Kirk-Othmer Encyclopedia of Chemical Technology.

FURNACES, ELECTRIC, RESISTANCE FURNACES

The most widely used and best known resistance furnaces are indirect-heat resistance furnaces or electric resistor furnaces. They are categorized by a combination of four factors: batch or continuous; protective atmosphere or air atmosphere; method of heat transfer; and operating temperature. The primary method of heat transfer in an electric furnace is usually a function of the operating temperature range. The three methods of heat transfer are radiation, convection, and conduction. Radiation and convection apply to all of the furnaces described. Conductive heat transfer is limited to special types of furnaces.

Operating temperature ranges are classified as low, medium, and high; there is no standard or precise definition of these ranges. Generally, a low temperature furnace operates below 760°C, medium temperature ranges from 760–1150°C, and furnaces operating above 1150°C are high temperature furnaces. There is often indiscriminate use of the words furnace and oven. The term *oven* should be used when temperatures are below 760°C, and the word *furnace* applied for higher temperatures. The term furnace is used here regardless of operating temperature.

1. Batch and Continuous Furnaces

The determination of the need for either a batch or continuous furnace is dependent on production rate and the physical size and weight of the work to be processed.

1.1. Batch Furnaces

In *batch furnaces* the desired time–temperature cycle for the product to be processed is accomplished by subjecting the entire furnace and its contents or charge of work to the particular cycle. Batch furnaces are most often used for very large and/or heavy charges, low production rates, infrequent operation, variable time–temperature cycle, and processing material that must be in batches because of previous or subsequent operations. Larger batch furnaces are often of the elevator or car-bottom type. A typical *electric elevator furnace* is shown in Figure 1. In this furnace, the charge of one or many pieces is loaded onto the hearth of a car. The car is moved under the furnace and is hoisted into the furnace by way of an elevator mechanism which is part of the furnace. Very large or heavy loads are often processed in a car-bottom furnace similar to the elevator furnace except that the furnace is not elevated and the car carries the work into the furnace through a door at one end.

Medium-sized loads are often processed in a bell furnace, as shown in Figure 2. The operation of this furnace is opposite to that of an elevator furnace: the work load is placed on a stationary hearth and the furnace is lowered over the hearth. *Bell furnaces* are often arranged with two or more bases (hearths) which permit more efficient use of the furnace because one base can be unloaded/loaded as the furnace carries out a heating cycle on another base.

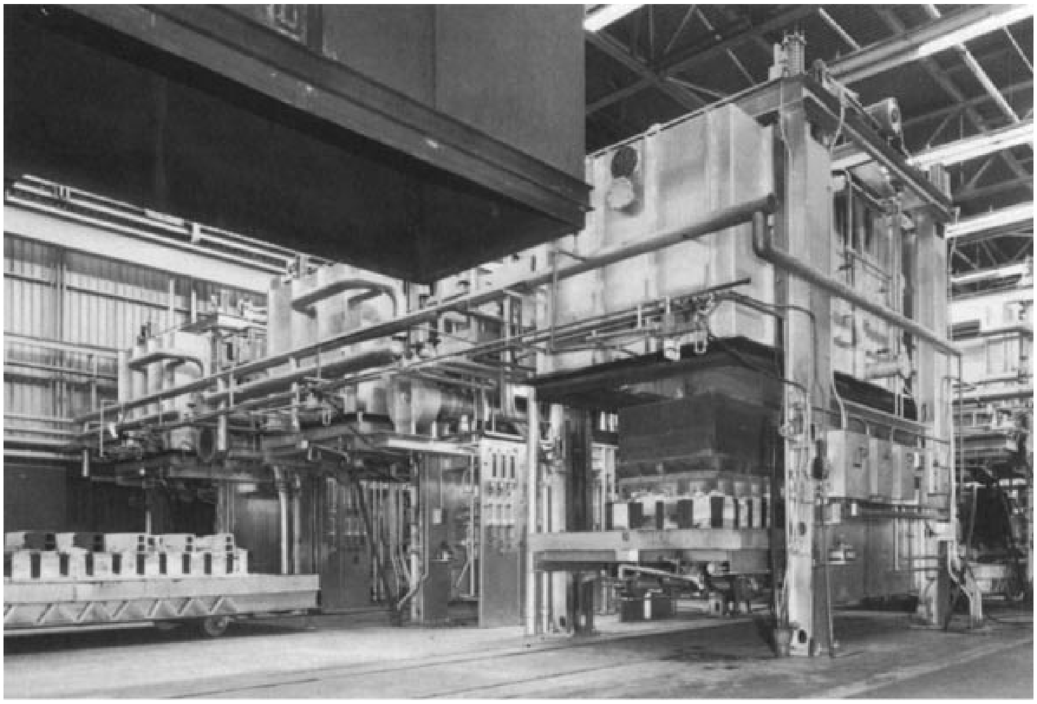

Fig. 1. Elevator furnace.Courtesy of Wellman Furnaces, Inc.

