FURNACES AND REFRACTORIES

1. INTRODUCTION

This section introduces furnaces and refractories and explains the various design and operation aspects.

1.1 What is a furnace?

A furnace is an equipment used to melt metals for casting or to heat materials to change their shape (e.g. rolling, forging) or properties (heat treatment).

Since flue gases from the fuel come in direct contact with the materials, the type of fuel chosen is important. For example, some materials will not tolerate sulphur in the fuel. Solid fuels generate particulate matter, which will interfere the materials placed inside the furnace. For this reason:

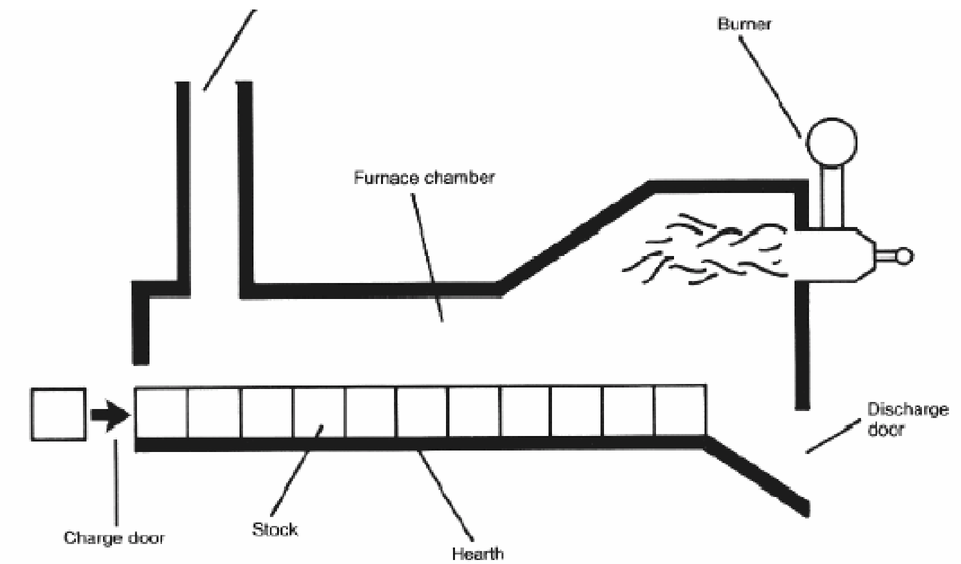
- Most furnaces use liquid fuel, gaseous fuel or electricity as energy input.
- Induction and arc furnaces use electricity to melt steel and cast iron.
- Melting furnaces for nonferrous materials use fuel oil.
- Oil-fired furnaces mostly use furnace oil, especially for reheating and heat treatment of materials.
- Light diesel oil (LDO) is used in furnaces where sulphur is undesirable.

Furnace ideally should heat as much of material as possible to a uniform temperature with the least possible fuel and labor. The key to efficient furnace operation lies in complete combustion of fuel with minimum excess air. Furnaces operate with relatively low efficiencies (as low as 7 percent) compared to other combustion equipment such as the boiler (with efficiencies higher than 90 percent. This is caused by the high operating temperatures in the furnace. For example, a furnace heating materials to 1200 ^{o}C will emit exhaust gases at 1200 ^{o}C or more, which results in significant heat losses through the chimney.

All furnaces have the following components as shown in Figure 1 (Carbon Trust, 1993):

- Refractory chamber constructed of insulating materials to retain heat at high operating temperatures.
- Hearth to support or carry the steel, which consists of refractory materials supported by a steel structure, part of which is water-cooled.
- Burners that use liquid or gaseous fuels to raise and maintain the temperature in the chamber. Coal or electricity can be used in reheating furnaces.
- Chimney to remove combustion exhaust gases from the chamber
- Charging and discharging doors through which the chamber is loaded and unloaded. Loading and unloading equipment include roller tables, conveyors, charging machines and furnace pushers.

Figure 1: Typical Furnace Components (The Carbon Trust, 1993)



1.2 What are refractories?[1]

Any material can be described as a 'refractory,' if it can withstand the action of abrasive or corrosive solids, liquids or gases at high temperatures. The various combinations of operating conditions in which refractories are used, make it necessary to manufacture a range of refractory materials with different properties. Refractory materials are made in varying combinations and shapes depending on their applications. General requirements of a refractory material are:

- Withstand high temperatures
- Withstand sudden changes of temperatures
- Withstand action of molten metal slag, glass, hot gases, etc
- Withstand load at service conditions

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[1] Section 1.2 is taken (with edits) from *Energy Efficiency in Thermal Utilities,* 2005 with permission from the Bureau of Energy Efficiency, Ministry of Power, India.

- Withstand load and abrasive forces
- Conserve heat
- Have low coefficient of thermal expansion
- Should not contaminate the material with which it comes into contact

Table 1 compares the thermal properties of typical high density and low density refractory materials.

Table 1. Typical Refractory Properties (The Carbon Trust, 1993)

Property	**High Thermal Mass (High density refractories)**	**Low Thermal Mass (Ceramic fiber)**
Thermal conductivity (W/m K)	1.2	0.3
Specific heat (J/kg K)	1000	1000
Density (kg/m3)	2300	130

Depending on the area of application such as boilers, furnaces, kilns, ovens etc, temperatures and atmospheres encountered different types of refractories are used. Typical installations of refractories are shown in Figure 2.

Figure 2a. Refractory lining of a furnace arch (BEE, 2005)

Figure 2b. Refractory walls of a furnace interior with burner blocks (BEE, 2005)

Some of the important properties of refractories are:

Melting point: Pure substances melt instantly at a specific temperature. Most refractory materials consist of particles bonded together that have high melting temperatures. At high temperatures, these particles melt and form slag. The melting point of the refractory is the temperature at which a test pyramid (cone) fails to support its own weight.

Size: The size and shape of the refractories is a part of the design of the furnace, since it affects the stability of the furnace structure. Accurate size is extremely important to properly fit the refractory shape inside the furnace and to minimize space between construction joints.

Bulk density: The bulk density is useful property of refractories, which is the amount of refractory material within a volume (kg/m3). An increase in bulk density of a given refractory increases its volume stability, heat capacity and resistance to slag penetration.

Porosity: The apparent porosity is the volume of the open pores, into which a liquid can penetrate, as a percentage of the total volume of the refractory. This property is important when the refractory is in contact with molten charge and slag. A low apparent porosity prevents molten material from penetrating into the refractory. A large number of small pores is generally preferred to a small number of large pores.

Cold crushing strength: The cold crushing strength is the resistance of the refractory to crushing, which mostly happens during transport. It only has an indirect relevance to refractory performance, and is used as one of the indicators of abrasion resistance. Other indicators used are bulk density and porosity.

Pyrometric cones and Pyrometric cones equivalent (PCE)**:** The 'refractoriness' of (refractory) bricks is the temperature at which the refractory bends because it can no longer support its own weight. Pyrometric cones are used in ceramic industries to test the refractoriness of the (refractory) bricks. They consist of a mixture of oxides that are known to melt at a specific narrow temperature range. Cones with different oxide composition are placed in sequence of their melting temperature alongside a row of refractory bricks in a furnace. The furnace is fired and the temperature rises. One cone will bends together with the refractory brick. This is the temperature range in oC above which the refractory cannot be used. This is known as Pyrometric Cone Equivalent temperatures. (Figure 3)

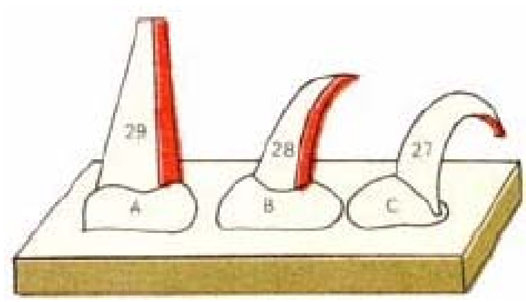

Figure 3: Pyrometric Cones
(Bureau of Energy Efficiency, 2004)

Creep at high temperature: Creep is a time dependent property, which determines the deformation in a given time and at a given temperature by a refractory material under stress.

Volume stability, expansion, and shrinkage at high temperatures: The contraction or expansion of the refractories can take place during service life. Such permanent changes in dimensions may be due to:

- The changes in the allotropic forms, which cause a change in specific gravity
- A chemical reaction, which produces a new material of altered specific gravity
- The formation of liquid phase
- Sintering reactions

- Fusion dust and slag or by the action of alkalies on fireclay refractories, to form alkali-alumina silicates. This is generally observed in blast furnaces.

Reversible thermal expansion: Any material expands when heated, and contracts when cooled. The reversible thermal expansion is a reflection on the phase transformations that occur during heating and cooling.

Thermal conductivity: Thermal conductivity depends on the chemical and mineralogical composition and silica content of the refractory and on the application temperature. The conductivity usually changes with rising temperature. High thermal conductivity of a refractory is desirable when heat transfer though brickwork is required, for example in recuperators, regenerators, muffles, etc. Low thermal conductivity is desirable for conservation of heat, as the refractory acts as an insulator. Additional insulation conserves heat but at the same time increases the hot face temperature and hence a better quality refractory is required. Because of this, the outside roofs of open-hearth furnaces are normally not insulated, as this could cause the roof to collapse. Lightweight refractories of low thermal conductivity find wider applications in low temperature heat treatment furnaces, for example in batch type furnaces where the low heat capacity of the refractory structure minimizes the heat stored during the intermittent heating and cooling cycles. Insulating refractories have very low thermal conductivity. This is usually achieved by trapping a higher proportion of air into the structure. Some examples are:

- Naturally occurring materials like asbestos are good insulators but are not particularly good refractories
- Mineral wools are available which combine good insulating properties with good resistance to heat but these are not rigid
- Porous bricks are rigid at high temperatures and have a reasonably low thermal conductivity.

2. TYPES OF FURNACES, REFRACTORIES AND INSULATION

This section describes the types of furnaces, refractories and insulation materials used in industry. It also gives criteria for selecting refractory types for optimum results.

