6. Drying

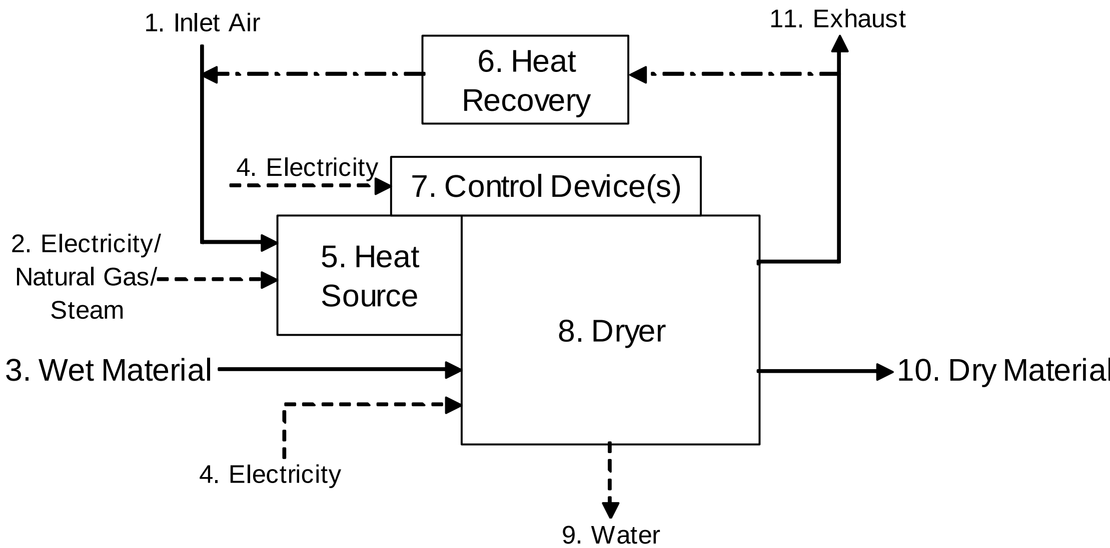

Figure 6.1 – Drying system diagram

Drying is the process of removing water or some other solvent from a solid by evaporation. It is an effective way to extend the life of foodstuff because the microorganisms and enzymes that reduce food quality over time require a sufficient amount of water to exist.

DRYING SYSTEM OVERVIEW (REFER TO FIGURE 6.1 ABOVE)
Several methods of drying are used in food processing including convection, conduction, and direct heating. The most common method is convection, which uses a heat source (5) to raise the temperature of the inlet air (1), which is then forced through a dryer (8). Water and other solvents are removed as the wet material (3) moves through the dryer (9). Dry material (10) and exhaust (11) are expelled. The exhaust not only contains water vapor, but it usually has a significant amount of heat that was not used inside the dryer. Many dryers are fitted with some sort of heat recovery (6) system to recapture as much of this energy as feasible. In many dryers, a control device (7) is used to improve energy efficiency and product quality.

Direct heating methods are used in some dryer designs to improve energy efficiency. The heating medium is eliminated, and induction, infrared, microwaves, or radio frequency waves are used to heat the wet material.

A variety of dryers are used in the food processing industry. A brief explanation of the more common types follows.

Industrial Dryer Types

Rotary dryers are inclined a few degrees and rotate slowly, typically 5-20 rpm. Product moves through the dryer continuously, and hot air is circulated sometimes in the same direction and sometimes in the opposite direction of the product flow. Rotary dryers vary in length from a few feet to over 300 feet.

Spray dryers have a cylindrical or conical vertical chamber into which liquid or slurry is sprayed. As liquid food droplets circulate, the hot air moving through the chamber evaporates the water; a cyclone is used to separate solids, typically with a moisture content less than 5%,[16] from exhaust air.

Band dryers use a perforated metal conveyor to transport wet foodstuff. Hot air is then circulated through the conveyor and the moist material to remove water. Band dryers run continuously and are well suited to products that require gentle handling.

Tray dryers usually operate in batch mode using shelves to hold product and circulating air over the material. Designs range from a simple oven to a rotating conformation of stacked trays. The latter design makes continuous feeding possible as the material enters on the top tray and is then automatically scraped onto successively lower trays as more and more moisture is removed until it leaves the bottom tray sufficiently dry.

Tunnel dryers convey heated air and a series of trays containing wet material through a tunnel. The sides of the tunnel may also be heated to enhance drying.

Fluidized bed dryers combine a perforated plate with regulated air flow rates such that the solid particles become suspended about the plate. These dryers can be operated in batch or continuous flow mode.

Drum dryers use conduction heating. Wet material is dropped onto one or more heated drums. The water evaporates, and the dry material is scraped off with a knife. This can be done in a vacuum chamber.