Small loads are commonly processed in a *box furnace*. The product is placed on the furnace hearth through a door. Box furnaces may be single-ended or double-ended. A single-ended box furnace is usually used in an air atmosphere application where the product can be removed hot from the furnace for cooling. A double-ended box furnace is usually used in a controlled atmosphere application. In this case a water cooler is attached to one end. The product can be placed on the hearth (in the heat chamber) through the front door, then after the product reaches temperature, it is manually transferred into the water cooler for cooling before it is manually removed out the exit door on the other end of the water cooler.

Other versions include the pit furnace, which is a box furnace with the door on top and which is often installed in a pit with the top of the furnace near floor level.

2. Continuous Furnaces

These furnaces are applicable for uniform charges of work that arrive at the furnace continuously, moderate to high production rates, constant time–temperature cycle, and continuous operation over at least one and preferably two or three shifts per day. The desired time–temperature cycle is designed into the continuous furnace. The charge is subjected to this cycle by moving it through chambers operating at different temperatures. Although temperatures may be varied, a sequence, eg, heat, cold, and cool, is a part of the furnace design, and it may be difficult and expensive to change this cycle once the furnace is built. Although multicycle continuous furnaces are possible, they are expensive and are subject to design limitations. Continuous furnaces are usually named for the method used to convey the material through the furnace.

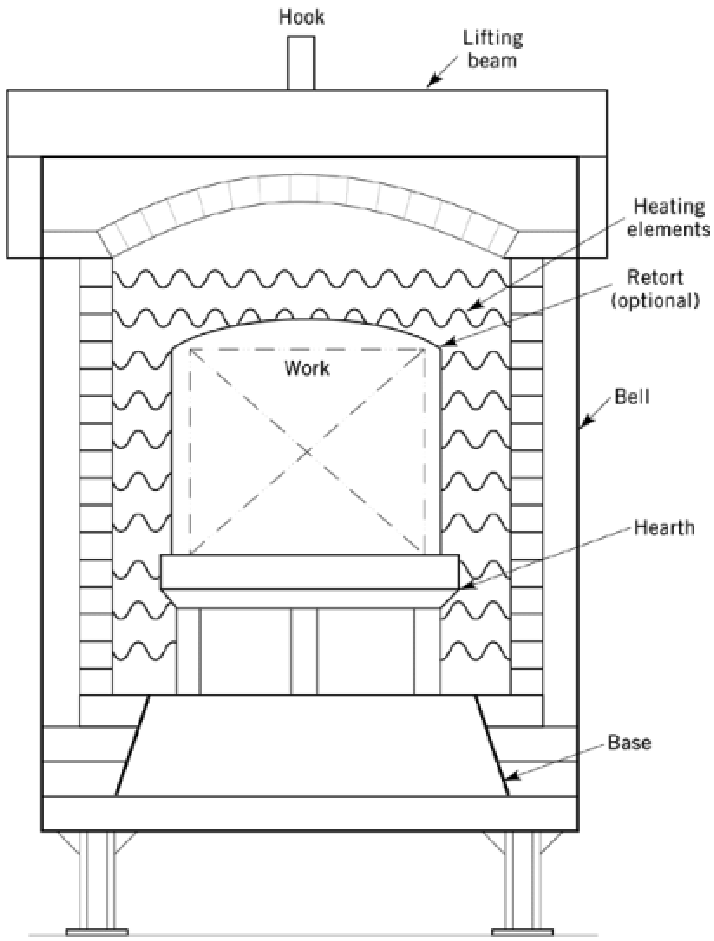

Fig. 2. Typical electric bell furnace.

The roller-hearth furnace shown in Figure 3 is used to process a wide variety of parts. Unless the configuration of the work permits it to roll on a roller conveyor, the charge is carried on a tray or, in the case of small parts, in a basket which is in turn carried by a tray. For any given operating temperature, the weight that can be carried per unit length of the furnace is limited by the strength of the rolls.