2.1 Types of furnaces

Furnaces are broadly classified into two types based on the heat generation method: combustion furnaces that use fuels, and electric furnaces that use electricity. Combustion furnaces can be classified in several based as shown in Table 2: type of fuel used, mode of charging the materials, mode of heat transfer and mode of waste heat recovery. However, it is not possible to use this classification in practice, because a furnace can be using different types of fuel, different ways to charge materials into the furnace etc. The most commonly used furnaces are described in the next sections

Table 2. Classification of furnaces

Classification method	Types and examples
Type of fuel used	Oil-fired
	Gas-fired
	Coal-fired
Mode of charging materials	Intermittent / Batch
	Periodical ▪ Forging ▪ Re-rolling (batch/pusher) ▪ Pot
	Continuous ▪ Pusher ▪ Walking beam ▪ Walking hearth ▪ Continuous recirculating bogie furnaces ▪ Rotary hearth furnaces
Mode of heat transfer	Radiation (open fire place)
	Convection (heated through medium)
Mode of waste heat recovery	Recuperative
	Regenerative

2.1.1 Forging furnace[2]

The forging furnace is used for preheating billets and ingots to attain a 'forge' temperature. The furnace temperature is maintained at around 1200 to 1250 ^{o}C. Forging furnaces use an open fireplace system and most of the heat is transmitted by radiation. The typical load is 5 to 6 ton with the furnace operating for 16 to 18 hours daily. The total operating cycle can be divided into (i) heat-up time (ii) soaking time and (iii) forging time. Specific fuel consumption depends upon the type of material and number of 'reheats' required.

2.1.2 Re-rolling mill furnace

a) Batch type

A box type furnace is used as a batch type re-rolling mill. This furnace is mainly used for heating up scrap, small ingots and billets weighing 2 to 20 kg for re-rolling. Materials are manually charged and discharged and the final products are rods, strips etc. The operating temperature is about 1200 ^{o}C. The total cycle time can be further categorized into heat-up time and re-rolling time. During heat-up time the material gets heated up-to the required temperature and is removed manually for re-rolling. The average output from these furnaces varies from 10 to 15 tons / day and the specific fuel consumption varies from 180 to 280 kg. of coal / ton of heated material.

b) Continuous pusher type

The process flow and operating cycles of a continuous pusher type is the same as that of the batch furnace. The operating temperature is about 1250 $_{o}$C. Generally, these furnaces operate 8 to 10 hours with an output of 20 to 25 ton per day. The material or stock recovers a part of the

[2] Sections 2.1.1 to 2.1.3 are taken (with edits) from *Energy Efficiency in Thermal Utilities*, 2005 with permission from the Bureau of Energy Efficiency, Ministry of Power, India.

heat in flue gases as it moves down the length of the furnace. Heat absorption by the material in the furnace is slow, steady and uniform throughout the cross-section compared with batch type.

2.1.3 Continuous reheating furnace

In continuous reheating, the steel stock forms a continuous flow of material and is heated to the desired temperature as it travels through the furnace. The temperature of a piece of steel is typically raised to between 900°C and 1250^{o}C, until it is soft enough to be pressed or rolled into the desired size or shape. The furnace must also meet specific stock heating rates for metallurgical and productivity reasons.

To ensure that the energy loss is kept to a minimum, the inlet and outlet doors should be minimal in size and designed to avoid air infiltration. Continuous reheating furnaces can be categorized by the two methods of transporting stock through the furnace:

- Stock is kept together to form a stream of material that is pushed through the furnace. Such furnaces are called pusher type furnaces.
- Stock is placed on a moving hearth or supporting structure which transports the steel through the furnace. The furnaces include walking beam, walking hearth, continuous recirculating bogie furnaces, and rotary hearth furnaces.

Table 3 compares the main types of continuous reheating furnaces used in industry.

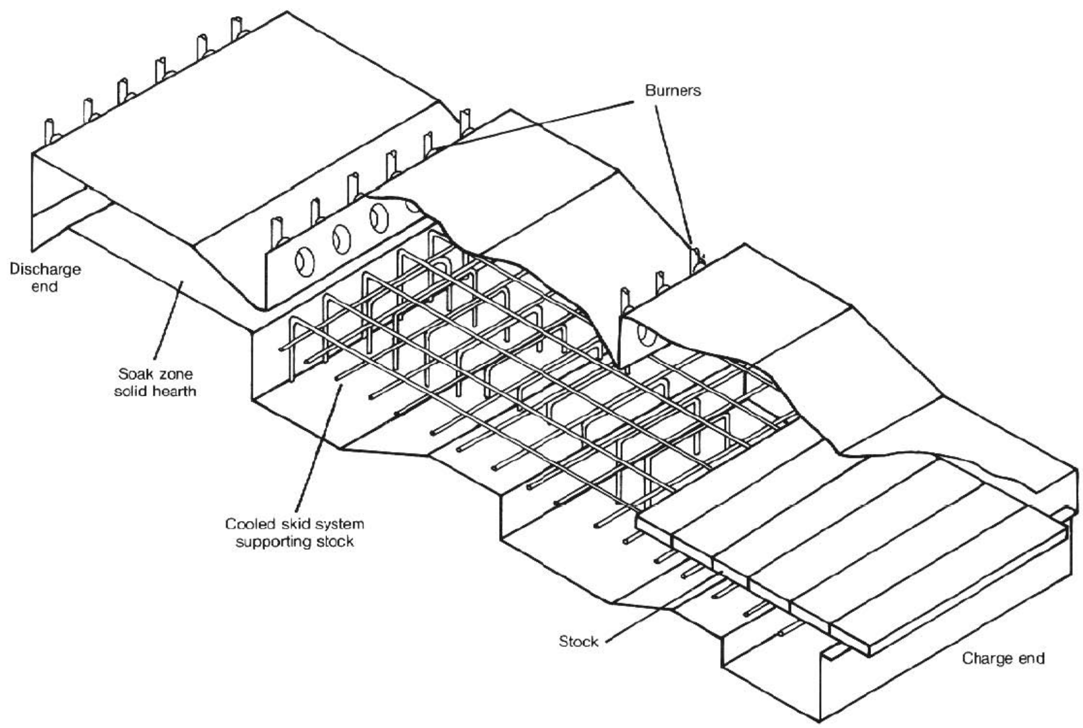

Figure 4. Pusher Furnace (The Carbon Trust, 1993)

Table 3. Comparison of Different Continuous Reheating Furnaces (Adapted from The Carbon Trust, 1993 and BEE, 2005)

Type	Description	Advantages	Disadvantages
Pusher furnace (Figure 4)	The main features are: ▪ Furnaces may have solid hearth, but in most cases pushers are used to charge and discharge stock, that move on "skids" (rails) with water-cooled supports. ▪ These furnaces typically have a hearth sloping towards the discharge end of up to 35 meters divided into five zones in top-fired furnaces. ▪ Firing of furnace by burners located at the discharge end of the furnace, or at top and/or bottom to heat stock from both top and/or bottom ▪ The discharge ends of these furnaces have a chimney with a recuperator for waste heat recovery.	Low installation and maintenance costs (compared with moving hearth furnaces) Advantages of top and bottom firing: ▪ Faster heating of stock ▪ Lower temperature differences within stock ▪ Reduced stock residence time ▪ Shorter furnace lengths (compared to solid hearth furnaces)	▪ Water cooling energy losses from the skids and stock supporting structure in top and bottom fired furnaces ▪ Discharge must be accompanied by charge ▪ Stock sizes/weights and furnace length are limited by friction and possibility of stock pile-ups ▪ Furnace needs facilities to be completely emptied ▪ Quality reduction by (a) physical marking by skids or 'skid marks' (b) temperature differences along the stock length caused by the water cooled supports in top and bottom fired furnaces
Walking beam furnace (Figure 5)	These furnaces operate as follows: ▪ Stock is placed on stationary ridges ▪ Walking beams are raised from the bottom to raise the stock ▪ Walking beams with the stock move forwards ▪ Walking beams are lowered at end of the furnace to place stock on stationary ridges ▪ Stock is removed from furnace and walking beams return to furnace entrance Initially temperatures were limited 1000 ^{0}C but new models are able to reach 1100 ^{0}C	▪ Overcomes many of the problems of pusher furnaces (skid marks, stock pile-ups, charge/discharge) ▪ Possible to heat bottom face of the stock resulting in shorter stock heating times and furnace lengths and thus better control of heating rates, uniform stock discharge temperatures and operational flexibility	▪ High energy loss through water cooling (compared with walking hearth furnaces) ▪ Much of the furnace is below the level of the mill; this may be a constraint in some applications ▪ Sometimes when operating mechanism of beam make it necessary to fire from the sides, this results in non-uniform heating of the stock

Type	Description	Advantages	Disadvantages
Walking hearth furnace (Figure 6)	These furnaces are designed so that the stock rests on fixed refractory blocks, which are extended through openings in the hearth. The stock is transported towards the discharge end in discrete steps by "walking the hearth", similar to walking beam furnaces	▪ Simplicity of design ▪ Ease of construction ▪ Ability to cater for different stock sizes (within limits) ▪ Negligible water cooling energy losses ▪ Can be emptied ▪ Minimal physical marking of the stock	▪ Temperatures across the stock are not uniform because the bottom of stock cannot be heated and small spaces between the stock limits heating of the sides. Large spaces between stocks can partially alleviate this. But this increases stock residence time to up to several hours, which affects furnace flexibility and yield
Continuous recirculating bogie furnace (Figure 7)	The furnace has the shape of a long and narrow tunnel with rails inside and works as follows: ▪ Stock is placed on a bogie (cart with wheels) with a refractory hearth ▪ Several bogies move like a train over the entire furnace length through the furnace ▪ Stock is removed at the discharge end and the bogie returns to the charge end of the furnace	▪ Suitable for compact stock of variable size and geometry	▪ The stock in the bogie has to undergo a cycle of heating and cooling then again heating ▪ Heat storage loss through heating and cooling of the bogies ▪ Inadequate sealing of the gap between the bogies and furnace shell, difficulties in removing scale, and difficulties in firing across a narrow hearth width caused by the narrow and long furnace shape
Rotary hearth furnace (Figure 8)	More recent developed furnace type that is overtaking the bogie furnace. The walls and the roof of the furnace remains stationery while the hearth moves in a circle on rollers, carrying the stock. Heated gas moves in opposite direction of the hearth and flue gases are discharged near the charging door. The temperature can reach 1300 ^{o}C	▪ Suitable for stock of variable size and geometry ▪ Reduced heat storage loss compared to bogie furnace	▪ More complex design with an annular shape and revolving hearth ▪ Possible logistical problems in layout of some rolling mills and forges because of close location of charge and discharge positions

