

# TECHAPPLICATION

# INDIRECT RESISTANCE HEATING

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## Clean, Controlled Heating

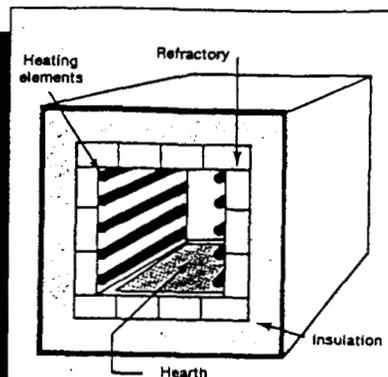
Electric resistance furnaces offer a safe, efficient, reliable and clean method for heat treating, melting, heating prior to forming, and brazing metals. Electric furnaces are also easy to control, and operate over a wide temperature range. In addition to heating metals, they are used for melting glass, sintering ceramics, and curing coatings. And the number of applications continues to grow as technological developments broaden the operating temperature range of electric furnaces, and the demand for automatic process control increases.

Resistance heating is based on the principle that, when a current is passed through an electrical resistor, electrical energy is converted to thermal energy. The thermal energy then is transferred to the part by convection, radiation and/or conduction. This issue of *TechCommentary* describes indirect resistance heating and discusses the technical and economic factors to consider when deciding if the process could benefit a particular application or product. Direct resistance heating and encased resistance heaters are discussed in *TechCommentary*, Vol. 3, No. 8.

## Advantages

Often, an electric resistance furnace and a gas-fired furnace are equally appropriate for a particular application, and the choice is based on economics. However, several characteristics of electric resistance furnaces may make them the better choice for your application. The advantages of electric resistance furnaces include:

- Flexibility. Both operating temperature and furnace atmosphere can be varied. Resistance heating elements are available for all temperatures of importance in



**Schematic diagram of an indirect resistance heating furnace showing the arrangement of the heating elements on the walls.**

Below about 1250 F, heat transfer to the workpiece is primarily by convection, sometimes with the aid of fans, as in "forced" convection furnaces. Radiation is the major mode of heat transfer at temperatures above about 1250 F and in vacuum furnaces where there is no atmosphere to support convection.

industrial processing, whereas the maximum temperature of gas-fired furnaces is limited to approximately 2400 F. Heating in a controlled atmosphere or a vacuum is easily achieved with an electric furnace. Such control is more difficult in a gas furnace unless radiant tubes or protective muffles are used.

- Automatic temperature control. Microprocessors and solid-state switches can control furnace temperature automatically. Because the location and configuration of electric elements can be easily tailored to a given application, temperature is more uniform than with other types of furnaces.
- Improved working conditions. Electric furnaces are quiet because

there is no combustion or blower noise (except in forced air furnaces, where there is some fan noise). The absence of smoke and hot flue gases makes the plant both cleaner and cooler, thus minimizing concerns for worker safety and environmental pollution.

- Cost savings. For some applications resistance furnaces are more energy efficient and save space. Resistance furnace efficiency is relatively independent of temperature, whereas the efficiency of gas-fired furnaces drops sharply with increasing temperature. Waste heat is minimized since there are no hot flue gases in an electric furnace. Space is saved because there is no need to store or pipe in flammable fuel or remove exhaust gases.
- Safety. There is little explosion hazard connected with the heating system with an electric resistance furnace.
- Serviceability. Every industrial company is likely to have an electrician with the skills to repair an electric heating system. Burner experts are less common, but are necessary to maintain the efficiency of a gas-fired system.

## Applications

Indirect resistance heating is used primarily in the metals, ceramics, electronics and glass industries. The more frequently used processes that incorporate this heating technique include:

- Heat treatment of metals
- Metal melting
- Heating prior to forming
- Brazing
- Sintering ceramics
- Curing coatings
- Glass tempering.

Temperature Range	Heat Treatment
300–600 F	Age hardening light metals, e.g., aluminum alloys Blueing steels Tempering ultrahigh-strength steels and carburized components
600–1000 F	Nitriding Annealing copper Solution treating aluminum alloys
700–1400 F	Tempering steels Annealing and stress relieving wrought steels and steel welds Annealing copper alloys
1450–1700 F	Carbonitriding Carburizing
1450–2000 F	Austenitizing low and medium alloy steels Annealing specialty steels Sintering nonferrous powdered metals
1900–2400 F	Heat treating tool steels Sintering ferrous powdered metals Solution treating nickel-based alloys

**Table 1. Common Heat Treatments and Their Temperature Ranges**

**Heat treatment of metals**—Indirect resistance heating is used for annealing, austenitizing, normalizing, hardening, tempering, nitriding, carburizing, and sintering a wide range of ferrous materials. It is also used for annealing, solution treating, and aging nonferrous metals. These processes are carried out at temperatures ranging from 300 to 2400 F, as shown in Table 1.

Both gas-fired and indirect resistance furnaces can be used at low temperatures and where there are no special atmosphere demands. However, aerospace alloys and tool steels often have to be treated in a controlled atmosphere. For example, titanium alloys, which are prone to contamination, particularly hydrogen pickup, must be processed in a vacuum or an inert atmosphere. Similarly, tool steels often must be heat treated in a vacuum or special atmosphere to prevent vaporization of important alloying elements at the surface. These special conditions are easily arranged in an indirect resistance furnace but difficult to achieve in a gas furnace.