Light loads are often processed in a *mesh-belt furnace* which usually carries the work load directly on the mesh belt. At a given operating temperature, loading per unit area of the belt is limited by its tensile strength. Cast-link belt furnaces function in the same manner as mesh-belt furnaces except that the former carry heavier loads because the belt is made from suitable alloy castings instead of woven wire. The belt is normally contained in the furnace on both the working and return sides, whereas the mesh-belt usually exits the furnace with the work load and returns outside the furnace. Because of its large weight, it is uneconomical to let the cast-link belt cool on the return and reheat it with the work load.

In *pusher furnaces*, the product (work load) is pushed through the furnace in steps by a hydraulic or electromechanical mechanism that pushes each load into the furnace, thus pushing all work in the furnace ahead one work space. The walking-beam furnace lifts the work load on a walking beam, advances the load a

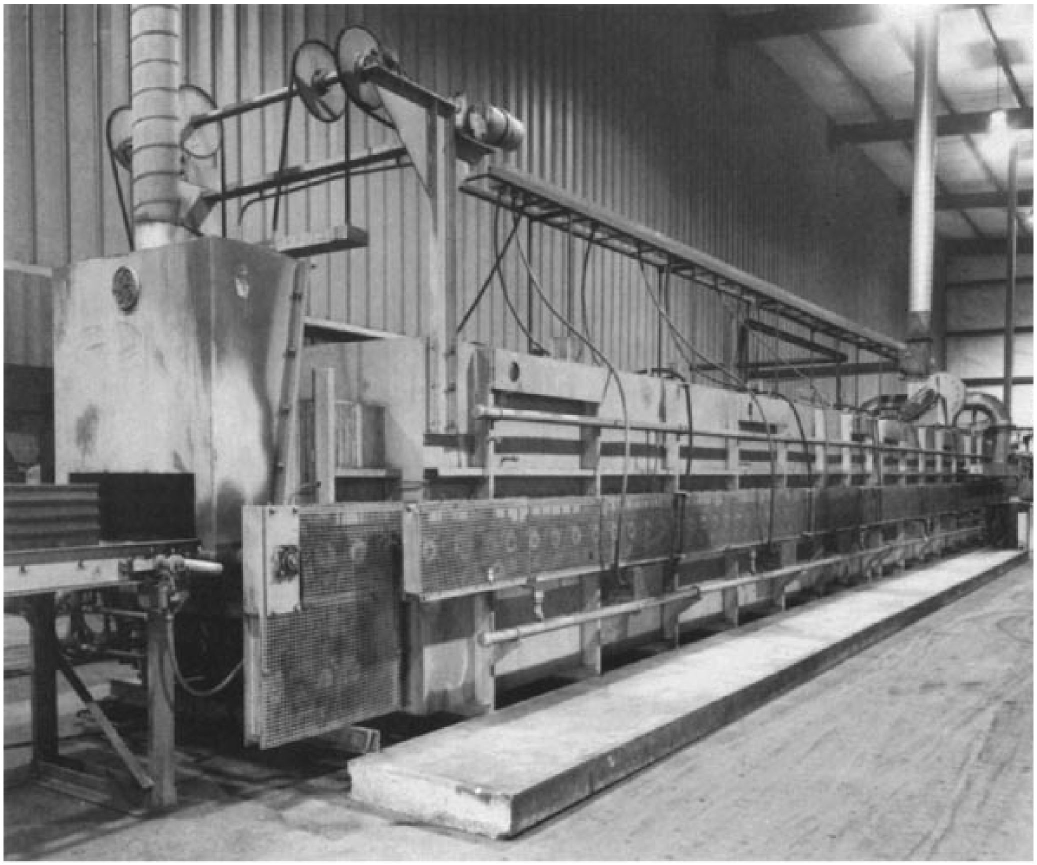

Fig. 3. Roller-hearth furnace. Courtesy of Wellman Furnaces, Inc.

step, and returns the work to the hearth. The walking beam then returns to its original position (under the hearth) in preparation for the next step.

3. Furnace Atmospheres

Electric furnaces can operate either with air in the interior of the furnace or with a protective atmosphere; the choice is dictated by the process requirements of the work. The furnace must be designed for the atmosphere to be used, because the combination of temperature and atmosphere are significant factors in selecting internal materials used in the furnace construction; this applies particularly to the selection of heating element (resistor) material. It is feasible and common to design an electric furnace that can operate in both air and protective atmospheres although shortened element life generally results from frequent alternating between reducing atmospheres and oxidizing atmospheres. There are exceptions to this rule as some resistor materials must be periodically oxidized, if used in a reducing atmosphere. Other resistor materials are limited to a particular atmosphere.