Pneumatic dryers use a fast-moving stream of air to convey the material up through the chamber. A cyclone at the top allows the dried material to be collected.

Freeze drying is one of the oldest of all drying methods. Ancient Peruvian Incas stored potatoes and other foodstuffs high in the mountains during the winter. The cold temperatures froze the food and the water inside slowly evaporated under the low air pressure of the high altitude.[17] Today, material is first frozen and then placed in a vacuum. This makes it possible to vaporize the frozen water without going through the liquid phase; this is known as sublimation. Heat is applied to accelerate the sublimation process, and, finally, condensers remove the vaporized water from the vacuum chamber.

---

[16] *Introduction to Food Engineering, 3rd Ed.*, by Singh and Heldman, p. 567, Academic Press, San Diego, CA, 2001.

[17] *Freeze-Drying & Freeze-Dried Food* by Mary Bellis, http://www.culinary-cooking-schools-institutes.com/article_freezedried.html, 2003.

ENERGY EFFICIENCY

When considering opportunities for saving energy, it is necessary to view the system holistically, from energy source to exhaust gas recirculation. Potential energy savings must be weighed against other factors including capital expenditure, safety, emissions, and product quality.

Mechanical Dewatering

One effective way to reduce the energy required for the drying process is to use mechanical means whenever possible to reduce the water content prior to any thermal drying. Methods of mechanical dewatering include filtration, centrifugal force, gravity, high velocity air, or compression to force water from the material. Means of compression include presses, rollers, and belts that squeeze water out of the material.

The effectiveness of these methods is limited, and additional thermal drying is usually required. However, the energy used in mechanical dewatering is only 1% of the energy used to evaporate the same quantity of water.

Direct Heating

Direct heating is not feasible in some food processing applications and is often not an economical retrofit option. However, when applicable, direct heating provides significant energy savings because it eliminates the inefficiency of transferring heat to air and from the air to the wet material. The energy efficiency of direct heating is about 90%, compared to the typical 50-60% for a conventional steam-raising boiler and associated distribution system.[18]

Control

Dryers have a number of inputs that, if properly controlled, will result in a cost-effective product that is of acceptable quality. Poorly controlled dryers waste energy both directly by consuming more energy than necessary and indirectly by yielding a product that doesn't meet specifications and must be discarded.

Dryer inputs fit in two categories: those that can be manipulated (e.g., valve, damper, and burner settings, fan speeds, and belt feed rates) and those that are not easily manipulated but that can greatly disturb components of the process (e.g., ambient air temperature and humidity, feedstock composition, and moisture content).

"The aim of a control system is to maintain the values of the outputs, i.e., quality and cost, at as near to their desired values as possible by changing the manipulable inputs so as to compensate for fluctuations in the values of the non-manipulable [sic] inputs."[19]

---

[18] *Learning from Experiences with Industrial Drying Technologies*, CADDET Energy Efficiency Analysis Series No. 12, p. 32, CADDET, Sittard, Netherlands, 1994.

[19] *Learning from Experiences with Industrial Drying Technologies*, CADDET Energy Efficiency Analysis Series No. 12, p. 83, CADDET, Sittard, Netherlands, 1994.

Feedback controllers monitor the output, often outlet air temperature and humidity, and adjust manipulatable inputs like fan speed and/or feed rate. The limitation of such a system is that, in many cases, there is a significant lag between when the manipulatable inputs are adjusted and the corresponding changes affect the outputs. During the lag time, significant amounts of out-of-specification product can be produced.

Feedforward controllers monitor "disturbance" inputs like ambient air temperature and humidity and/or product moisture content and adjust the manipulatable inputs accordingly. The challenge with these systems is the need for a mathematical model that accurately predicts the effects of changes to the inputs on the final outputs. Since an accurate model does not always exist, a combination of feedback and feedforward control is used in some cases.

The economic payback of improving control systems depends on the complexity of the system and expense of new instrumentation, if any. In general, the higher the system's energy bill, the shorter the payback period.

Heat Recovery

Hot air moving through a dryer usually cannot become fully saturated. This is not due to poor design but rather to the rapid drying times in a commercial operation. Equilibrium humidity is the point at which water will not transfer between air and wet material. If the actual humidity of the dryer's exhaust air is below the equilibrium humidity, the unused potential to absorb more moisture is wasted. Consider the following from the Center for Analysis and Dissemination of Demonstrated Energy Technologies:

> "For example, if the equilibrium humidity is 0.1 kg(water vapor)/kg(dry air), but the actual humidity of the exhaust air is 0.02 kg(water vapor)/kg(dry air) then, for a flow rate of 50 kg(dry air)/s, the same rate of water removal could theoretically be achieved using a flow rate of 10 kg(dry air)/second. Consequently the remaining 40 kg(dry air)/s is not removing water from the material, but has still been heated. This heat is wasted.
>
> "It is not possible to achieve 100% of the equilibrium humidity because the rate of drying is proportional to the difference between the equilibrium and the actual humidities: the smaller the difference, the slower the rate of drying. However, many dryers could operate at higher exhaust air humidities without any significant reduction in the drying rate."[20]