Induction is occasionally used if rapid heating is required. However, the cost of coils and power supplies makes it economical only in high volume applications.

**Metal melting**—Indirect resistance furnaces for melting and holding metals, especially nonferrous alloys, have become popular in the casting industry in the last ten years. The reason for this popularity is the

increased availability of light-weight refractory materials for building indirect-resistance-heated crucible furnaces. The low thermal mass of these materials makes the furnaces very energy efficient.

In modern aluminum foundries there is often an electric resistance crucible furnace at each casting machine to hold the molten aluminum at the optimal casting temperature (1100–1200 F depending on the alloy). Gas furnaces can be used, but it is more difficult to maintain their contents at a constant temperature. In addition to allowing excellent temperature control, electric heating minimizes gas pickup by the molten metal, or oxidation of the surface. Together, these factors can reduce metal loss by half. Electric heating also limits hot spots and thermal stresses in the furnace; and, because there are no combustion products, the crucible is not eroded by hot gases.

The capital cost of an electric crucible furnace is somewhat higher than that of a gas-fired furnace (\$18,000 versus \$14,000 for 500 lb capacity), but the extra cost can be quickly paid back by decreased material loss.

Some materials, especially reactive or refractory metals like titanium and molybdenum, must be melted in a vacuum. While this can be done in a resistance heated furnace, vacuum melting is usually done with induction, arc or electron beam heating since

these methods result in faster melting and a more homogeneous product.

**Heating prior to forming**—In the forging industry, electric-based heating is gaining in popularity for billet preheating. The reason is that electric furnaces are considerably more efficient than gas-fired furnaces, even those with recuperators, at preheating temperatures (around 2100 F, the exact temperature depending on the specific material).

Direct resistance and induction heating are two other methods used for preheating materials. Both heat faster than indirect resistance because the heat is generated within the workpiece. However, they only work efficiently for simply-shaped blanks, such as rods and bars, made of fairly high-resistivity metals. There are essentially no restrictions on the materials or workpiece shapes that can be heated in an indirect resistance furnace. And a single furnace can be used to heat a wide variety of parts.

**Brazing**—Metal components are often brazed in indirect resistance furnaces because of the need for a controlled atmosphere (or vacuum) or a carefully controlled thermal cycle. Induction brazing is also done, but is economical only for high-volume applications because the complex coils required are so expensive.

**Sintering ceramics**—Ceramic materials are widely used in the production of various electronic components including capacitors, resistors and piezoelectric elements. They are also being developed for use in internal combustion engines. These ceramic materials must often be fired, or sintered, at temperatures as high as 3000 F, and both temperature and furnace atmosphere have to be precisely controlled. The electronics industry also uses indirect resistance furnaces for growing, purifying and processing the silicon and germanium crystals and wafers used in many semiconductor devices.

**Curing coatings**—Resistance furnaces are used in the finishing industry for baking vitreous enamel coatings onto metal substrates and for drying and curing organic coatings, such as paints and varnishes, on a variety of materials. The main competitors to indirect resistance furnaces are medium and short wave infrared ovens.

**Glass tempering**—Glass is tempered by heating to a carefully controlled temperature (usually around 1100 to 1200 F) followed by rapid but uniform cooling. Tempering results in residual compressive stresses on the surface that provide greater resistance to fracture and damage. Typical products include automobile and architectural glass. Tempering is almost always carried out in resistance furnaces.

## Technical Considerations

Indirect resistance furnaces are usually designed for a particular application, although modifying an existing furnace to operate at a different temperature range is quite feasible.

Important factors to consider in selecting an indirect resistance furnace are:

- Heating element characteristics
- Form and arrangement of heating elements
- Material handling
- Power requirements.

### Heating element characteristics—

The choice of furnace heating elements is influenced by both the temperature required and the furnace atmosphere. Commercially available resistance heating elements are broadly characterized as metallic or nonmetallic. Common metallic elements, made of alloys containing various percentages of iron, nickel, chromium and aluminum, work up to approximately 2400 F. For temperatures above about 2200 F, however, noble or refractory metals, such as platinum, molybdenum, tantalum, or tungsten, or ceramic elements, including silicon carbide, molybdenum disilicide and graphite, are used.

The specific heating process and the workpiece material determine whether the furnace should have an air, inert, oxidizing, or reducing atmosphere, or whether a vacuum is appropriate. Many metallic heating elements can be used in air. However, molybdenum, tantalum, and tungsten elements cannot be exposed to oxygen. Molybdenum and tungsten work well in hydrogen or inert gas and in a vacuum. Tantalum absorbs hydrogen as it cools below 1200 F and also absorbs residual oxygen in an atmosphere. Therefore, tantalum elements are best used only in a

Element Material	Maximum Operating Temperature F	Operating Environment
Metal-sheathed elements	1300	Air
• Fe-Ni-Cr alloys	1850	Air
• Ni-Cr alloys	2000	Air
• Fe-Cr-Al alloys	2400	Air
Platinum	2900	Air
Platinum-rhodium alloys	3250	Air
Molybdenum	3400	Hydrogen
	4080	Vacuum
Tantalum	4000	Helium/argon
	4710	Vacuum
Tungsten	5425	Vacuum
• Silicon carbide	3100	Air
• Molybdenum disilicide	3275	Air
Carbon/graphite	5450	Helium/argon

\* These elements can also be used in a protective atmosphere. The maximum operating temperature will depend on the composition of the atmosphere. Consult heating element manufacturers for further details.