3.1. Air-Atmosphere Furnaces

These furnaces are applied to processes where the work load can tolerate the oxidation that occurs at elevated temperatures in air. In some special applications, the oxidation is not only tolerable but is desired. Some furnaces heat the work solely to promote oxidation. Furnaces designed for air operation are not completely gas-tight which results in somewhat lower construction costs. There are no particular problems encountered in selecting the insulation systems because almost all refractory insulations are made up of oxides. Heating element materials are readily available for the common temperature ranges used with air atmospheres.

3.2. Protective-Atmosphere Furnaces

These furnaces are used where the work cannot tolerate oxidation or where the atmosphere must provide a chemical or metallurgical reaction with the work. In some cases, mainly in high temperature applications, the atmosphere is required to protect the electric heating element from oxidation.

Protective-atmosphere furnaces are of two general types. In one type, the work is inside a muffle (retort) and the protective atmosphere is inside the muffle. The outside of the muffle and the interior of the furnace operate in air and are designed accordingly. The other type is gas-tight, and the atmosphere is introduced directly into the furnace, obviating the expensive and expendable retort or muffle. It does require careful selection of the internal furnace parts which must not be adversely affected by the atmosphere. The selection of electric heating elements must be carefully made with respect to operating temperature and atmosphere. The best material to use for a given application is a function of the combination of temperature and atmosphere.

The true operating temperature range and atmosphere must be specified in a description of an electric controlled-atmosphere furnace. Frequently, a higher temperature is specified than required for the contemplated operations, apparently with the thought that the higher temperature construction results in a safety factor. In the case of heating elements it can result in more expensive materials which, at the true operating temperature, are actually inferior to less expensive element materials. In addition to heating elements, there are other materials used in furnace construction that are satisfactory for one temperature range but are not suitable for a lower temperature operation.

4. Low Temperature Convection Furnaces

Low temperature convection furnaces are designed to transfer the heat from the heating elements by forced convection. Convection is normally used in furnaces operating below 760°C because it is the most effective means of heat transfer that can maintain good uniformity of temperature on various workload configurations. Convection furnaces also are used (in this range of temperatures) where it is important that no part of the work load exceed the controlled temperature. This is accomplished by shielding the work load from any view of the heating elements and by controlling the temperature of the air or atmosphere, which carries the heat from the heating elements to the work, at the desired maximum temperature.

One design for a *low temperature convection furnace* shown in Figure 4 utilizes an external circulating fan, heating chamber, and duct system. The fan draws air (or a protective atmosphere) from the furnace and passes through the external heating chamber and back into the furnace past the work. This system minimizes the chance that the work receives any direct heat radiation. In theory it is less efficient because the external blower, heating chamber, and ductwork add external surfaces that are subject to heat losses.

Another design, shown in Figure 5, functions similarly but all components are inside the furnace. An internal fan moves air (or a protective atmosphere) down past the heating elements located between the sidewalls and baffle, under the hearth, up past the work and back into the fan suction. Depending on the specific application, the flow direction may be reversed if a propeller-type fan is used. This design eliminates

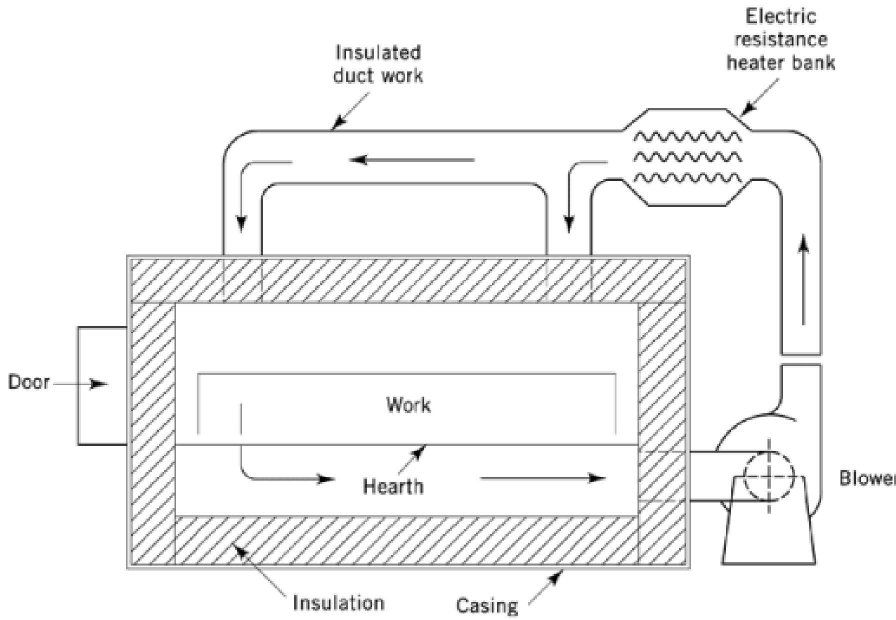

Fig. 4. External heating chamber convection furnace.

floorspace requirements and eliminates added heat losses of the external system but requires careful design to prevent radiant heat transfer to the work.