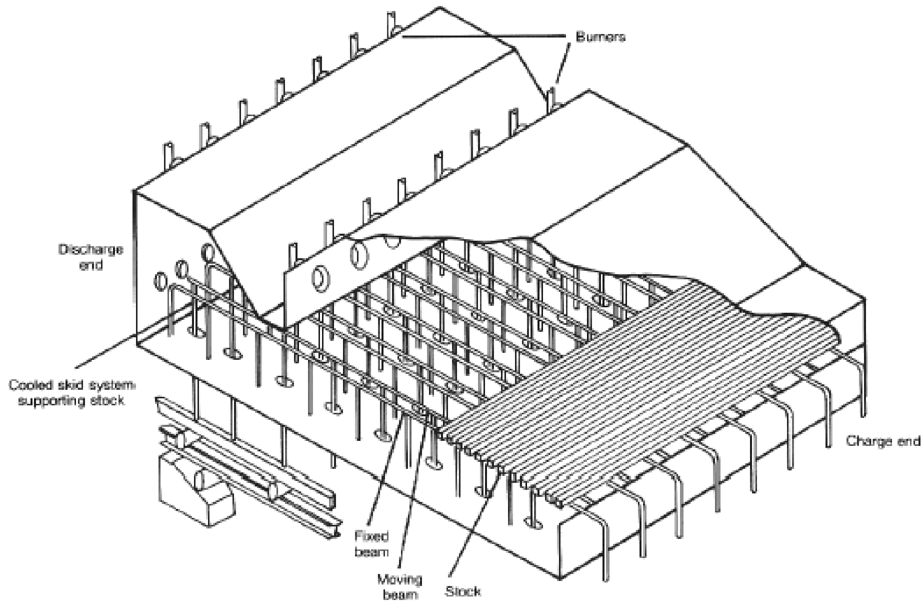

Figure 5. Walking Beam Furnace (The Carbon Trust 1993)

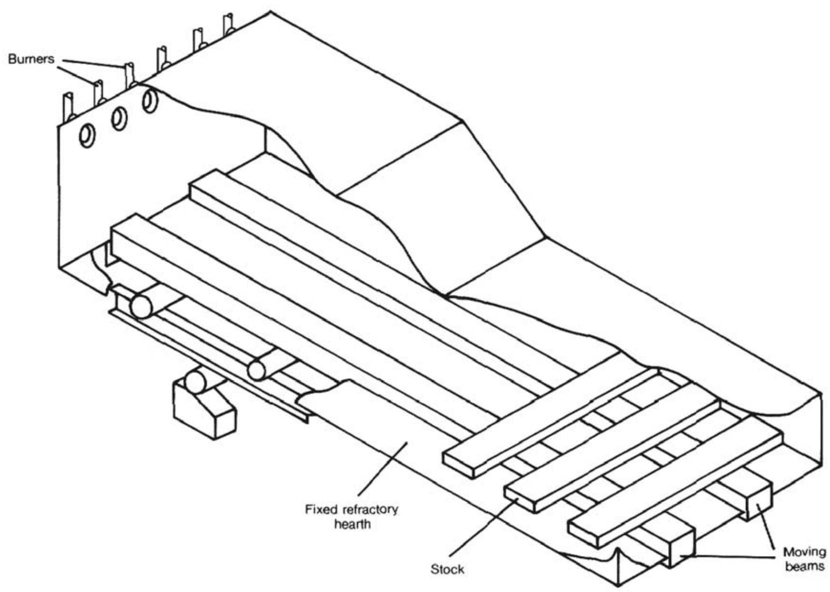

Figure 6. Walking Hearth Furnace (The Carbon Trust, 1993)

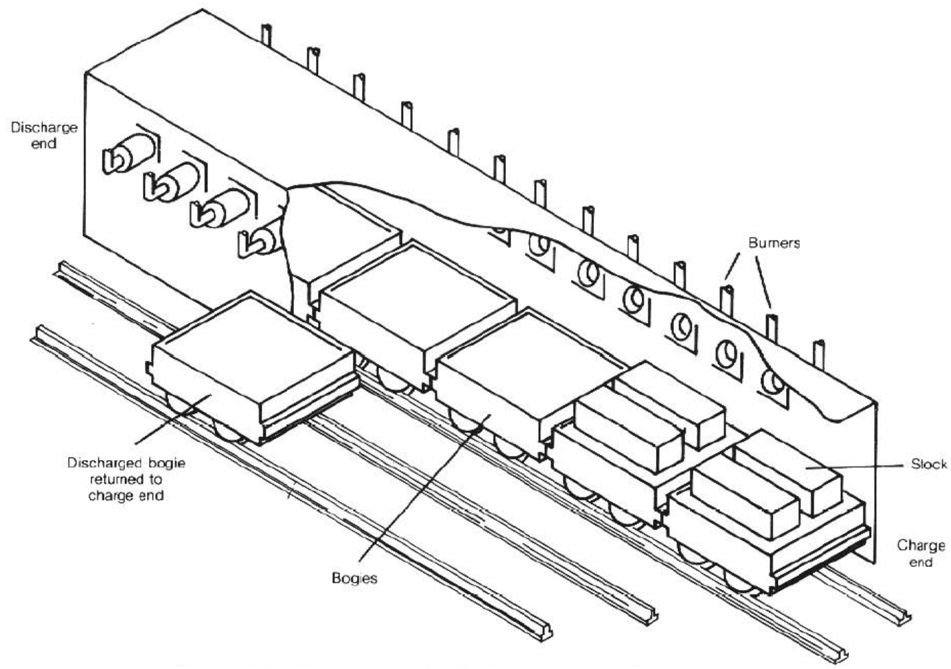

Figure 7. Continuous Re-circulating Bogie Furnace (The Carbon Trust, 1993)

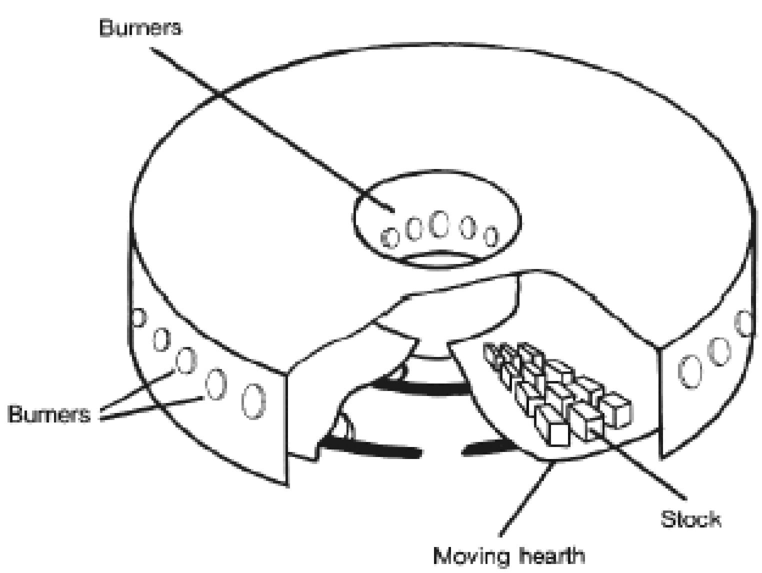

Figure 8. Rotary Hearth Furnace (The Carbon Trust, 1993)

2.2 Types of refractories [3]

Refractories can be classified on the basis of chemical composition, end use and methods of manufacture as shown below.

Table 4. Classification of refractories based on chemical composition (Adapted from Gilchrist)

Classification method	Examples
Chemical composition	
ACID, which readily combines with bases	Silica, Semisilica, Aluminosilicate
BASIC, which consists mainly of metallic oxides that resist the action of bases	Magnesite, Chrome-magnesite, Magnesite-chromite, Dolomite
NEUTRAL, which does not combine with acids nor bases	Fireclay bricks, Chrome, Pure Alumina
Special	Carbon, Silicon Carbide, Zirconia
End use	Blast furnace casting pit
Method of manufacture	Dry press process, fused cast, hand moulded, formed normal, fired or chemically bonded, unformed (monolithics, plastics, ramming mass, gunning castable, spraying)

2.2.1 Fireclay refractories

Firebrick is the most common form of refractory material. It is used extensively in the iron and steel industry, nonferrous metallurgy, glass industry, pottery kilns, cement industry, and many others.

Fireclay refractories, such as firebricks, siliceous fireclays and aluminous clay refractories consist of aluminum silicates with varying silica (SiO_2) content of up to 78 percent and Al_2O_3 content of up to 44 percent. Table 5 shows that the melting point (PCE) of fireclay brick decreases with increasing impurity and decreasing Al_2O_3. This material is often used in furnaces, kilns and stoves because the materials are widely available and relatively inexpensive.

Table 5. Properties of typical fireclay bricks (BEE, 2005)

Brick type	Percentage SiO_2	Percentage Al_2O_3	Percentage other constituents	PCE ^oC
Super Duty	49-53	40-44	5-7	1745-1760
High Duty	50-80	35-40	5-9	1690-1745
Intermediate	60-70	26-36	5-9	1640-1680
High Duty (Siliceous)	65-80	18-30	3-8	1620-1680
Low Duty	60-70	23-33	6-10	1520-1595

[3] Section 2.2 is taken (with edits) from *Energy Efficiency in Thermal Utilities,* 2005 with permission from the Bureau of Energy Efficiency, Ministry of Power, India.

2.2.2 High alumina refractories
Alumina silicate refractories containing more than 45 percent alumina are generally termed as high alumina materials. The alumina concentration ranges from 45 to 100 percent. The refractoriness of high alumina refractories increases with increase in alumina percentage. The applications of high alumina refractories include the hearth and shaft of blast furnaces, ceramic kilns, cement kilns, glass tanks and crucibles for melting a wide range of metals.

2.2.3 Silica brick
Silica brick (or Dinas) is a refractory that contains at least 93 percent SiO_2. The raw material is quality rocks. Various grades of silica brick have found extensive use in the iron and steel melting furnaces and the glass industry. In addition to high fusion point multi-type refractories, other important properties are their high resistance to thermal shock (spalling) and their high refractoriness. The outstanding property of silica brick is that it does not begin to soften under high loads until its fusion point is approached. This behavior contrasts with that of many other refractories, for example alumina silicate materials, which begin to fuse and creep at temperatures considerably lower than their fusion points. Other advantages are flux and stag resistance, volume stability and high spalling resistance.

