Making A Case for Continuous Furnaces

Fred Dimock, BTU International, North Billerica, Mass.

A continuous furnace is ideal for processes requiring high production volumes, process consistency, and precision control. This overview discusses some of the newer temperature and atmosphere capabilities of continuous furnaces and addresses the various components that make up a continuous furnace.

Furnace technology, economics and part quality influence the decision on whether to use a continuous or a batch operation. The economics questions center around cost of ownership, which can include initial cost, operating costs, repair costs, product yields and return on investment. Quality issues often are associated with process stability, quality and consistency, while technology focuses on ease of operation, process definition, thermal cycles, temperature requirements, atmosphere conditions, weight of product and desired throughput. The questions and their relative importance vary from industry to industry, company to company and person to person always there. The one universal set of questions always concerns continuous furnace design.

Continuous furnaces are divided into four subgroups: belt furnaces, pushers, walking beams, and car bottom. The main differences are load, temperature, and atmosphere capability as shown in Table 1. A continuous furnace, in its simplest form, consists of a heated tunnel and equipment to transport product through it. In a slightly more complicated form, the tunnel has insulation and multiple areas for controlled heat and cooling. The tunnel can be lined with a metal or ceramic enclosure, called a muffle, to contain a controlled atmosphere. Correct application and design of a continuous furnace requires complete details of the thermal profile (Fig. 1) required for the product and physical properties of the material to be heated.

Heating technology

Methods used to heat continuous furnaces depend on use temperature, atmosphere, power, and application and include hot air convection, gas firing, molydisilicide heaters, silicon-carbide rods and refractory-metal ribbon, rods and mesh. Hot air convection generally is used in low-temperature solder-reflow ovens (100 to 300°C, or 210 to 570°F) in air and nitrogen. Silicon-carbide heaters work best at temperatures from 800 to1600°C (1470 to 2910°F) in air, and refractory metal heaters (molybdenum and tungsten) are used in inert atmospheres at temperatures higher than 1500°C (2730°F). Graphite heaters, which can operate at very high temperatures, require atmospheres having extremely low oxygen levels to survive.

Continuous belt furnace

Table 1 Continuous-furnace operation specifics

Furnace type	Max. loading, lb/ft^2 (kg/m^2)	Max. operating temp., °C (°F)	
		Oxidizing atm.	Reducing atm.
Belt			
Graphite(a)	3 (15)	—	2800 (5070)
Metal	15 (75)	1150 (2100)	1150 (2100)
Pusher	100 (490)	1600 (2910)	1800 (3270)
Walking beam	400 (1,950)	1600 (2910)	2200 (3990)
Car bottom	800 (3,900)	1600 (2910)	—

(a) Reducing atmosphere only

Two fundamental parts of temperature control are a measuring device and a controller. The most popular temperature-measuring device is the thermocouple, while other temperature-measuring devices used to a lesser extent than thermocouples include optical pyrometers, RTDs (resistance temperature detectors), thermisters, and IC sensors.

Controllers use the output of the temperature-sensing device to adjust the power supplied to the heater to control the temperature to a set point or target. Due to rapid advancements in technology, the practice of using individual control devices for each zone is seeing a changeover to using

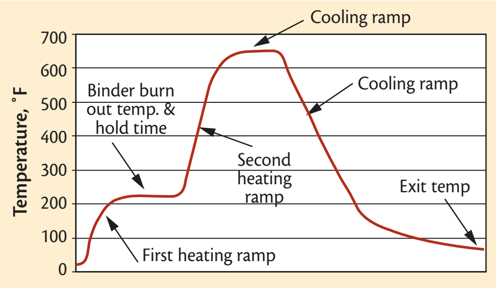

***Fig 1** Representative process thermal profile*

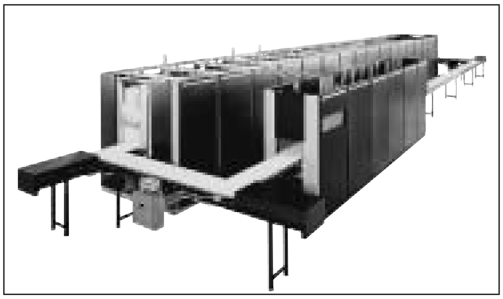

***Fig 2** Continuous pusher furnace with preheat zone*

single microprocessors having expanded capability. Today's microprocessor controller uses sophisticated algorithms to determine the amount of change to the power and time increment between changes for precision temperature control. These algorithms, called PIDs, are divided into three parts. In the case of BTU International, the algorithms are called pro-band, reset and rate. Pro-band (short for proportional band) determines the amount of power to be added or subtracted based on the deviation from the set point. Reset adds the time factor to the calculation. If reset is too low, the response is slow and the furnace temperature will not respond to changing loads. If it is too high, the power changes too fast and there are wide oscillations in temperature. Rate is a "look-ahead" function that anticipates where the temperature will be in the future and begins to compensate in advance of arriving at the set point.