Heating elements operating $<760^\circ$C are almost always of a chrome–nickel resistance alloy and are in the form of ribbon, cast alloy, open wire coils, or sheathed construction. Several alloys are suitable in this temperature range and all are satisfactory if properly applied. In general, the more expensive alloys are used when physical space limitations dictate higher watts per area dissipation from the element.

5. Radiation Furnaces

5.1. Low Temperature Radiation Furnaces

These are of the infrared heater type. Heat transfer is by direct radiation from a high temperature heating element. Control of the heat is obtained by controlling the time of exposure to the heat radiation. This type of furnace is normally used for such applications as drying of paint films. Heating elements are nickel–chrome resistance wire which is wound on ceramic supports or contained in sheaths. Other materials include tungsten resistors in glass or quartz envelopes which exclude oxygen from the resistors.

5.2. Medium Temperature Radiation Furnaces

The temperature range is generally 760–1150°C. Most of the heat is transferred directly to the work by radiation from the heating elements and by radiation to the furnace refractory which reradiates the energy to the work. Heating elements may be located in the sidewalls, roof, or floor of the furnace. Location of heating elements must be selected to assure uniform temperatures in the work zone. Elements located below the hearth level require protection from falling work or other contaminants. Figure 6 shows a typical cross section through a radiation furnace.

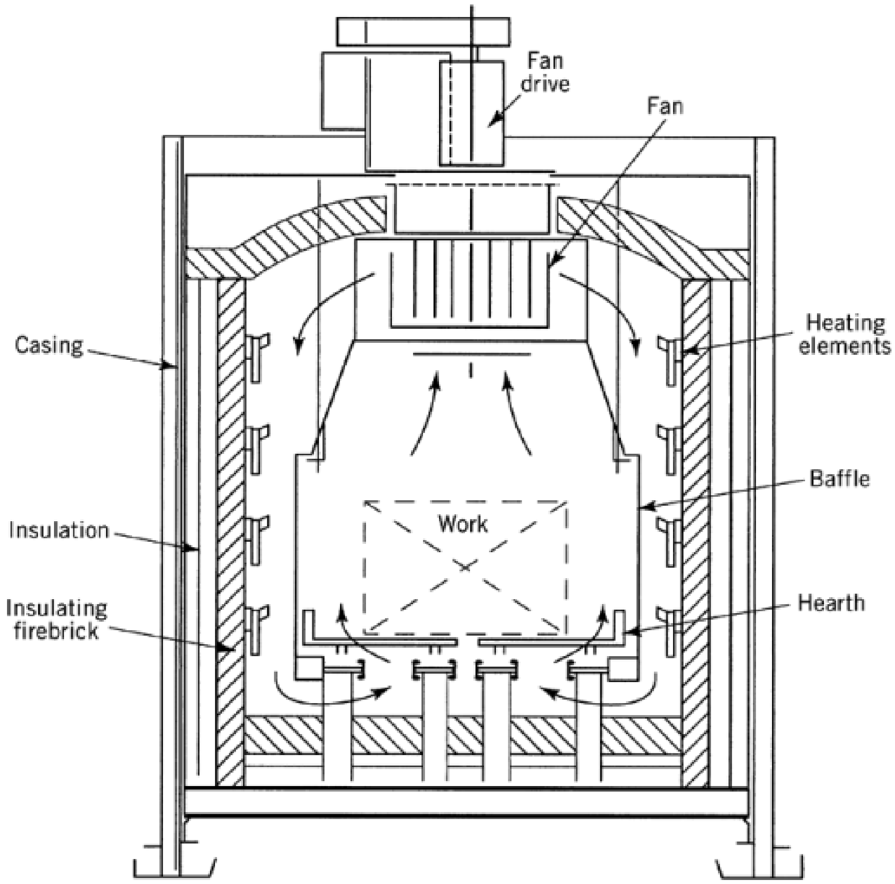

Fig. 5. Internal heating-element convection furnace cross section.