2.2.4 Magnesite
Magnesite refractories are chemically basic materials, containing at least 85 percent magnesium oxide. They are made from naturally occurring magnesite ($MgCO_3$). The properties of magnesite refractories depend on the concentration of silicate bond at the operating temperatures. Good quality magnesite usually results from a CaO-SiO_2 ratio of less than two with a minimum ferrite concentration, particularly if the furnaces lined with the refractory operate in oxidizing and reducing conditions. The slag resistance is very high particularly to lime and iron rich slags.

2.2.5 Chromite refractories
Two types of chromite refractories are distinguished:

- Chrome-magnesite refractories, which usually contain 15-35 percent Cr_2O_3 and 42-50 percent MgO. They are made in a wide range of qualities and are used for building the critical parts of high temperature furnaces. These materials can withstand corrosive slags and gases and have high refractoriness.
- Magnesite-chromite refractories, which contain at least 60 percent MgO and 8-18 percent Cr_2O_3. They are suitable for service at the highest temperatures and for contact with the most basic slags used in steel melting. Magnesite-chromite usually has a better spalling resistance than chrome-magnesite.

2.2.6 Zirconia refractories
Zirconium dioxide (ZrO_2) is a polymorphic material. It is essential to stabilize it before application as a refractory, which is achieved by incorporating small quantities of calcium, magnesium and cerium oxide, etc. Its properties depend mainly on the degree of stabilization, quantity of stabilizer and quality of the original raw material. Zirconia refractories have a very high strength at room temperature, which is maintained up to temperatures as high as 1500^0C. They are therefore useful as high temperature construction materials in furnaces and kilns. The thermal conductivity of zirconium dioxide is much lower than that of most other refractories and the material is therefore used as a high temperature insulating refractory. Zirconia exhibits very

low thermal losses and does not react readily with liquid metals, and is particularly useful for making refractory crucibles and other vessels for metallurgical purposes. Glass furnaces use zirconia because it is not easily wetted by molten glasses and does not react easily with glass.

2.2.7 Oxide refractories (Alumina)

Alumina refractory materials that consist of aluminium oxide with little traces of impurities are known as pure alumina. Alumina is one of the most chemically stable oxides known. It is mechanically very strong, insoluble in water, super heated steam, and most inorganic acids and alkalies. Its properties make it suitable for the shaping of crucibles for fusing sodium carbonate, sodium hydroxide and sodium peroxide. It has a high resistance in oxidizing and reducing atmosphere. Alumina is extensively used in heat processing industries. Highly porous alumina is used for lining furnaces operating up to 1850^{o}C.

2.2.8 Monolithics

Monolithic refractories are single piece casts in the shape of equipment, such as a ladle as shown in Figure 9. They are rapidly replacing the conventional type fired refractories in many applications including industrial furnaces. The main advantages of monolithics are:

- Elimination of joints which is an inherent weakness
- Faster application method
- Special skill for installation not required
- Ease of transportation and handling
- Better scope to reduce downtime for repairs
- Considerable scope to reduce inventory and eliminate special shapes
- Heat savings
- Better spalling resistance
- Greater volume stability

Monolithics are put into place using various methods, such as ramming, casting, gunniting, spraying, and sand slinging. Ramming requires proper tools and is mostly used in cold applications where proper consolidation of the material is important. Ramming is also used for air setting and heat setting materials. Because calcium aluminate cement is the binder, it will have to be stored properly to prevent moisture absorption. Its strength starts deteriorating after 6 to 12 months.

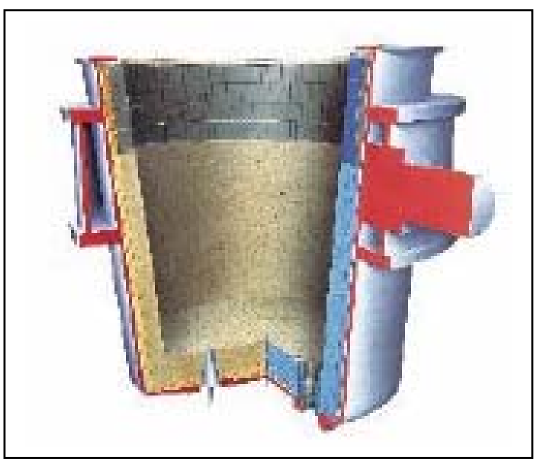

Figure 9. A Monolithic Lining for Ladel

2.3 Insulating materials[4]

Insulating materials greatly reduce the heat losses through walls. Insulation is achieved by providing a layer of material with low heat conductivity between the internal hot surface of a furnace and the external surface, thus keeping the temperature of the external surface low.

Insulating materials may be classified into the following groups:
- Insulating bricks
- Insulating castables
- Ceramic fiber
- Calcium silicate
- Ceramic coating

Insulating materials owe their low conductivity to their pores while their heat capacity depends on the bulk density and specific heat. Air insulating materials consist of minute pores filled with air, which have a very low thermal conductivity. Excessive heat affects all insulation material adversely, but at what temperatures this takes place varies widely. Therefore the choice of an insulating material must be based on its ability to resist heat conductivity and on the highest temperature it will withstand. One of the most widely used insulating materials is diatomite, also known as *kiesel guhr,* which consists of a mass of skeletons of minute aquatic plants deposited thousands of years ago on the beds of seas and lakes. Its chemical composition is silica contaminated with clay and organic matter. A wide range of insulating refractories with wide combinations of properties is now available. Table 6 shows important physical properties of some insulating refractories.

Table 6. Physical properties of insulating materials (BEE, 2005)

Type	**Thermal conductivity at 400^{o}C**	**Max. safe temperature (^{o}C)**	**Cold crushing strength (kg/cm^2)**	**Porosity percent**	**Bulk density (kg/m^3)**
Diatomite Solid Grade	0.025	1000	270	52	1090
Diatomite Porous Grade	0.014	800	110	77	540
Clay	0.030	1500	260	68	560
High Alumina	0.028	1500-1600	300	66	910
Silica	0.040	1400	400	65	830

2.3.1 Castables and concretes

Monolithic linings of furnace sections can be constructed by casting refractory insulating concretes, and stamping lightweight aggregates into place that are suitably bonded. Other applications include the bases of tunnel kiln cars used in the ceramic industry. The ingredients are similar to those insulation materials used for making piece refractories, except that concretes contain either Portland or high-alumina cement.

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[4] Section 2.3 is taken (with edits) from *Energy Efficiency in Thermal Utilities,* 2005 with permission from the Bureau of Energy Efficiency, Ministry of Power, India.

2.3.2 Ceramic fiber
Ceramic fiber is a low thermal mass insulation material, which has revolutionized furnace design lining systems. Ceramic fiber is manufactured by blending and melting alumina and silica at a temperature of 1800 – 2000^{o}C, and breaking the molten stream by blowing compressed air or dropping the molten stream on a spinning disc to form loose or bulk ceramic fiber. The bulk fiber is used to produce various insulation products including blankets, strips, veneering and anchored modules, paper, vacuum formed boards and shapes, ropes, wet felt, mastic cement etc. Fibers are usually produced in two temperature grades based on Al_2O_3 content. A new product is ZrO_2 added alumino-silicate fiber, which helps to reduce shrinkage levels and thereby making the fiber suitable for higher temperatures. Continuous recommended operating temperature for fibers are given in the Table 7.

Table 7. Continuous recommended operating temperature for fibers (BEE, 2005)

	Al_2O_3	**SiO_2**	**ZrO_2**
1150^{o}C	43 – 47 percent	53 – 57 percent	-
1250^{o}C	52 – 56 percent	44 – 48 percent	-
1325^{o}C	33 – 35 percent	47 – 50 percent	17 – 20 percent

Ceramic fibers are generally produced in bulk wool form and needled into a blanket mass of various densities ranging from 64 to 190 kg/m^3. Converted products and over 40 different forms are made from blankets to suit various requirements.

The characteristics of ceramic fibers are a remarkable combination of the properties of refractories and traditional insulation material.

a) Lower thermal conductivity
Because of the low thermal conductivity (0.1 kCal/m per hour per ^{o}C at 600 ^{o}C for a blanket with 128 kg/m^3 density) it is possible to construct thinner linings with the same thermal efficiency as conventional refractories. As a result of thinner lining, the furnace volume is higher. It is 40 percent more effective than good quality insulation brick and 2.5 times better than asbestos. Ceramic fiber is a better insulator than calcium silicate.

b) Light weight
The average density of ceramic fiber is 96 kg/m^3. It is one tenth of the weight of insulating brick and one third of the weight of asbestos / calcium silicate boards. For new furnaces structural supports can be reduced by 40 percent.

c) Lower heat storage
Ceramic fiber linings absorb less heat because of their lower density. Furnaces can therefore be heated and cooled at faster rates. Typically the heat stored in a ceramic fiber lining system is in the range of 2700 - 4050 kCal/m^2 (1000 – 1500 Btu/Ft^2) as compared to 54200-493900 kCal/m^2 (20000 – 250000 Btu/Ft^2) for conventionally lined systems.

d) Thermal shock resistant
Ceramic fiber linings resist thermal shock due to their resilient matrix. This also allows for faster heat up and cool down cycles, thereby improving furnace availability and productivity.

e) Chemical resistance
Ceramic fiber resist most of the chemical attack and is unaffected by hydrocarbons, water and steam present in flue gases.

f) Mechanical resilience
The high mechanical resilience of ceramic fiber makes it possible to manufacture fiber-lined furnaces off-site, transport them to the site in assembled form without the risk of damage.

g) Low installation cost
As the application of ceramic fibers is a standardized process, no special skills are required. Fiber linings require no dry out or curing times and there is no risk of cracking or spalling when they are heated after installation.

h) Ease of maintenance
In case of physical damage, the section of damaged ceramic fiber can be quickly removed and replaced with a new piece. Entire panel sections can be prefabricated for fast installation with minimal down time.

i) Ease of handling
All product forms are easily handled and most can be quickly cut with a knife or scissors. Vacuum formed products may require cutting with a band saw.

j) Thermal efficiency
Thermal efficiency of a furnace lined with ceramic fiber is improved in two ways. First, the low thermal conductivity of ceramic fiber allows the lining to be thinner and therefore the furnace can be smaller. Second, the fast response of ceramic fiber to temperature changes also allows for more accurate control and uniform temperature distribution within the furnace.