A combination of good thermocouples, microprocessor controllers, and sophisticated control algorithms result in furnaces that can operate at ±2°C (±4°F) around a 1000°C (1830°F) use temperature. BTU recently provided a 24-in. (610 mm) wide belt furnace for thick-film resistors, which has across-belt uniformity of ±1°C (±2°F). Very tight temperature control was important because resistor values are very dependent on firing temperature and firing time, which allowed the user to have better process yield and more consistent product.

Product-transport methods

Metal mesh belts offer simplicity and ease of operation for transporting product through a furnace, but they have strength limitations when the load exceeds 12 lb/ft^2 (58 kg/m^2) or temperatures higher than 1150°C (2100°F). Ceramic belts have been used at higher temperatures, but they have proven to be brittle and thus have low weight-carrying capability.

When the load or temperature exceeds the capability of a belt, a pusher furnace is an alternative (Fig. 2). In a pusher, ceramic, refractory metal or graphite slabs or boats push each other through the furnace via an indexing device, which moves the product forward. A single boat or slab can be added to the train during each cycle. Most precision pushers use recirculating ball screws and dc-motor systems to achieve precise speed control.

A major problem with pusher furnaces is a jam, where a boat gets out of line and snags in the furnace. When this happens, the train either accordions up into the tunnel insulation or the slabs slide over each other. Much work has been done to detect jams including the use of force monitors, which release the pressure when it exceeds a preset level, and linear motion detectors at each end of the furnace to confirm both ends of the train are moving at the prescribed rate. In either case, when a jam is detected, the forward motion of the pusher is stopped before the furnace is damaged. A jam can result in downtime ranging from as short as a few minutes to as long as days.

When the weight of the load or length of the furnace exceeds the capabilities of the pusher, a walking-beam furnace is next choice. A walking-beam furnace eliminates any possibility of a jam by lifting and moving the boats with a beam rather than having them push against each other. The boats do not contact each other and there is no abrasion of the beam or product carriers. Walking-beam furnaces can be used with oxidizing to fully reducing atmospheres.

Even heavier loads can be fired in car bottom furnaces, where the bottom of the furnace is the top surface of a small rail cart that moves through the tunnel. The rail carts are aligned end to end and continuously pushed through the furnace. Car bottom furnaces can approach 200 to 300 ft (60 to 90 m) long and usually are limited to use at temperatures around 1600°C (2910°F) in oxidizing atmospheres.

Insulation

Improper furnace insulation can damage the furnace, or excessively high-energy costs could put you out of business. Furnace damage can occur from overheating and chemical reactions with byproducts from the workload or atmosphere. For example, furnaces using alumina insulation can have very short lives (less than 1 year) at temperatures higher than 1600°C and a dew point less than -80°C, but can last for 5 years or more when the dew point is near 0°C.

Insulating materials that can withstand high temperatures generally have lower insulating properties, so combinations of materials are used. Higher temperature materials are used near the heat and lower temperature, more efficient materials near the outside.

Common forms of insulation materials are brick, board and ceramic fiber, made of inorganic materials such as alumina, silica and zirconia. Solid forms generally are used closest to the product (at the higher temperatures), while fibrous materials are used as backing and fill material (Fig. 3). New high-performance insulation board, a specialized form of fiber where the fibers are bonded or woven together, can be either solid or flexible like a blanket.

Metal heat barriers are used in process applications where brick or ceramic cannot be tolerated. These are known as cold wall systems because the outer surface of the furnace is a jacket that contains water for cooling. Layers of metals such as tungsten and molybdenum are used as heat shields to facilitate temperature gradients between the hot working section and cold water jacket. Cold wall furnaces use a lot of energy because they lack insulation properties and they are limited to reducing atmospheres.

Graphite is a high-performance insulating material because of its high temperature capability and resistance to heat flow. However, it is limited to very dry-reducing atmospheres because it will decompose in the presence of low levels of oxygen. Also, graphite furnaces tend to be expensive.