From 760 to 960°C, circulating fans, normally without baffles, are used to improve temperature uniformity and overall heat transfer by adding some convection heat transfer. They create a directional movement of the air or atmosphere but not the positive flow past the heating elements to the work as in a convection furnace. Heating elements are commonly chrome–nickel alloys in the forms described previously. Sheathed elements are limited to the very low end of the temperature range, whereas at the upper end silicon carbide resistors may be used. In this temperature range the selection of heating element materials, based on the combination of temperature and atmosphere, becomes critical (1).

5.3. High Temperature Radiation Furnaces

These furnaces are similar in construction to medium temperature radiation furnaces, but operate above 1150°C. The insulation system must be designed to withstand the high temperatures, and internal structural parts become critical.

At temperatures above 1150°C, alloys used for the hearth or material handling systems in low and medium temperature furnaces lose strength rapidly (2) and temperatures are reached where ceramic refractories are required to support the work. This results in less use of roller-hearth and belt-type hearths and greater use of pushers or walking-beam designs for continuous furnaces.

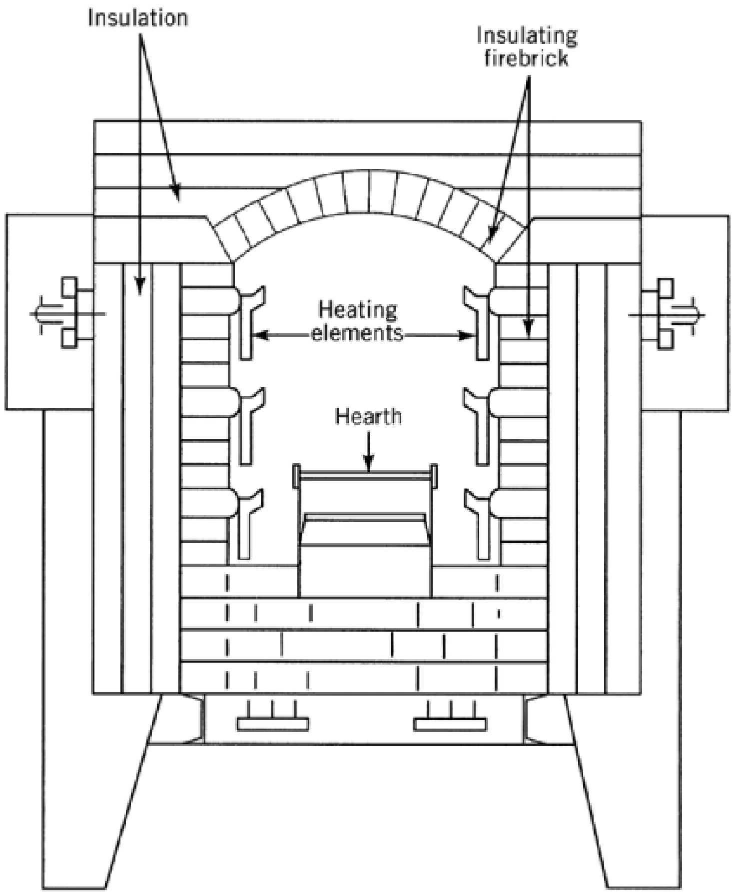

Fig. 6. Typical medium temperature radiation furnace cross section.

Chrome–nickel alloy heating elements that commonly are used in low temperature furnaces are not suitable above the very low end of the range. Elements commonly used as resistors are either silicon carbide, carbon, or high temperature metals, eg, molybdenum and tungsten. The latter impose stringent limitations on the atmosphere that must be maintained around the heating elements to prevent rapid element failure (3), or the furnace should be designed to allow easy, periodic replacement.

Refractory selection becomes critical with high temperature radiation furnaces that have molybdenum or tungsten heating elements. Although these elements are stable in vacuum or inert atmospheres, many applications require a reducing atmosphere, often high in hydrogen content and very dry. In these cases, there is the possibility of reducing the oxides that make up refractory insulations. Published data are available relating temperature and dew point at which hydrogen reduces the various oxides present in insulations (4). If this point is reached, the reduction process begins to destroy the insulation system of the furnace, thus limiting the maximum practical operating temperature to less than the capability of the heating element material (see Refractories).

5.4. Vacuum Radiation Furnaces

Vacuum furnaces are used where the work can be satisfactorily processed only in a vacuum or in a protective atmosphere. Most vacuum furnaces use molybdenum heating elements. Because all heat transfer is by radiation, metal radiation shields are used to reduce heat transfer to the furnace casing. The casing is water-cooled and a sufficient number of radiation shields between the inner cavity and the casing reduce the heat flow to the casing to a reasonable level. These shields are substitutes for the insulating refractories used in other furnaces.

