Many plant operators believe they’re losing material in their continuous convection dryers but don’t know how or why. Material loss can result from a poorly operating gas-material separation device, such as a cyclone or airlock, but the primary cause of material loss during drying is thermal particle damage. This article describes the causes of thermal particle damage in high-capacity, continuous convection dryers and explains how to prevent it.

Ever wonder where the lint comes from in your clothes dryer at home? You put in clean, damp clothes and pull out clean, dry clothes…and lint. Your dryer’s harsh convective heat forces are damaging your clothes every time you dry them. The evidence of that damage is in the lint trap.

Does your plant’s high-volume, continuous convection dryer produce lint? If you suspect that your plant’s dryer is losing material, thermal particle damage is probably the culprit. Thermal particle damage is the partial destruction of a particle’s outer layer, which is driven off in the form of volatile organic compounds (VOCs), fines, or other pollutants. Any material can be thermally damaged at a high enough temperature, but organic materials, such as grains or wood products, are particularly susceptible. Secondary cleanup equipment, such as a baghouse, thermal oxidizer, or scrubber, can remove some or all of these emissions from your dryer’s exhaust stream, but by that time, the damage to your material has already been done.

While thermal particle damage can occur in any type of dryer, it’s a particularly common problem in continuous convection dryers (such as rotary, ring, conveyor, spray, fluid-bed, and others) because of how these dryers operate. Unlike a batch dryer (like your clothes dryer at home), in which the material is manually loaded before the dryer is started and then removed when the material is dry and the dryer is stopped, a continuous dryer operates without interruption. Material is automatically fed into the unit, dried, and discharged in a continuous stream. And unlike in a conduction (or indirect) dryer, in which heat is indirectly transferred through a hot surface to the wet feed material, in a convection (or direct) dryer, heated gas directly contacts and transfers heat to the material, typically exposing it to harsher heat forces than in a conduction dryer. [Editor’s note: For more information about dryer types and how they operate, see the “For further reading” section.]

Costs of thermal particle damage

To illustrate what thermal particle damage in your continuous convection dryer can cost you, let’s consider an example application: drying distiller’s dried grains with solubles (DDGS), a by-product of ethanol production. Assuming that you can sell the DDGS for $200/t, every ton of DDGS that leaves your dryer in the exhaust gas stream rather than in the material stream will cost you $200. If your dryer damages 1,000 tons of DDGS per year,
that’s $200,000. A thousand tons of damaged material per year may seem like a lot, but it’s surprising how many dryers have material losses of several hundred pounds or more per hour.

Even if the dryer in this example recycles its exhaust gas back into the combustion chamber — called exhaust gas recycling (or flue gas recycling), discussed later in this article — and burns the damaged DDGS as fuel to power the dryer, you’ll still lose money. DDGS has an energy content of 18.15 million BTUs/t. At $200/t, that’s $11 per million BTUs. If the cost of natural gas to power your dryer is $4 per million BTUs, you’ll lose about $127 for every ton of recycled exhaust DDGS the dryer burns instead of natural gas.

Thermal particle damage can also create a fire or explosion hazard in your plant. The VOCs and airborne fines created by thermal damage are much more likely than undamaged material to ignite and create a deflagration or explosion.

**What causes thermal particle damage**

A high inlet temperature, radiant heat, a low wet-bulb temperature, and overdrying all can cause thermal particle damage in your continuous convection dryer.

**High inlet temperature.** A very high inlet temperature (typically 1,000°F or greater, depending on the material) can sear the material as it enters the dryer.

**Radiant heat.** Radiant heat from the dryer’s burner can damage material regardless of temperature, similar to how the sunlight can burn your skin even on a relatively cool day. Most organic materials are susceptible to radiant heat above solar radiation levels, while most inorganic materials are less sensitive to radiant heat.

**Low wet-bulb temperature.** Particle damage can also result in a dryer where the drying gas has significantly lower wet-bulb temperature (less than 100°F) than dry-bulb temperature (from 400°F to 1,100°F), particularly when you’re drying organic material. The wet-bulb temperature (Twb) is the drying gas’s temperature at saturation (100 percent humidity), while the dry-bulb temperature (Tdb) is the drying gas’s actual temperature as measured by a thermometer. Gas with a high Twb contains more moisture than gas with a low Twb.

In a convection dryer, evaporation doesn’t begin until the particle’s surface temperature rises above the drying gas’s Twb. The lower the Twb, the less time it takes for drying to begin. This may sound like a good thing, but it also means that there’s less time for heat to migrate to the particle’s interior before its exterior dries. If the particles exiting your dryer are dry on the outside but still wet on the inside, this is likely what’s occurring.