**Table 2. Operating Characteristics of Various Heating Element Materials**

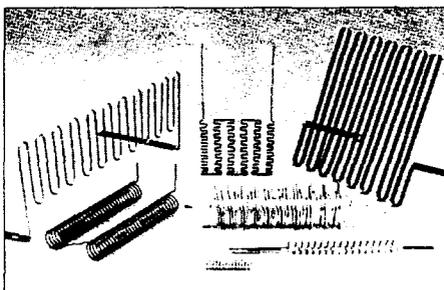
vacuum. Because they oxidize rapidly, graphite elements must also be used only in an inert or vacuum environment. However, silicon carbide and molybdenum disilicide can be used at high temperatures and in air. Maximum operating temperatures and environments for various heating element materials are shown in Table 2.

Heating element life is influenced by both operating temperature and furnace environment. However, average values are:

Operating Temperature F	Element Life Years
Below 1200	More than 4
1400-1600	2-4
2000	1-2

### Form and arrangement of heating elements—

Metallic heating elements come in a variety of forms, most commonly wires, rods, strips, ribbons, sheets, plates, and bars (Figure 1). Nonmetallic elements are usually rod-



**Figure 1. Common shapes and forms of metallic elements.**

shaped. Element form, as well as placement of elements within the furnace, is generally determined by the furnace manufacturer. A variety of factors influence the final choice. They include volume and shape of the furnace enclosure and the area available for the heating elements, and ease of installation and replacement of elements. Also considered are the types of treatment to be performed, the mode of heat transfer (radiation or convection), furnace insulation, the method of transporting material through the furnace, and the mechanical strength of the heating elements.

Element strength determines whether heating elements are arranged horizontally or vertically in the furnace. Horizontally mounted metallic elements tend to sag at high temperatures. Suspending them vertically relieves this problem. Element strength also determines to a certain extent whether radiant heat is transferred directly or indirectly from the elements to the charge. A "muffle" or tube furnace is used for indirect radiant heating. Heat passes by radiation from the heating element to the walls of the tube and then to the workpiece within the tube; such a design protects the heating elements and evens out temperature gradients and hot spots.

**Material handling**—Indirect resistance furnaces are available with both batch and continuous material handling. Batch furnaces can be used for a wider variety of products and

parts, and have more flexible cycle times. In continuous furnaces, the charge is moved through at a constant rate, either on a high-temperature mesh conveyor belt or by a mechanical pusher.

**Power requirements**—Because of the many material and processing parameters involved, precise estimates of power requirements for indirect resistance furnaces are best left to experienced furnace manufacturers or utility experts.

## Economic Considerations

The following factors should be taken into consideration in determining the economic feasibility of indirect resistance furnaces:

- Equipment cost
- Energy cost
- Maintenance costs.

**Equipment cost**—The cost of an indirect resistance furnace is deter-

mined mostly by size and operating temperature. A 2 x 3 x 1.5 ft. furnace operating up to about 2000 F would cost around \$60,000. Increasing the size to 5 x 6 x 5 ft. would increase the cost to \$200,000. Furnaces operating to higher temperatures are more expensive because of increased material costs.

**Energy cost**—Energy cost is determined by fuel cost and the operating efficiency of the furnace. On a per-BTU basis, natural gas usually costs about one-third as much as electricity. However, at 1800–2200 F a gas-fired furnace without a recuperator is only about 20% efficient. Adding a recuperator increases efficiency to 35–40%. But electric furnaces are typically 60–70% efficient. Thus, increased efficiency can often compensate for higher energy costs. The actual utilization break point at which electric resistance furnaces are more economical than gas-fired furnaces depends on the relative costs of electricity and gas.

**Maintenance costs**—Indirect resistance furnaces require no burner adjustment or other special maintenance. The major tasks are replacing burned out elements, which is usually easy, and cleaning out the furnace when necessary.

## In Summary

Indirect resistance heating is appropriate for a variety of heat treating, preheating, sintering, and brazing processes. The ease of temperature control, atmosphere control, and maintenance, combined with high energy efficiency, make it an attractive technique in the metals, ceramics, electronics, and glass industries, among others.

The information discussed in this issue of *TechCommentary* is an overview and intended only to familiarize you with the basic aspects of indirect resistance heating. If you are interested in more detailed information, please contact CMF or an equipment manufacturer.

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**CENTER FOR MATERIALS FABRICATION**

An EPRI R&D Applications Center

505 King Avenue • Columbus, Ohio 43201-2693

(614) 424-7742 • FAX (614) 424-4320

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