6. Conduction Furnaces

Conduction furnaces utilize a liquid at the operating temperature to transfer the heat from the heating elements to the work being processed. Some furnaces have a pot filled with a low melting metal, eg, lead, or a salt mixture, eg, sodium chloride and potassium chloride, with a radiation-type furnace surrounding the pot. Although final heat transfer to the work is by conduction from the hot lead or salt to the work, the initial transfer of heat from the resistors to the pot is by radiation.

Conduction furnaces are of three general types. One has a pot or crucible with suitable exterior insulation. Sheathed resistance elements are inside the pot which contains molten lead or another low melting metal. The molten metal can be the conductive medium that transfers heat to the work immersed in it, or the molten metal may be the work. Such furnaces are often used to supply molten-type metal, lead, zinc, etc. As the molten metal is removed, bars of the metal are added for melting. The initial charge of solid metal does not provide good surface contact with the heating elements and, because of this, the metal around the heating elements is often melted initially with a torch or other auxiliary heat during start up.

The *salt-bath furnace* is another type of conduction furnace. A molten salt not only provides the medium for conductive heat transfer, the salt is the heating resistor. These furnaces commonly are applied for temperatures ranging from slightly above the melting point of the salt to 1260°C. The salt-bath furnace shown in Figure 7 consists of a metal (or for higher temperatures, ceramic) crucible that is surrounded by a suitable insulating refractory and the outer casing. Metal electrodes immersed in the salt are connected to a low voltage power source. Placement of electrodes is important because the mean path through the salt determines the resistance of the salt which serves as heating resistor. The current should flow from electrode to electrode with a negligible amount of current passing through the work when it is immersed in the bath.

Cold sodium chloride, either granulated or solidified after melting, has a high electrical resistance and low heat conductance (see Sodium compounds). It is, therefore, necessary to make provisions for melting the initial charge of salt. This can be done by melting it in a radiation furnace and pouring the molten salt into the salt-bath furnace or by melting the salt in the salt-bath furnace with a torch. The torch method is necessary when a salt bath solidifies as a result of a planned maintenance shutdown or a prolonged power failure. If the shutdown is planned, heat conducting metal tubes can be placed in the bath to improve heat transfer when remelting the salt.

The third type of conduction furnace is a fluidized bed. In this design the product to be heated is submerged in sand, which is supported by a high porosity plate. Heated air (or atmosphere) is recirculated through the porous plate and sand, which gives a high heat-transfer efficiency to the product. The disadvantage of this furnace is the product usually has a lot of warpage. To correct this, fixturing usually is required, which means more mass needs to be heated. Fluidized-bed furnaces are usually used at low and medium temperature ranges; the higher the temperature the more maintenance is needed on the recirculating fan.

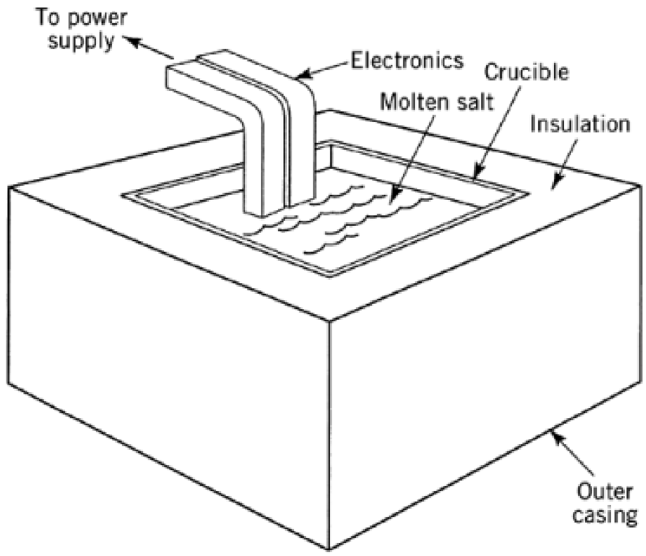

Fig. 7. Salt-bath furnace.

7. Direct-Heat Electric-Resistance Furnaces

Direct-heat electric furnaces use the material to be heated as the resistor, and the furnace consists of an insulated enclosure to retain the heat, a power source of suitable voltage, and means of attaching the power leads to the work (Fig. 8). This type of furnace has several limitations that have prevented widespread use. Since the work is the resistor, it must have a uniform cross section between power connection points, and the material must be homogeneous. Varying sections or nonuniformities in the material can produce hot or cold spots in proportion to the change in electrical resistance. Also, a given furnace must be designed for work in which each piece to be heated has about the same resistance and power requirements. Although voltage and power can be controlled, a furnace designed to heat a part with a given cross section and length probably does not have the voltage required to heat a part of twice the length and half the cross section or have the current capacity to heat a part of half the length and twice the cross section.

