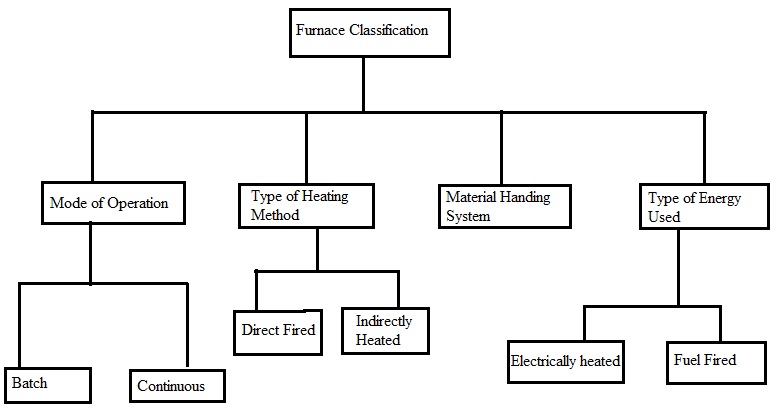
**FURNACES**

Furnaces are enclosed vessel in which heat is produced by the combustion of fuel. The produced heat is then employed to process raw materials such as melting of metal, warming a house, glass making, manufacturing, ceramic processing, calcination in cement production, for baking pottery etc. Depending on the type of use, these furnaces are named accordingly.

**Types and Classification of Different Furnaces**

Furnaces are classified into different ways as shown below



There are several methods of classifying furnaces. Out of those methods, furnaces are classified based upon the heating (input) method. Thus it is divided into mainly two types: (i) Combustion based heating (fuel used) (ii) Electric based heating.

Again combustion type furnaces are broadly classified into three types (i) Oil fired (ii) Coal fired, (iii) Gas fired. Based on the mode of charging of material furnaces can be classified as (i) Intermittent or batch type furnace or Periodical furnace and (ii) Continuous furnace.

* Based on mode of waste heat recovery as recuperative and regenerative furnaces.
* Another type of furnace classification is made based on mode of heat transfer, mode of charging and mode of heat recovery as shown in the Figure below.[1]

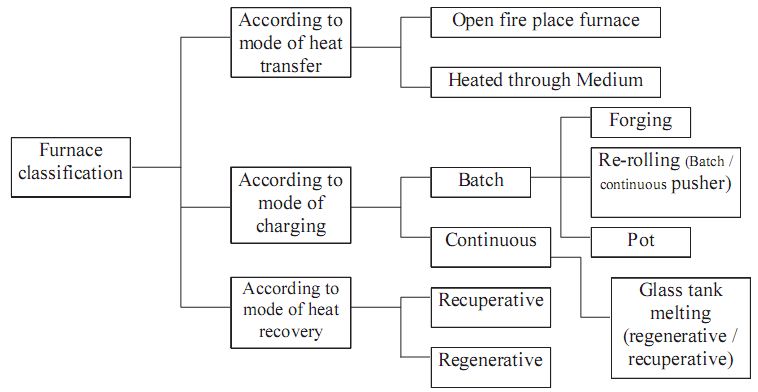


Fig: Classification of furnaces

**Characteristics of an Efficient Furnace**

Furnace are designed to heat the material to an uniform temperature and also to get the maximum possible output with less consumption of fuel. In order to make this an achievable one, the following parameters are considered:

1. Determination of the quantity of heat to be imparted to the material or charge.
2. Liberation of sufficient heat within the furnace to heat the stock and overcome all heat losses.
3. Transfer of available part of that heat from the furnace gases to the surface of the heating stock.
4. Equalization of the temperature within the stock.
5. Reduction of heat losses from the furnace to the minimum possible extent [1]