Other advantages offered by ceramic fiber are:
- Lightweight furnace
- Simple steel fabrication work
- Low down time
- Increased productivity
- Additional capacity
- Low maintenance cost
- Longer service life
- Higher thermal efficiency
- Faster response

2.3.3 High emissivity coatings
Emissivity (i.e. the measure of a material’s ability to both absorb and radiate heat) is often considered as an inherent physical property that does not normally change (other examples are density, specific heat and thermal conductivity). However, the development of high emissivity

coatings allows the surface emissivity of materials to be increased. High emissivity coatings are applied on the interior surface of furnaces. Figure 10 shows that the emissivity of various insulating materials reduces with increasing process temperatures. The advantage of high emissivity coatings is that the emissivity remains more or less constant.

The emissivity of furnaces that operate at high temperatures is 0.3. By using high emissivity coatings this can go up to 0.8, resulting in an increase of heat transfer through radiation.

Other benefits of high emissivity coatings in furnace chambers are uniform heating and extended life of refractories and metallic components such as radiant tubes and heating elements. For intermittent furnaces or where rapid heating is required, use of such coatings was found to reduce fuel or power by 25 - 45 percent.

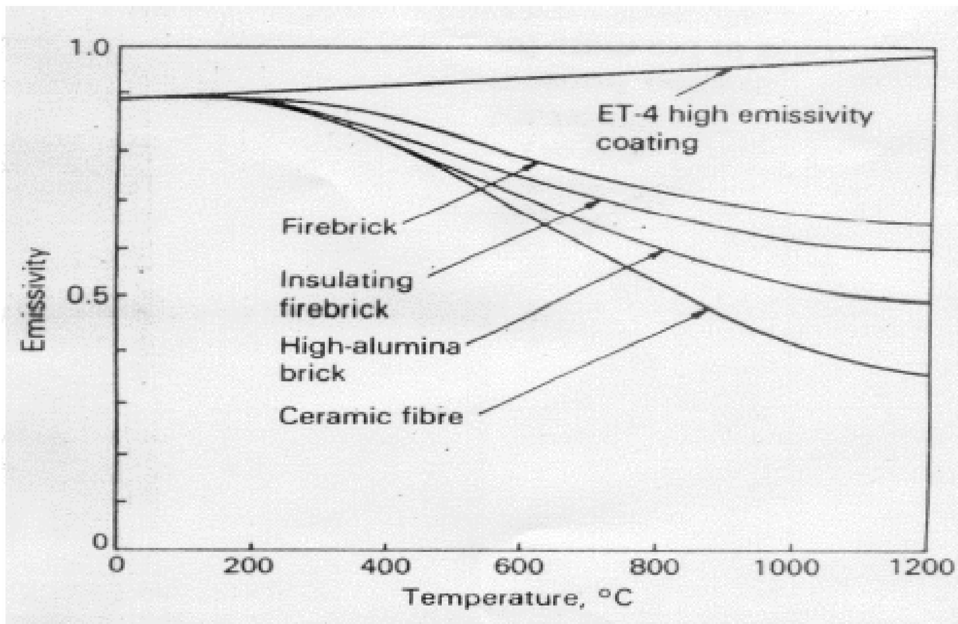

Figure 10. Emissivity of Refractory Materials at Different Temperatures (BEE, 2005)

3. ASSESSMENT OF FURNACES

This section describes the various methods and techniques used to quantify the losses from the furnace and the methods to carry out performance assessment of typical furnaces.

3.1 Heat losses affecting furnace performance

Ideally, all heat added to the furnaces should be used to heat the load or stock. In practice, however, a lot of heat is lost in several ways as shown in Figure 11.

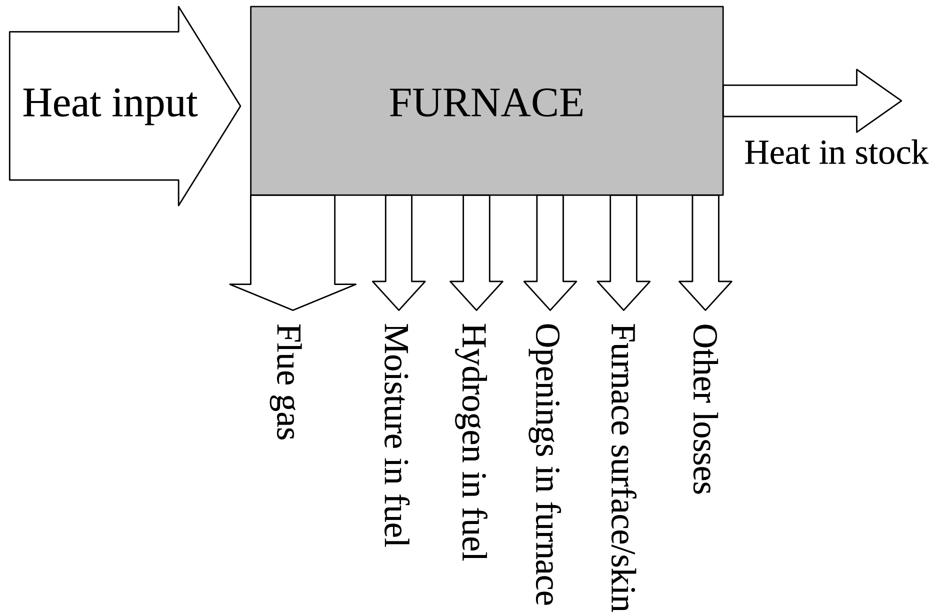

Figure 11. Heat Losses in a Furnace

These furnace heat losses include (BEE, 2005 and US DOE, 2004):

- ***Flue gas losses:*** part of the heat remains in the combustion gases inside the furnace. This loss is also called waste-gas loss or stack loss.
- ***Loss from moisture in fuel:*** fuel usually contains some moisture and some of the heat is used to evaporate the moisture inside the furnace
- ***Loss due to hydrogen in fuel*** which results in the formation of water
- ***Loss through openings in the furnace:*** radiation loss occurs when there are openings in the furnace enclosure and these losses can be significant, especially for furnaces operating at temperatures above 540°C. A second loss is through air infiltration because the draft of furnace stacks/chimneys cause a negative pressure inside the furnace, drawing in air through leaks or cracks or when ever the furnace doors are opened.
- ***Furnace skin / surface losses,*** also called wall losses: while temperatures inside the furnace are high, heat is conducted through the roof, floor and walls and emitted to the ambient air once it reaches the furnace skin or surface.
- ***Other losses:*** there are several other ways in which heat is lost from a furnace, although quantifying these is often difficult. Some of these include
  - Stored heat losses: when the furnace is started the furnace structure and insulation is also heated, and this heat only leaves the structure again when the furnace shuts down. Therefore this type of heat loss increases with the number of times the furnace is turned on and off
  - Material handling losses: the equipment used to move the stock through the furnace, such as conveyor belts, walking beams, bogies etc, also absorb heat. Every time equipment leave the furnace they loose their heat, therefore heat loss increases with the amount of equipment and the frequency by which they enter and leave the furnace

- Cooling media losses: water and air are used to cool down equipment, rolls, bearing and rolls, but heat is lost because these media absorb heat
- Incomplete combustion losses: heat is lost if combustion is incomplete because unburnt fuel or particles have absorbed heat but this heat has not been put to use
- Loss due to formation of scales

3.2 Instruments to assess furnace performance[5]

Furnace efficiency is calculated after subtracting the various heat losses. In order to find out furnace efficiency using the indirect method, various parameters must be measured, such as hourly furnace oil consumption, material output, excess air quantity, temperature of flue gas, temperature of furnace at various zones, and others. Date for some of these parameters can be obtained from production records while others must be measured with special monitoring instruments. Table 8 lists the instruments that are needed to measure these parameters.

Table 8. Instruments for Measuring Furnace Performance Parameter (BEE, 2005)

Parameters to be measured	Location of measurement	Instrument required	Required Value
Furnace soaking zone temperature (reheating furnaces)	Soaking zone and side wall	Pt/Pt-Rh thermocouple with indicator and recorder	1200-1300^{o}C
Flue gas temperature	In duct near the discharge end, and entry to recuperator	Chromel Alummel Thermocouple with indicator	700^{o}C max.
Flue gas temperature	After recuperator	Hg in steel thermometer	300^{o}C (max)
Furnace hearth pressure in the heating zone	Near charging end and side wall over the hearth	Low pressure ring gauge	+0.1 mm of Wc
Oxygen in flue gas	In duct near the discharge end	Fuel efficiency monitor for oxygen and temperature	5% O_2
Billet temperature	Portable	Infrared pyrometer or optical pyrometer	-

3.3 Calculating furnace performance

A furnace's efficiency increases when the percentage of heat that is transferred to the stock or load inside the furnace increases. The efficiency of the furnace can be calculated in two ways, similar to that of the boiler: direct method and indirect method. Both methods are explained below.

[5] Sections 3.2 is taken (with edits) from *Energy Efficiency in Thermal Utilities,* 2005 with permission from the Bureau of Energy Efficiency, Ministry of Power, India.

3.3.1 Direct method

The efficiency of a furnace can be determined by measuring the amount heat absorbed by the stock and dividing this by the total amount of fuel consumed.

$$\text{Thermal efficiency of the furnace} = \frac{\text{Heat in the stock}}{\text{Heat in the fuel consumed for heating the stock}}$$

The quantity of heat (Q) that will be transferred to stock can be calculated with this equation:

$$Q = m \times C_p (t_1 - t_2)$$

Where, Q = Quantity of heat of stock in kCal
m = Weight of the stock in kg
C_p= Mean specific heat of stock in kCal/kg ^oC
t_1 = Final temperature of stock in ^oC
t_2 = Initial temperature of the stock before it enters the furnace in ^oC

An example calculation is given in section 3.3.3.

3.3.2 Indirect method

The furnace efficiency can also be determined through the indirect method, similar to the evaluation of boiler efficiency. The principle is simple: the heat losses are substracted from the heat supplied to the furnace. Different types of heat losses are illustrated in Figure 11. Typical thermal efficiencies for common industrial furnaces are given in the Table 9.