Atmosphere control

Three categories of furnace atmospheres are air, nitrogen or nonflammable gasses and hydrogen or flammable combinations of gasses. Even a simple furnace using an air atmosphere needs a control system. Whether it be gas volume or direction of the gas stream, control is important for product consistency and uniformity. Air and nonflammable gas combinations require fewer safety interlocks than explosive and flammable gasses.

In most cases, gas flow should be from the cooling area of the furnace toward the entrance so the contaminants are swept away from the hot zone and not deposited on the product as it cools. This flow pattern is established by placing the gas inlets after the hot zone and gas exit stacks near the entrance of the furnace. Venturis on the stacks, which suck the gas out of the furnace, can assist in directing the gas flow. In some cases, additional gas inlet and exit stacks are added near the entrance end of the furnace to increase the gas flow in that area and assist in clearing volatile organics.

Use of a liner or muffle in the furnace offers the capability for precision atmosphere control (including explosives gasses). Metal muffles usually are made of carbon steel, stainless steel, or nickel-base alloy, while glass and ceramic muffles usually are quartz or silicon carbide. When a glass or ceramic muffle is used with an explosive atmosphere, the furnace case has to be sealed because these muffles are not gas tight.

The ends of the muffle present a unique challenge because they have to allow the product to pass through while keeping outside atmosphere out of the furnace. This is done by means of purge boxes and gas curtains, which are extremely effective in separating atmospheres. Additionally, internal gas barriers can separate and isolate atmospheres in different sections of the furnace. Atmosphere separations that allow a furnace to run at less than 2 ppm of oxygen in either hydrogen or nitrogen are common, together with dew points of -80°C. These levels are dependent upon the quality of the supply gas. Many brazing people are switching from vacuum furnaces to continuous belt furnaces because of the ability to control dew point and oxygen at low levels while economically brazing parts. On the other end of the atmosphere scale, high dew points can be achieved with gas saturators that add moisture to the gas before it enters the furnace or air bleeds, which can increase the oxygen level in nitrogen for binder burnout.

BTU International developed a furnace specifically designed for direct-bond copper, which controls nitrogen at 50 ppm of oxygen in the binder burnout section and less than 5 ppm in the firing section.

When using a process gas that is explosive, additional precautions must be taken to ensure the furnace is safe. Mixing 18% air with hydrogen and introducing an ignition source will result in the "rapid development of water," or an explosion. Hydrogen mixtures containing as low as 4% air will burn. Because of this, purge boxes and gas curtains are used with an inert gas such as nitrogen to separate the outside air from the process. A gas curtain is shown in Fig. 4. Argon can be substituted for nitrogen in cases where nitriding is a problem, but it is expensive. When less precise atmosphere control is needed, a gas curtain can be replaced with a flame curtain (Fig. 5).

Product cooling

It is important to cool the workload before it exits the controlled atmosphere. Some products, such as those con-

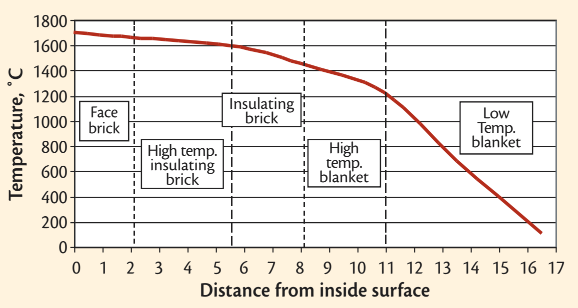

Fig 3 *Example of continuous-furnace through-wall temperatures*

Fig 4 *Gas curtain used to keep outside air from the furnace*

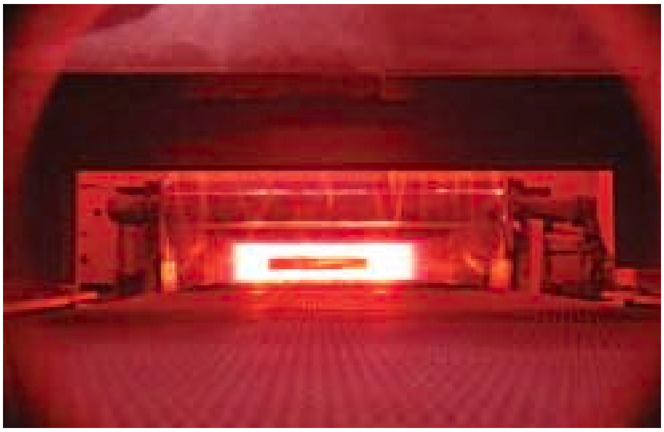

Fig 5 *Continuous furnace with flame curtains*

taining glass, require slow cooling rates to prevent breaking due to thermal shock, while other products can be cooled as fast as they will give up heat.