Several characteristics of a dryer can be modified to reduce energy consumption and drying rate. For example, the area of contact between air and material, length of the dryer, and the rate at which air moves can all be increased. These factors are best

[20] *Learning from Experiences with Industrial Drying Technologies*, CADDET Energy Efficiency Analysis Series No. 12, p. 56, CADDET, Sittard, Netherlands, 1994.

considered during the design of the system and are usually not viable options for retrofit because of space limitations and/or reductions in the rate of system's output.

Perhaps the simplest form of heat recovery in retrofit situations is *exhaust air recirculation*. When the space is available for ductwork and the distance between the input and the exhaust is not too great, a portion of the exhaust air can be routed back to the input of the heat source, which preheats the inlet air and reduces the energy consumption at that point.

Plate or tubular heat exchangers are used where mingling exhaust air and inlet air is not advisable.

If there's no room for additional ductwork or the distance is to great to make it feasible, a "*run-around coil*" can be used. The coil contains a heating medium, like water or a water/anti-freeze mixture, which is heated by the exhaust air. The heated medium is routed through the coil to the inlet and then to the dryer where fresh air absorbs the recycled heat.

In some applications the exhaust air is cooled below the dew point and the latent heat of vaporization is released. This energy is significant but difficult to capture because the temperature is usually too low for effective recovery. A *heat pump* may be a cost-effective alternative in these applications.

<u>Insulation</u>

Many dryers have hot surfaces that are exposed to air. Any loss of heat through these surfaces reduces energy efficiency. Insulating exposed surfaces and repairing damaged insulation can minimize heat loss. Properly insulating flanges and valves can help, as well.

The importance of good insulation cannot be overestimated. Poor insulation may reduce the effectiveness of other system changes like increasing the temperature differential in order to improve the productivity of the dryer. Higher temperatures and inadequate insulation means more radiant heat loss and wasted energy.

<u>Good Housekeeping</u>

Poor maintenance can increase energy consumption by as much as 10 percent. A few easy housekeeping measures can help to minimize wastefulness:

- Check burner efficiency in heaters.
- Check heat exchangers for fouling and leaks.
- Check filters for fouling and increases in pressure drop.
- Look for water leaks; inspect steam traps regularly.
- Check for air leaks; make sure that doors fit well and seals work.
- Have instruments serviced regularly according to the manufacturer's recommendations.
- Check thermocouples and humidity sensors for fouling.

Economic Benefit

When calculating payback on energy-efficiency projects, it is important to include indirect and non-energy-related benefits.

For example, indirect energy savings are realized if an improvement to a control system reduces the amount of product that doesn't meet specifications. In other words, total output is reduced, which, in turn, saves energy.

Non-energy-related benefits include an increase in system capacity that occurs when a bottleneck resource is able to produce more product for which there is an immediate customer demand. Continuing with the previous example of an improved control system, if better control reduces the volume of rejected product or increases the product feed rate so that daily output can be increased and if that additional capacity can be converted into additional sales, profit will increase significantly. This is because the additional sales will come with no additional operating expense, and the entire amount of the selling price (above the cost of raw materials and shipping) will go directly to the bottom line.

In many cases, the non-energy-related financial benefits are far greater than the direct and indirect energy-related savings. If correctly identified and accounted for, these additional dollars reduce the actual payback period to a matter of a few months.

RESOURCES

Printed Material

Learning from Experiences with Industrial Drying Technologies, CADDET Energy Efficiency Analysis Series No. 12, p. 56, CADDET, Sittard, Netherlands, 1994.

Singh, R.P. and Heldman, D.R., Introduction to Food Engineering, Academic Press, 3rd ed., 2001.

Wulfinghoff, D.R., Energy Efficiency Manual, Energy Institute, MD, 1999.

On-Line Tools

Earle, R.L., Unit Operations in Food Processing: http://www.nzifst.org.nz/unitoperations/index.htm

Energy Manager Training: http://www.energymanagertraining.com/new_index.php

Online Chemical Engineering Information, Pinch Technology: Basics for Beginners: www.cheresources.com/pinchtech1.shtml.

Singh, Paul, Teaching Resources: Animation: http://www.rpaulsingh.com/animated%20figures/animationlist.htm

Organizations

Association of Energy Engineers: www.aeecenter.org

International Energy Agency: www.iea.org

Iowa Energy Center: www.energy.iastate.edu

Iowa State University Industrial Assessment Center (IAC): (515) 294-3080 or www.me.iastate.edu/iac