Table 9. Thermal Efficiencies for Common Industrial Furnaces (BEE 2005)

Furnace type	Typical thermal efficiencies (percent)
1) **Low Temperature furnaces**	
a. 540 – 980 ^oC (Batch type)	20-30
b. 540 – 980 ^oC (Continous type)	15-25
c. Coil Anneal (Bell) radiant type	5-7
d. Strip Anneal Muffle	7-12
2) High temperature furnaces	
a. Pusher, Rotary	7-15
b. Batch forge	5-10
3) Continuous Kiln	
a. Hoffman	25-90
b. Tunnel	20-80
4) Ovens	
a. Indirect fired ovens (20 ^oC –370 ^oC)	35-40
b. Direct fired ovens (20 ^oC –370 ^oC)	35-40

An example calculation using the indirect method is given in the next section.

3.3.3 Example calculation of furnace efficiency

Calculate the efficiency of an oil-fired reheating furnace with the direct and indirect method using the data below.

Operating temperature:	$1340^{o}C$
Exit flue gas temperature after preheater:	$750^{o}C$
Ambient temperature:	$40^{o}C$
Preheated air temperature:	$190^{o}C$
Specific gravity of fuel oil:	0.92
Average fuel oil consumption:	400 liters / hr = 400 x 0.92 =368 kg/hr
Calorific value of oil	10000 kCal/kg
Average O_2 percentage in flue gas:	12 percent
Moisture in 1 kg of fuel oil:	0.15 kg
H_2 in 1 kg of fuel oil:	0.1123 kg
Theoretical air required to burn 1 kg of oil:	14 kg
Weight of stock:	6000 kg/hr
Specific heat of billet:	0.12 kCal/kg/^{0}C
Furnace wall thickness (D):	460 mm
Billet extraction outlet (X):	1 m x 1 m
Average surface temperature of heating + soaking zone:	122 ^{o}C
Average surface temperature of area other than heating and soaking zone:	80 ^{o}C
Area of heating + soaking zone:	70.18 m^2
Area other than heating and soaking zone:	12.6 m^2

Direct method calculation

The heat input is 400 liters per hour. The specific gravity of fuel is used to convert this into kg. Therefore: 400 l/hr x 0.92 kg/l = 368 kg/hr

The heat output is calculated as follows:

= m x Cp x ΔT
= 6000 kg x 0.12 x (1340 – 40)
= 936000 kCal

The efficiency is:

= (heat input / heat output) x 100
= [(936000 / (368 x 10000)] x 100 = 25.43 percent

The approximate heat loss is 100% – 25% = 75%

Indirect method

The different heat losses are calculated below.

a) Heat loss in flue gas

Excess air (EA)
$= O_2$ percent / ($21 - O_2$ percent)
$= 12 / (21 - 12)$
$= 133$ %

Mass of air supplied
$= (1 + EA/100) \times$ Theoretical air
$= (1 + 1.13) \times 14$
$= 32.62$ kg/kg fuel oil

$$\% \text{ Heat loss in flue gas} = \frac{m \times C_p \times \Delta T \times 100}{\text{GCV of fuel}}$$

Where,
m = weight of flue gas (air + fuel) = 32.62 + 1.0 = 33.62 kg/kg oil
C_p = specific heat
ΔT = temperature difference

$$\% \text{ Heat loss} = \frac{\{33.62 \times 0.24 \times (750 - 40)\} \times 100}{10000} = 57.29\%$$

b) Heat loss from moisture in fuel

$$\% \text{ Heat loss from moisture in fuel} = \frac{M \times \{584 + C_p (T_f - T_{amb})\} \times 100}{\text{GCV of fuel}}$$

Where,
M = kg of moisture in 1 kg of fuel oil
T_{fg} = Flue gas temperature, ^0C
T_{amb} = Ambient temperature, ^0C
GCV = Gross Calorific Value of fuel, kCal/kg

$$\% \text{ Heat loss} = \frac{0.15 \times \{584 + 0.45\,(750 - 40)\} \times 100}{10000} = 1.36\%$$

c) Loss due to hydrogen in fuel

$$\% \text{ Heat loss due to hydrogen in fuel} = \frac{9 \times H_2 \times \{584 + C_p (T_f - T_{amb})\} \times 100}{\text{GCV of fuel}}$$

Where,

H_2 = kg of H_2 in 1 kg of fuel oil (= 0.1123 kg/kg of fuel oil)

$$\% \text{ Heat loss} = \frac{9 \times 0.1123 \times \{584 + 0.45\ (750 - 40)\} \times 100}{10000} = 9.13\%$$

d) Heat loss due to openings in furnace

$$\% \text{ Heat loss from openings in furnace} = \frac{(\text{Black body radiation factor} \times \text{emissivity} \times \text{factor of radiation} \times \text{area of opening}) \times 100}{\text{Quantity of oil} \times \text{GCV of oil}}$$

The factor of radiation through openings and the black body radiation factor can be obtained from standard graphs as shown in Figure 12 and Figure 13.

- Factor of radiation (refer Figure 12) = 0.71
- Black body radiation at 1340 ^{0}C (refer Figure 13) = 36 kCal/kg/cm2/hr
- The area of the opening is 100 cm x 100 cm = 10000 cm^2
- Emissivity = 0.8

$$\% \text{ Heat loss from furnace openings} = \frac{36 \times 0.8 \times 0.71 \times 10000 \times 100}{368 \times 10000} = 5.56\%$$

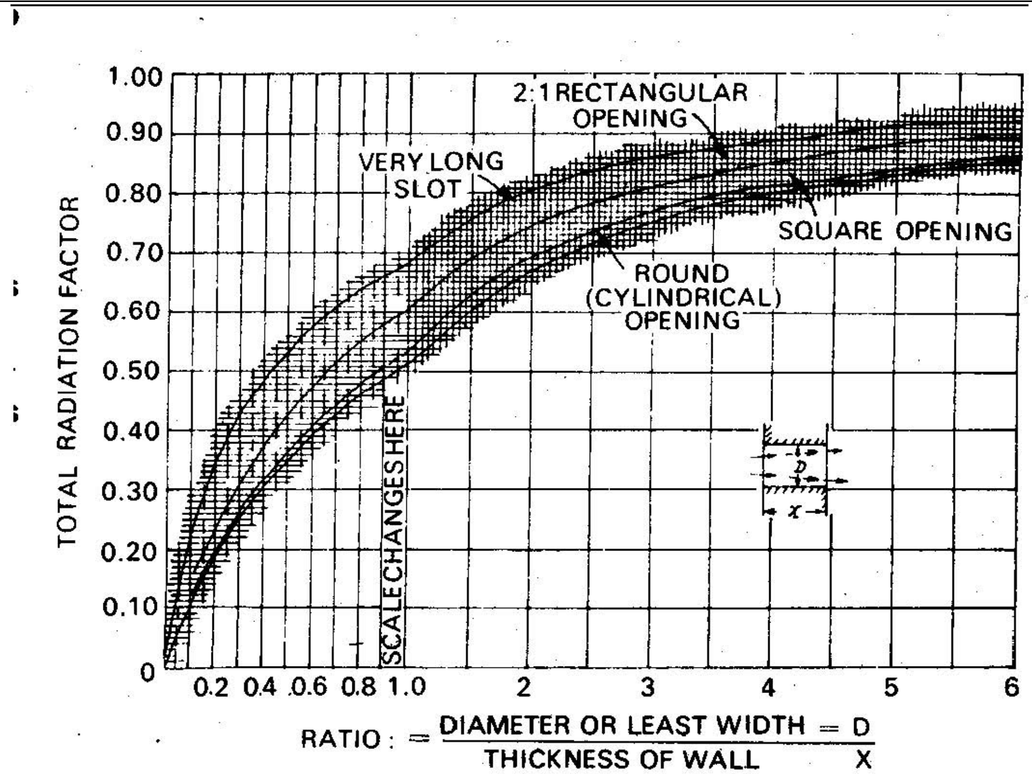

Figure 12. Radiation Factor for Heat Release through Openings relative to the Quality of Heat Release from Perfect Black Body (BEE, 2005)

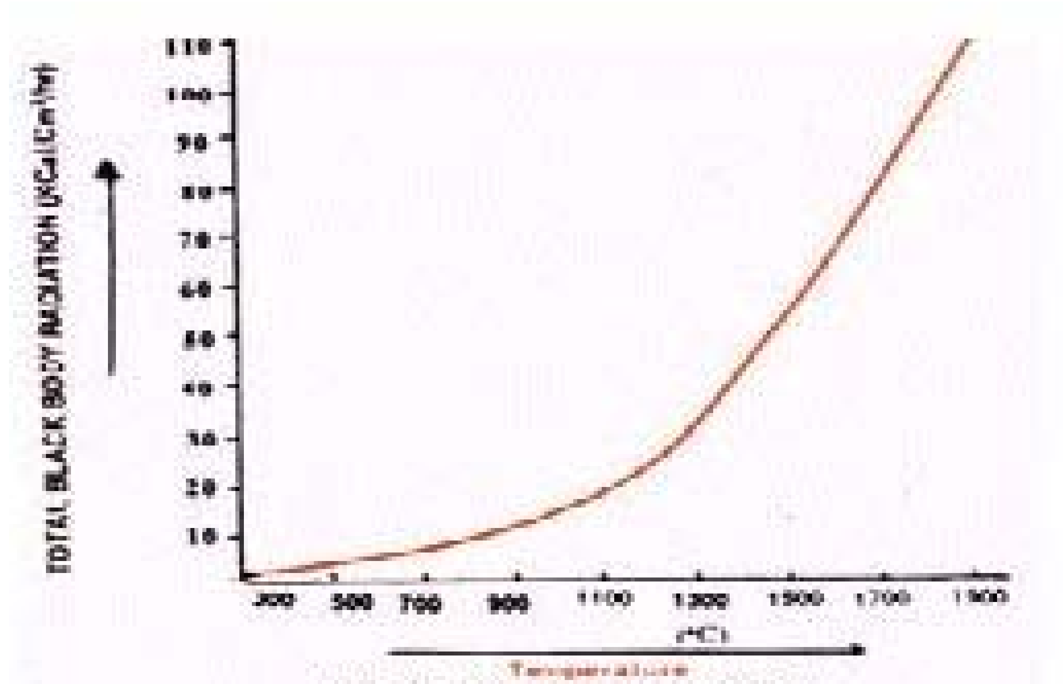

Figure 13. Black Body Radiation at Different Temperatures (BEE, 2005)

e) Heat loss through furnace skin

To determine the heat loss through the furnace skin, first the heat loss through the roof and sidewalls and through other areas must be calculated separately.

i). Heat loss through roof/ceiling and sidewalls (= heating and soaking zone):

- Total average surface temperature = 122^oC
- Heat loss at 122^oC (Refer Figure 14) = 1252 kCal /m^2 hr
- Total area of heating + soaking zone = 70.18 m^2

$$\text{Heat loss through furnace roof} = \frac{\text{Heat loss from roof and walls}}{\text{Area of roof and walls}}$$

Total heat loss = 1252 kCal / m^2 hr x 70.18 m^2 = 87865 kCal/hr

ii) Heat lost from area other than heating and soaking zone

- Total average surface temperature = 80 oC
- Heat loss at 80^oC (Refer Figure 14) = 740 kCal / m^2 hr
- Total area = 12.6 m^2

$$\text{Heat loss through other areas} = \frac{\text{Heat loss from roof other areas}}{\text{Area of other areas}}$$

Total heat loss = 740 kCal / m^2 hr x 12.6 m^2 = 9324 kCal/hr

$$\text{\% Heat loss through furnace skin} = \frac{\text{(Heat loss i + heat loss ii) x 100}}{\text{GCV of oil x Quantity of oil per hour}}$$

$$\text{\% Heat loss through furnace skin} = \frac{\text{(87865 kCal/hr + 9324 kCal/hr)}}{\text{10000 kCal/kg x 368 kg/hr}} \text{ x 100} = 2.64\%$$

f) Unaccounted losses

The unaccounted losses cannot be calculated unless the other types of losses are known.

