color, while it may make the dryer ideal for a product that requires drying at a high temperature without a color change. The dryer's localized steam condensation can also change product properties. It may reduce an organic product's residual odor or another organic product's residual bioactivity, which could increase its shelf life.

In some cases, the steam-atmosphere dryer can change a product's appearance without affecting its desired properties. For instance, distillers spent grains darken after steam-atmosphere drying because of the method's higher operating pressure and temperature. While some processors see this color change as a disadvantage, it apparently has very little effect on the grain's nutritive properties.

Testing to select a steam-atmosphere dryer

Even though steam-atmosphere drying's potential to reduce your dryer operating costs may make a switch from convection to steam-atmosphere drying appealing, you need to determine whether your dried product will have the same — or better — quality after processing in the steam-atmosphere dryer. This requires testing your product under a range of operating conditions in the dryer.

Testing will ensure that drying your product in superheated steam — a completely different environment than the air in a convection dryer — can produce the results you need without any unpleasant surprises. The steam-atmosphere dryer supplier can help you design drying tests that closely duplicate your production drying process's actual operating conditions and then run the tests over a period long enough to ensure that the new dryer can be commissioned without problems. Some suppliers offer a portable steam-atmosphere test dryer that can be installed in your process. Using the portable dryer eliminates the need to take representative feed samples and ship them to the dryer supplier's test facility; the portable dryer can receive truly representative feed directly from your upstream process, improving the accuracy of your test results.

Once the testing is complete, the results will tell you whether steam-atmosphere drying can work with your feed, yield a final product with the characteristics you require, and improve your operating efficiency. **PBE**

For further reading

Find more information on drying methods and equipment in articles listed under "Drying" in *Powder and Bulk Engineering*'s comprehensive article index at www.powderbulk.com and in the December 2007 issue.

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