There are additional problems in making the electrical connections to the work to be heated. The connection must have low electrical resistance to prevent overheating at the point of contact, but such a connection has a low resistance to heat transfer, thus conducting heat away from the work. These problems have limited the use of direct-resistance heating mainly to heating of pipe, tubing, bars, or small identical parts. This heating is a one-piece-at-a-time batch operation and often does not use an insulated housing; instead it is used as a preheater for a forming operation that takes place as soon as the work reaches the desired temperature.

There are large-scale operations using direct-heat resistance furnaces. These are mainly in melting bulk materials where the liquid material serves as a uniform resistor. The material is contained in a crucible of fixed dimensions which, coupled with a given resistivity of the material, fixes the total resistance within reasonable limits. The most common application for this type of direct-heat electric resistance furnace is the melting of glass (qv) and arc furnaces for the melting of steel (qv).

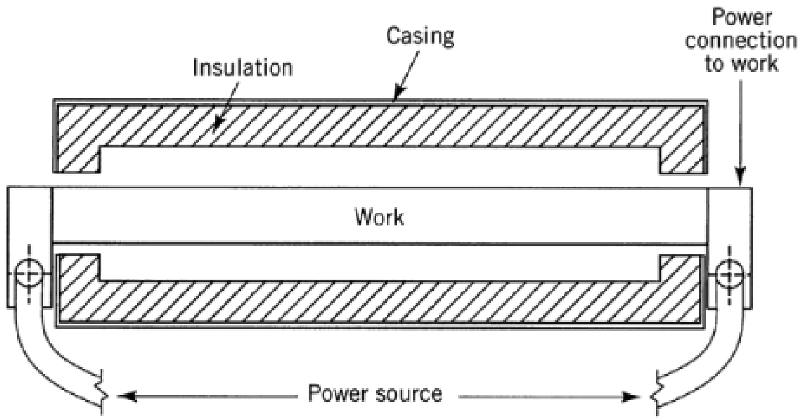

Fig. 8. Direct-heat resistance furnace.

8. Applications

Electric furnaces are used for annealing, brazing, carburizing, galvanizing, forging, hardening, melting, sintering, enameling, and tempering metals, most notably aluminum, copper, iron and steel, and magnesium alloys. Protection of metals is done in exothermic (lean and rich), prepared nitrogen (lean and rich), endothermic (lean and rich), charcoal, exothermic–endothermic (lean and rich), dissociated ammonia, and combusted ammonia (lean and rich) atmosphere.

BIBLIOGRAPHY

"Resistance Furnaces" under "Furnaces, Electric" in *ECT* 1st ed., Vol. 7, pp. 16–23, by V. Paschkis, Columbia University; in *ECT* 2nd ed., Vol. 10, pp. 269–278, by V. Paschkis, Columbia University; in *ECT* 3rd ed., Vol. 11, pp. 551–562, by R. M. Miller, Wellman Thermal Systems Corp.

Cited Publications

1. C. D. Starr and F. M. Cole, *Ind. Heat Mag.* (Oct. 1963).
2. *High Alloy Data Sheets, Heat Series*, Alloy Casting Institute Division, Steel Founders' Society of America, New York, 1973.
3. *How to Make Out With Moly*, Schwarzkopf Development Corp., Holliston, Mass.
4. *Hydrogen Atmospheres, Their Influence on Serviceability of Refractories*, paper 2, Babcox & Wilcox Co., Refractories Division, Augusta, Ga., 1971.

General References

5. W. Trinks and M. Mawhinney, *Industrial Furnaces, Principles of Design and Operation*, 5th ed., Vol. **1**, John Wiley & Sons, Inc., New York, 1961, 486 pp.

6. W. Trinks and M. Mawhinney, *Industrial Furnaces, Fuels, Furnace Types and Furnace Equipment—Their Selection and Influence Upon Furnace Operation*, 4th ed., Vol. **2**, John Wiley & Sons, Inc., New York, 1967, 358 pp.
7. V. Paschkis and J. Persson, *Industrial Electric Furnaces and Appliances*, 2nd ed., Interscience Publishers, a division of John Wiley & Sons, Inc., New York, 1960.

ROBERT R. WALTON
Wellman Furnaces, Inc.

Related Articles

Furnaces, Electric, Introduction; Furnaces, Electric, Arc Furnaces; Furnaces, Electric, Induction; Furnaces, fuel-fired; Refractories