The first cooling section of a usually is called insulated, or free, cooling. This insulated area is without a heater and eases the product on its downward temperature path while affording a separation between the high temperature of a heated zone and the forced cooling to follow. This next cooling step can be a gas jet that blows cool controlled gas on the part. Gas jets usually are used at high temperatures when a part has just gone through a spike profile and needs to be cooled quickly. Gas jets also can be used as the supply point for some furnace atmospheres. The insulated cooling section is kept to a minimum when cooling jets are used.

The workload finally enters a cooling area where water is used to cool the outside of the furnace chamber. Water-cooling usually is done in multiple zones. Three methods of containing the water are integral jacket, plate coils and tubing having high conductivity heat sinks. All methods work well, but the plate coil and integral jacket can be expensive to replace if there is leak

Many manufacturers skimp on the cooling length when there are space limitations, willing to live with a workload that is too hot to handle or adding external cooling fans to a return conveyor. Although this first looks to be acceptable, it is not good practice from a safety, process design and product viewpoint. Handling a hot workload is not safe, and a hot workload entering an area where there is uncontrolled atmosphere can oxidize. Also, the process engineer loses the flexibility to increase throughput or adjust the process.

A solution to this problem lies in a device called a cooling eductor (Fig. 6). BTU International patented an eductor driven cooling system that shortens the cooling section by about 50%. It uses the venturi principle to remove hot gas from the cooling area, pass it through a cooled tube and return it to the chamber. It also enhances the turbulence in the cooling section of the furnace, thus increasing the heat transfer between the gas, cold walls and workload.

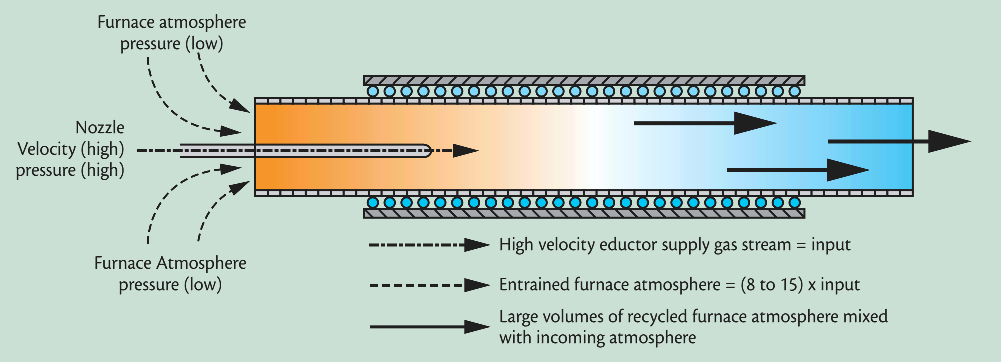

Fig 6 *Eductor operating principle*

Other process enhancers

Just as the cooling eductor adds turbulence and increases cooling, eductors in the hot zone increase the efficiency of gas use in the hot zone. The gas is preheated as the supply lines pass into the furnace. The turbulence from the hot-zone eductors assist in getting gas through tortuous paths in the workload and fixtures and thus produce more consistent parts. An added benefit is that the conductive heat flow is increased, thus providing slightly better temperature uniformity. Many furnaces designed for copper and nickel brazing of stainless steel heat exchangers use eductors in the hot zone.

Another furnace option is to add heat barriers and gates to the muffle near the hot zone. Heat barriers assist the process by limiting the heat flow between zones due to radiation and conduction, thus allowing larger temperature gradients. This is important for temperature profiles having fast spikes or a long hold for binder burnout before a high-temperature sinter. There is liberal use of heat barriers in furnaces designed for spike profiles for forming solder bumps on ball grid arrays and the binder burnout holds for low temperature cofired ceramic (LTCC). **IH**

For more information: *Fred Dimock is senior process engineer, BTU International, 23 Esquire Rd., North Billerica, MA 01862; tel: 978-667-4111, ext. 207; fax: 978-667-9068; e-mail: fdimock@btu.com*