How this process occurs in a dryer with low-Twb drying gas is shown in Figure 1. A uniformly moist particle at ambient temperature (80°F) enters the dryer, as shown in Figure 1a, and its exterior is flashed dry because the particle’s surface temperature almost immediately rises above the low (80°F) Twb, as shown in Figure 1b. The particle’s flash-dried exterior then insulates its moist interior so it heats up more slowly. Once the particle’s unprotected dry exterior reaches about 200°F (depending on the material), the high heat damages the particle’s surface layer, as shown in Figure 1c. Hydrocarbon materials are driven off, producing VOCs. Finally, the heat reaches the particle’s interior and forces the moisture to migrate to the surface. The migrating moisture forms a vapor film that protects the surface layer from further damage and allows the particle’s heated interior to dry, as shown in Figure 1d.

**Overdrying.** Overdrying frequently causes thermal damage. If your feed material’s particle size is inconsistent, your dryer may be more likely to overdry and damage smaller particles while ensuring that the larger particles are adequately dried. If your dryer recycles material, it’s very easy to over-recycle and overdry some particles. Also, any inconsistencies in the feed material’s moisture content or flowrate can throw off the dryer control system and create conditions where the material is alternately under- and overdried.

**How to diagnose thermal particle damage**

The law of conservation of mass tells us that the mass of the moist material entering the dryer should equal the mass of the dry material exiting the dryer plus the mass of the water vapor driven off. If the masses are unequal, it’s likely that the material’s been thermally damaged during drying and VOCs have been driven off. Also, the theoretically calculated energy expenditure needed to evaporate 1 pound-mass of water is 1,300 BTUs. If your dryer seems to be using less than that, it’s likely getting the extra energy by incinerating the damaged material and VOCs.

Here are two steps you can take to determine whether your dryer is thermally damaging your material:

**Perform a mass and energy balance analysis.** Have your dryer supplier perform a mass and energy balance analysis on your drying system, including the dryer and connected equipment. This will tell you if some of your material’s mass has been driven off during drying. For the analysis, the supplier will take measurements, such as pressure drop across fans, wet- and dry-bulb temperatures, gas-flow velocity, natural gas (or other fuel) usage, material moisture content and density, and more. The analysis should also determine whether carbon monoxide, nitrogen oxides (NOX), or other pollutants are present in the dryer’s exhaust gas stream, and, if so, whether they’re coming from the combustion fuel or from damaged material.
Monitor pollution tests. Keep an eye on your dryer’s pollution tests, whether or not you have secondary cleanup equipment, and perform EPA test methods 5 and 25 regularly on your dryer’s exhaust stream both before it enters and after it exits secondary cleanup equipment. Test method 5 tells you if there’s particulate matter in the dryer’s exhaust gas stream, but the test can’t detect all types of VOCs. Test method 25 tells you if you have harmful gaseous emissions — likely from VOC creation or NOx from the dryer’s burner. High or increased levels of pollution in these tests can signal increased rates of particle damage and VOC creation. Testing the dryer’s exhaust gas stream before it enters secondary cleanup equipment is important because most of the VOCs detected will have been created by overdrying and damaging the particle surfaces. Also, if your dryer has a thermal oxidizer that’s not using much fuel, it’s likely burning improperly separated material, thermally damaged material, VOCs, or all three. [Editor’s note: For more information about EPA test methods 5 and 25, visit www.epa.gov/ttn/emc.]

How to reduce or prevent thermal particle damage

Recycle the exhaust gas. You can raise the drying gas’s Twb by using exhaust gas recycling, which involves recycling a portion of the dryer’s heated exhaust gas stream back into the dryer. This is beneficial in two ways: It reduces the amount of fuel needed to heat the drying gas (since you’re reusing gas that’s already been heated), and it increases the drying gas’s water vapor content (since the recycled gas stream contains the moisture driven off the material during previous cycles). The drying gas’s increased water vapor content raises the Twb within the dryer and reduces the chances for thermal particle damage.

How exhaust gas recycling can raise the drying gas’s Twb to prevent thermal particle damage is shown in Figure 2. A uniformly moist particle at ambient temperature (80°F) enters the dryer, as shown in Figure 2a, but its surface isn’t immediately flashed dry because it takes longer for the particle’s surface temperature to rise above the drying gas’s Twb (170°F). This allows the particle’s interior to
heat before evaporation begins. The heat energy forces the water vapor at the particle’s interior to steadily migrate to the surface, forming a protective vapor film that prevents thermal particle damage, as shown in Figure 2b.

**Eliminate radiant heat.** If your material can “see” the burner’s flame at any point in the drying process, it’s susceptible to radiant thermal damage. Shielding the flame from the material can reduce the potential for damage. In some cases, a simple metal shield can be added inside the dryer to cover the flame but still allow the heated drying gas to flow past the flame and through the dryer.

For further reading
Find more information on this topic in articles listed under “Drying” in Powder and Bulk Engineering’s article index in the December 2014 issue or the Article Archive on PBE’s website, www.powderbulk.com. (All articles listed in the archive are available for free download to registered users.)

Becky Long is a dryer design engineer specializing in thermodynamic properties and energy balances at Thompson Dehydrating Co. (785-272-7722, beckyl@thompsondryers.com). She has a BS in mechanical engineering from Kansas State University in Manhattan, Kan.

Thompson Dehydrating Co.
Topeka, KS
785-272-7722
www.thompsondryers.com