Furnace efficiency

Adding the losses a to f up gives the total losses:

a) Flue gas loss = 57.29 %

b) Loss due to moisture in fuel = 1.36 %
c) Loss due to H_2 in fuel = 9.13 %
d) Loss due to openings in furnace = 5.56 %
e) Loss through furnace skin = 2.64 %
Total losses = 75.98 %

The furnace efficiency calculated through the indirect method = 100 – 75.98 = 24.02%

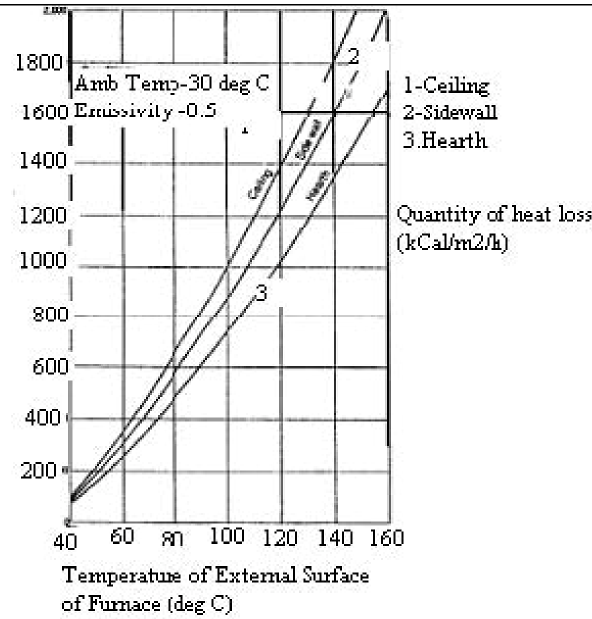

Figure 14. Heat Loss from the Ceiling, Sidewall and Hearth of Furnace (BEE, 2005)

4. ENERGY EFFICIENCY OPPORTUNITES

This section explains the various energy saving opportunities in furnaces.[6] Typical energy efficiency measures for an industry with furnace are:

1. Complete combustion with minimum excess air
2. Proper heat distribution
3. Operation at the optimum furnace temperature
4. Reducing heat losses from furnace openings
5. Maintaining correct amount of furnace draft
6. Optimum capacity utilization
7. Waste heat recovery from the flue gases
8. Minimum refractory losses
9. Use of ceramic coatings
10. Selecting the right refractories

[6] Section 4 is taken and adapted from *Energy Efficiency in Thermal Utilities (2005)* with permission from the Bureau of Energy Efficiency, Ministry of Power, India

4.1 Complete combustion with minimum excess air

The amount of heat lost in the flue gases (stack losses) depends on the amount of excess air. To obtain complete combustion of fuel with the minimum amount of air, it is necessary to control air infiltration, maintain pressure of combustion air, fuel quality and monitor the amount excess air. Too much excess air will reduce flame temperature, furnace temperature and heating rate. Too little excess air will result in an increase in unburnt components in flue gases that are carried away through the stack and it also causes more scale losses.

Optimizing combustion air is the most attractive and economical measure for energy conservation. Potential savings are higher when the temperature of furnace is high. The air ratio (= actual air amount / theoretical combustion air amount) gives an indication of excess air air. If a reheating furnace is not equipped with an automatic air/fuel ratio controller, it is necessary to periodically take a sample of gas in the furnace and measure its oxygen contents with a gas analyzer.

4.2 Proper heat distribution

A furnace should be designed to ensure that within a given time the stock is heated uniformly to a desired temperature with the minimum amount of fuel.

Where burners are used to fire the furnace, the following should be ensured for proper heat distribution:

- The flame should not touch or be obstructed by any solid object. Obstruction causes the fuel particles to de-atomize, which affects combustion and causes black smoke. If the flame impinges on the stock scale losses will increase. If the flame impinges on refractories, products from incomplete combustion can settle and react with the refractory constituents at high temperatures.
- The flames of different burners should stay clear of each other, as intersecting flames cause incomplete combustion. It is also desirable to stagger burners on opposite sides.
- The burner flame has a tendency to travel freely in the combustion space just above the material. For this reason, the axis of the burner in small furnaces is never placed parallel to the hearth but always at an upward angle, but the flame should not hit the roof.
- Large burners produce longer flames, which may be difficult to contain within the furnace walls. More burners of less capacity ensure a better heat distribution inside the furnace and also increase the furnace life.
- In small furnaces that use furnace oil, a burner with a long flame with a golden yellow color improves uniform heating. But the flame should not be too long, because heat is lost of the flame reaches the chimney or the furnace doors.

4.3. Operation at the optimum furnace temperature

It is important to operate the furnace at its optimum temperature. Operating temperatures of various furnaces are given in Table 10. Operating at too high temperatures causes heat loss, excessive oxidation, de-carbonization and stress on refractories. Automatic control of the furnace temperature is preferred to avoid human error.

Table 10. Operating Temperatures of Various Furnaces

Slab Reheating furnaces	1200^{o}C
Rolling Mill furnaces	1200^{o}C
Bar furnace for Sheet Mill	800^{o}C
Bogie type annealing furnaces	650^{o}C –750^{o}C

4.4. Prevent heat loss through openings

Heat can be lost by direct radiation through openings in the furnace, such as the charging inless, extracting outlet and the peephole in the wall or ceiling. Heat is also lost due to pressure differences between the inside of the furnace and the ambient environment causing combustion gases to leak through the openings. But most heat is lost if outside air infiltrates into the furnace, because in addition to heat loss this also causes uneven temperatures inside the furnace and stock and can even lead to oxidization of billets.

It is therefore important to keep the openings as small as possible and to seal them. Another effective way to reduce the heat loss through furnace openings is by opening the furnace doors less frequent and for the shortest time period as possible (another option is described under item 4.5). This heat loss is about 1 percent of the total quantity of heat generated in the furnace, if furnace pressure is controlled properly.

Section 3.3.3 already explained one way of calculating heat loss through openings. But an alternative way is calculating heat loss with the following equation:

$$Q = 4.88 x \left(\frac{T}{100}\right)^4 x a x A x H$$

Where,

Q = heat loss
T = absolute temperature (K)
a = factor for total radiation
A = area of opening, m^2
H = time (hours)

For example, a reheating furnace with a temperature of 1340 oC, the wall thickness is 460 mm (X) and the door is 1 m high (D) by 1 m wide. D/X = 1/0.460 = 0.71, and in Figure 12 this corresponds with a factor for total radiation of 0.71. The heat loss from openings in therefore:

$$Q = 4.88 x \left(\frac{1340+273}{100}\right)^4 x 0.71 x 1 = 2{,}34{,}500\, kCal/hr$$

4.5. Control of furnace draft

If negative pressures exist inside the furnace, air can infiltrate through cracks and openings and affect the air-fuel ratio control. This in turn can cause metal to not reach the desired temperature or non-uniform temperatures, which affects the next processes like forging and rolling. Fuel consumption and product rejection rates increase. Tests conducted on seemingly airtight furnaces have shown air infiltration up to 40 percent. To avoid this, slight positive pressure should be maintained inside the furnace (in addition to the measures mentioned under 4.4).

But the pressure difference should not be too high because this will cause ex-filtration. While this is less of a problem than infiltration, it can still result in flames reaching out of the furnace, overheating of refractories leading to reduced brick life, increased furnace maintenance, and burnout of ducts and equipment.

Proper management of the pressure difference between the inside and outside of the furnace is therefore important to minimize heat loss and adverse impacts on products.

4.6. Optimum capacity utilization

One of the most vital factors affecting the furnace efficiency is the load. This includes the amount of material placed in the furnace, the arrangement inside the furnace and the residence time inside the furnace.

a) Optimum load
If the furnace is under loaded the proportion of total heat available that will be taken up by the load is smaller, resulting in a lower efficiency. Overloading can lead to the load not heated to the right temperature within a given period of time.

There is a particular load at which the furnace will operate at maximum thermal efficiency, i.e. where the amount of fuel per kg of material is lowest. This load is generally obtained by recording the weight of material of each charge, the time it takes to reach the right temperature, and the amount of fuel used. The furnace should be loaded to the optimum load at all times, although in practice this may not always be possible.

b) Optimum arrangement of the load
The loading of materials on the furnace hearth should be arranged so that

- It receives the maximum amount of radiation from the hot surfaces of the heating chambers and flames
- Hot gases are efficiently circulated around the heat receiving surfaces of the materials
- Stock is not placed in the following position:
  - In the direct path of the burners or where flame impingement is likely to occur
  - In an area that is likely to cause a blockage or restriction of the flue system of the furnace
  - Close to any door openings where cold spots are likely to develop

c) Optimum residence time of the load
Fuel consumption is kept at a minimum and product quality is best if the load only remains inside the furnace until it has the required physical and metallurgical properties.

