Using Superheated Steam in Drying and Sterilization

It seems counterintuitive to use water vapor in a process to remove water or to heat materials that can be damaged by moisture, but such processes exist and can offer advantages. Superheated steam drying is discussed by Prachayawarakorn and Soponronnarit (2010). Steam sterilization has been previously discussed in this column (2007). Here we will summarize those sources and describe a specific application.

Superheated Steam
Superheating simply means heating vapor above its boiling point at a given pressure; in the case of water at one atmosphere, this is 100°C (212°F). So-called dry steam then behaves like any other hot gas, heating material that it contacts by giving up sensible heat and lowering its temperature in doing so. Water vapor has about half the specific heat of liquid water, so in losing one Fahrenheit degree, superheated steam supplies one-half a British Thermal Unit (BTU) per pound of vapor. (One BTU is the energy required to change one pound of matter by one degree F.)

If superheated steam cools to its saturation temperature—the boiling point at a given pressure—it will begin to condense on the material it is heating. The energy released in condensation is 1,000 BTU/lb of vapor, many times the sensible heat obtained by cooling. What this means in practice when trying to dry a food is that moisture is added to the food at the start of drying. At the same time, the food is heated quite rapidly to the vapor saturation point, where condensation then ceases and moisture is removed.

Since so much heat is given off by condensation, the amount of added moisture is actually quite small and the hotter the steam is initially, the less water is condensed. Nonetheless, this phenomenon increases the amount of drying that must be done compared to drying with hot air. So, one might ask, why even consider using superheated steam?

Some possible advantages of superheated steam drying include the following. It provides an oxygen-free environment, preventing oxidative reactions. Pasteurization, sterilization, deodorization and, possibly, cooking can occur while drying. There can be a reduction of separate steps for some products, such as parboiled rice. Drying rates may possibly be higher if the temperature is high enough. It may be possible to reuse exhaust steam elsewhere. There may be an increase in porosity of the dried product, which would improve rehydration.

Some of these advantages simply result from higher temperatures, while others occur because of the slightly moist environment. For instance, microbes are generally more vulnerable to wet heat than to dry heat. The concept of reuse is intriguing and exists because the exhaust stream from a superheated steam dryer should still be superheated to prevent condensation. Thus, its considerable heat of condensation is still available for use in another heating application.

There are some disadvantages as well. These
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include the previously mentioned increase in drying duty due to initial condensation and the possible disruption of a fluidized bed dryer due to wetting of particles. In addition, it requires more complex equipment and is of limited value for heat-sensitive materials because of the relatively high temperatures.

Starch may be more gelatinized in superheated steam drying than in air drying because of the initial surface wetting since starch requires wet heating to gelatinize. This can have a favorable effect on the appearance of dried particles.

Some specific applications include parboiled rice in which several previously separate operations can be combined, with a shorter overall time of processing, simpler equipment, and better quality. Likewise, superheated steam drying of paddy rice after soaking improved yield in milling compared with ambient air drying.

Soybean meal needs to be heat treated to inactivate antinutritional factors. Hot air heating alone requires increasing the moisture content and relatively long heating times, while superheated steam was effective even for dry soy meal and at lower temperatures. The lower temperatures and shorter time improved the digestibility and other nutrient properties of the meal.

Superheated steam can cause puffing in some products, such as banana, because of the rapid expansion of moisture within the pieces. However, in other cases, such as popping seeds, volume expansion in superheated steam was reduced, probably because the seed coats were softened by wetting. In popping, the seed coats act like little pressure vessels that eventually burst when the interior pressure gets to be high enough.

As these examples show, superheated steam can be a useful technique in drying certain foods, but it is not a sure solution for every situation.

Steam Sterilization

Products such as tree nuts, herbs, and teas may require sterilization or disinfection without overcooking or leaving residual moisture that could support mold growth. Several techniques have been developed that generally involve carefully controlling exposure to steam and then rapidly removing heat and moisture. Often, vacuum is used to improve heat transfer, reduce temperature, and accelerate cooling. The various processes differ in material handling approaches, methods of contacting, and capacities.

Several devices use screw conveyors as contacting methods for heating and cooling continuously. One heats the conveyor electrically while another relies on the steam for heat.

Direct steaming of the surface of meat animal carcasses is an approved approach to sterilization that does not leave a residue, such as chlorinated or acidified water washes would do. The trick is to avoid cooking the surface while heating sufficiently to kill microbes.

Steam Sterilization—A Practical Application

BI Nutraceuticals, which has offices in Hong Kong and Long Beach, Calif., is a large supplier of botanicals used as food ingredients and in pharmaceuticals and supplements, according to George Pontiakos, CEO (gpton@botanicals.com). BI has about 700 products representing...
many different plant parts that are sourced all over the world. Many come from and are processed in China.

Pontiakos said that irradiation and ethylene oxide (EtO) have both been used effectively to sterilize such materials, but both have disadvantages. EtO is toxic and flammable, while irradiation can be expensive and is opposed in some areas, such as Europe. Neither approach is permitted for items labeled organic. Accordingly, BI sought an alternative technology and developed one that sounds similar to that offered by SteamLab Systems, Hamburg, Germany.

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Pontiakos said that BI tested an auger-based system, but company staff members were disappointed at its performance on powders. In an auger or screw conveyor, there must be a finite clearance between the screw and the trough, which means that there may always be a residue of material in the trough. Also, depending on material properties and the details of the device, mixing may be incomplete. In any case, BI uses a large room or autoclave into which material is loaded in permeable bags.

Steam is introduced, and then a vacuum is pulled to cool and dry the material. After treatment, the material must be milled and packaged in an isolated clean room to prevent subsequent contamination. The systems are said to cost about $1 million each, and BI has four, three in California and one in China.

BI ships large quantities of its products and sources from 35 different countries. The firm takes pride in its ability to surveil every step from harvest through packaging. As Pontiakos pointed out, once materials are milled to a powder, it is hard to identify and verify purity. Accordingly, there can be wide variation in pricing that may be achieved in some cases by adulteration or substitution of inferior materials. BI has SQF certification for one of its California mills and claims that it is the only supplier with such certification.

Culinary Steam

In both drying and sterilization by direct steam or superheated steam contact, the steam used should be culinary steam, meaning it is free of common boiler feed water chemicals often used to minimize corrosion and scaling. Culinary steam is generally produced near the point of use and requires a series of filters, valves, and heat exchangers. If the plant steam is clean enough, filtering may be adequate, but in other cases, plant steam is used to boil softened water in a stainless steel heat exchanger. Culinary steam is then distributed in stainless steel pipe or tubing as a food ingredient.

Because of how it is used, there may be too little culinary steam condensate to make recovery worthwhile. However, the possibility of reuse of superheated steam from a dryer should be considered as an energy efficiency step. The exhaust from a sterilizer, such as the one BI uses, is probably just condensed and discarded, but it might be worth trying to recover it unless it is contaminated by volatiles from the material being treated.

Superheated steam and steam followed by vacuum are versatile tools that could find wider use in the food industry, especially in response to demands from regulators and customers for strengthened food safety programs. They offer advantages over chemical sterilants and conventional drying in many cases. FT

REFERENCE