Sometimes the charge and production schedule does not correspond with the capacity of the furnace. If this is the case, either the
- Load is higher or lower than the optimum load
- Residence time is longer or shorter than the ideal residence time. Excessive residence time will increase oxidation of the material surface, which can result in rejection of products. The rate of oxidation is dependent upon time, temperature, as well as free oxygen content
- Temperature is increased to make up for shorter residence time. The higher the working temperature, the higher is the loss per unit of time.

All three result in fuel wastage and sometimes in reduced product quality. Coordination between the furnace operator, production and planning personnel is therefore essential.

Optimum utilization of furnace can be planned at design stage, by selecting the size and type (batch, continuous) that best matches the production schedule.

The overall efficiency of a continuous type furnace will increase with heat recuperation from the waste gas stream. If only batch type furnace is used, careful planning of the loads is important. Furnace should be recharged as soon as possible to enable use of residual furnace heat.

4.7. Waste heat recovery from furnace flue gases

In any industrial furnace the combustion products leave the furnace at a temperature higher than the stock temperature. Flue gases carry 35 to 55 percent of the heat input to the furnace with them through the chimney. The higher the amount of excess air and flue gas temperature, the higher the amount of waste heat that is available. However, the primary objective should be to minimize the amount of waste heat generated through energy conservation measures. Waste heat recovery should only be considered when further energy conservation is not possible or practical.

Waste heat in flue gases can be recovered for preheating of the charge (stock, load), preheating of combustion air or for other processes as described below.

a) Charge pre-heating
When raw materials are preheated by exhaust gases before being placed in a heating furnace, the amount of fuel necessary to heat them in the furnace is reduced. Since raw materials are usually at room temperature, they can be heated sufficiently using high-temperature flue gases to noticeably reduce the fuel consumption rate.

b) Preheating of combustion air
For a long time, fuel gases were only use for preheating of combustion air for large boilers, metal-heating furnaces and high-temperature kilns. But preheating using heat from flue gases is now also applied to compact boilers and compact industrial furnaces.

A variety of equipment is available to recover waste heat. External recuperators are most common, but other techniques are also used, such as self-recuperative burners. For example, a modern recuperator use furnace exhaust gas of 1000°C can preheat the combustion air to over 500 ^{o}C, which results in energy savings of up to 30 percent compared with using cold combustion air entering the furnace.

Since the volume of combustion air increases when it is preheated, it is necessary to consider this when modifying air-duct diameters and blowers. It should be noted that preheating of combustion gases from high-density oils with a high sulphur content, could cause clogging with dust or sulphides, corrosion or increases in nitrogen oxides.

c) Utilizing waste heat as a heat source for other processes
Other process (to generate steam or hot water by a waste heat boiler)

The temperature of furnace exhaust gas can be as high as 400- 600 °C, even after heat has been recovered from it for preheating the charge or combustion air. One possibility is to install a waste heat boiler to produce steam or hot water from this heat, especially when large quantities steam or hot water are needed in a plant. Sometimes exhaust gas heat can be used for heating purposes in other equipment, but only if the heat quantity, temperature range, operation time etc are suitable for this. Fuel consumption can be greatly reduced. One existing example is the use of exhaust gas from a quenching furnace as a heat source in a tempering furnace.

4.8. Minimizing furnace skin losses

About 30 to 40 percent of the fuel used in intermittent or continuous furnaces is used to make up for heat lost through the furnace skin/surface or walls. The extent of wall losses depend on:
- Emissivity of wall
- Thermal conductivity of refractories
- Wall thickness
- Whether the furnace is operated continuously or intermittently

There are several ways to minimize heat loss through the furnace skin:
- ***Choosing the appropriate refractory materials***
- ***Increasing the wall thickness***
- ***Installing insulating bricks.*** Outside wall temperatures and heat losses of a composite wall are much lower for a wall of firebrick and insulation brick compared to a wall of the same thickness that consists only of refractory bricks. The reason is that insulating bricks have a much lower conductivity.
- ***Planning operating times of furnaces.*** For most small furnaces, the operating periods alternate with the idle periods. When the furnaces are turn off, heat that was absorbed by the refractories during operation gradually dissipates through radiation and convection from the cold face and through air flowing through the furnace. When the furnace is turned on again, additional fuel is needed to heat up the refractories again. If a furnace is operated continuously for 24 hours in three days, practically all the heat stored in the refractories is lost. But if the furnace is operated 8 hours per day all the heat stored in the refractories is not dissipated. For a furnace with a firebrick wall of 350 mm thickness, it is estimated that during

the 16 hours that the furnace is turned off, only 55 percent of the heat stored in the refractories is dissipated from the cold surface. Careful planning of the furnace operation schedule can therefore reduce heat loss and save fuel.

The quantity (Q) of heat loss from the furnace skin is the sum of natural convection and thermal radiation. In addition to the method explain in section 3.3.3, the following equation can also be used:

$$Q = a\,x\,(t_1 - t_2)^{5/4} + 4.88\,E\,x\left(\left(\frac{t_1 + 273}{100}\right)^4 - \left(\frac{t_2 + 273}{100}\right)^4\right)$$

Where,

Q = Quantity of heat released (kCal/hr)

a = factor regarding direction of the surface of natural convection ceiling = 2.8, side walls = 2.2, hearth = 1.5

t_1 = temperature of external wall surface of the furnace (°C), based on the average of as many measurements as possible to reduce the error margin

t_2 = temperature of air around the furnace (°C)

E = emissivity of external wall surface of the furnace

The first part of the equation gives the heat loss though natural convection, and the second part the heat loss through radiation. Figure 14 shows the relation between the temperature of external wall surface and the quantity of heat release calculated with this formula.

An example calculation of the heat loss from a furnace's surface is as follows:
A reheating furnace has a ceiling, sidewalls and hearth with a 20 m^2, 50 m^2 and 20 m^2 surface area respectively. Their average measured surface temperatures 80°C, 90°C and 100°C respectively. Based on Figure 14, the quantities of heat release from ceiling, sidewalls and hearth per unit area are respectively 650 kCal/m^2h, 720 kCal/m^2h and 730 kCal/m^2h.

Therefore, the total quantity of heat release Q

= loss through ceiling + loss through sidewalls + loss through hearth

= (650 x 20) + (720 x 50) + (730 x 20)

= 13000 + 36000 +14600= 63,600 kCal/hr

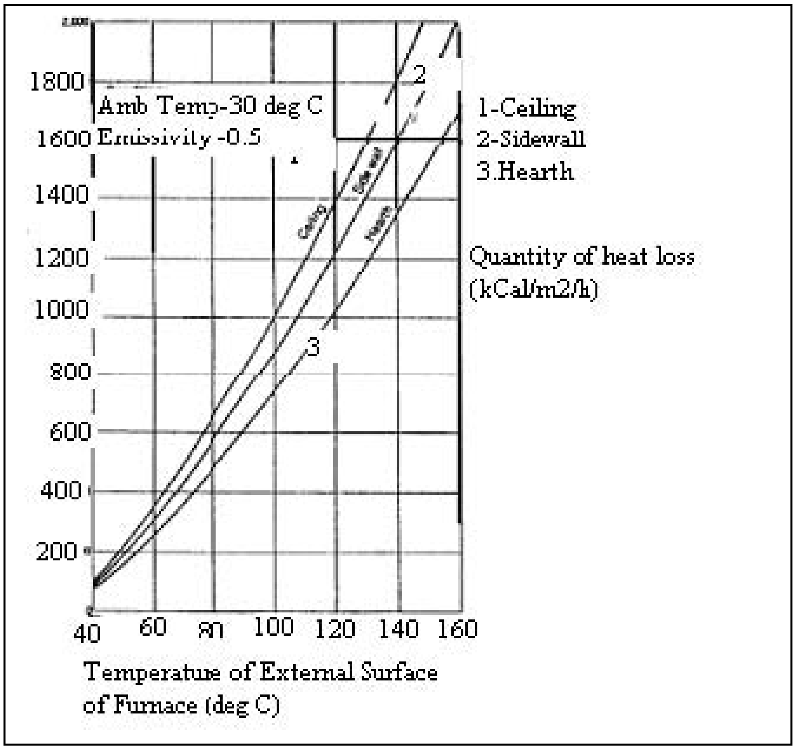

Figure 15. Relationship between Surface Temperature and Quantity of Heat Loss (BEE, 2005)

4.9 Use of ceramic coatings (high emissivity coatings)

Ceramic coatings in the furnace chamber promote rapid and efficient transfer of heat, uniform heating and extended life of refractories. The emissivity of conventional refractories decreases with increase in temperature whereas for ceramic coatings it increases slightly. This outstanding property has been exploited by using ceramic coatings in hot face insulation. Ceramic coatings are high emissivity coatings and a have a long life at temperatures up to 1350^{o}C. There are two types of ceramic coatings: those used for coating metal substrates, and those used for coating refractory substrates. The coatings are non-toxic, non-flammable and water based. Applied at room temperatures, they are sprayed and air-dried in less than five minutes. The coatings allow the substrate to maintain its designed metallurgical properties and mechanical strength. Installation is quick and can be completed during shut down. Energy savings of the order of 8-20 percent have been reported depending on the type of furnace and operating conditions. High emissivity coatings are further described in section 2.3.3.

4.10 Selection of refractories

The selection of refractories aims to maximize the performance of the furnace, kiln or boiler. Furnace manufacturers or users should consider the following points in the selection of a refractory:

- Type of furnace

- Type of metal charge
- Presence of slag
- Area of application
- Working temperatures
- Extent of abrasion and impact
- Structural load of the furnace
- Stress due to temperature gradient in the structures and temperature fluctuations
- Chemical compatibility to the furnace environment
- Heat transfer and fuel conservation
- Cost considerations

5. OPTIONS CHECKLIST

It is difficult to make a checklist of general options for furnaces, because options to improve energy efficiency vary between furnaces. But the main options that are applicable to most furnaces are:

- Check against infiltration of air: use doors or air curtains
- Monitor O_2 /CO_2/CO and control excess air to the optimum level
- Improve burner design, combustion control and instrumentation
- Ensure that the furnace combustion chamber is under slight positive pressure
- Use ceramic fibers in the case of batch operations
- Match the load to the furnace capacity
- Retrofit with heat recovery device
- Investigate cycle times and reduce
- Provide temperature controllers
- Ensure that flame does not touch the stock

6. WORKSHEETS

No worksheets were developed for furnaces and refractories

7. REFERENCES

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