**Furnace Energy Supply**

Since the products of flue gases directly contact the stock, type of fuel chosen is of importance. For example, some materials will not tolerate sulphur in the fuel. Also use of solid fuels will generate particulate matter, which will interfere the stock place inside the furnace. Hence, vast majority of the furnaces use liquid fuel, gaseous fuel or electricity as energy input. Melting furnaces for steel, cast iron use electricity in induction and arc furnaces. Non-ferrous melting utilizes oil as fuel.[1]

**Oil Fired Furnace**

Three types of liquid fuel may be used in furnaces i.e. gasoline, kerosene and furnace oil. Out of the three furnace oil is used in oil fired furnaces now a days because of the high cost of gasoline and kerosene. Furnace temperature can be achieved by controlling the valve fitted to the pipe line. In order to attain a temperature of 12000C and above, this type ( oil fired) of furnace is used. Also this type of furnaces are economical only at temperature above 10000C [2]. The key to efficient furnace operation lies in complete combustion of fuel with minimum excess air. Furnaces operate with efficiencies as low as 7% as against upto 90% achievable in other combustion equipment such as boiler. This is because of the high temperature at which the furnaces have to operate to meet the required demand. For example, a furnace heating the stock to 1200°C will have its exhaust gases leaving atleast at 1200°C resulting in a huge heat loss through the stack. However, efficiency can be improved by preheating of stock, preheating of combustion air and other waste heat recovery systems [1]

**Typical Furnace System**

(i ) *Forging Furnaces* Forge temperature is an essential requirement for preheating billets and ingots which can be attained in forging furnace. This type of furnace are designed to attain a temperature of 1200 to 1250°C [1]. Classification of forging furnace is mainly of two types (i) open-hearth furnace (ii) closed-hearth furnace. The typical loading in a forging furnace is 5 to 6 tonnes 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.

**Rerolling Mill Furnace**

1. **Batch type**

In a batch type furnace, the material is charged and discharged in batch or single unit. Mechanical loading is adopted for charging of heavy and bulky materials. Scrap, small ingots and billets weighing 2kg to 20kg can be heated in this type of furnace for rerolling. The charging and discharging of the ‘material’ is done manually. This type of furnace can used for heating materials to a temperature of about 12000C. The total cycle time can be further categorized into heat-up time and rerolling time. The material gets heated during heat-up time up to the required temperature and is removed manually for rerolling. The average output from these furnaces varies from 10 to 15 tonnes / day and the specific fuel consumption varies from 180 to 280 kg. of coal / tonne of heated material. [1]

**(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 temperature required for operation is about 1250 °C. Generally, operating time of these furnaces is around 8 to 10 hours with an output of 20 to 25 tonnes per day. Preheating of the material is done with the exhaust flue gases as the material 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 [1].

**(c) Continuous Steel Reheating Furnaces**

The main function of a reheating furnace is to raise the temperature of a piece of steel, typically to between 900°C and 12500C, until it is plastic enough to be pressed or rolled to the desired section, size or shape. The furnace must also meet specific requirements and objectives in terms of stock heating rates for metallurgical and productivity reasons. 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.

All furnaces possess the features shown in Figure below

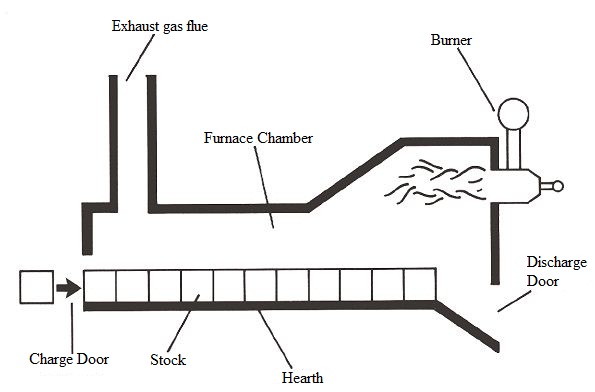


Fig: Furnace Feature

* A refractory chamber constructed of insulating materials for retaining heat at the high operating temperatures.
  + A hearth to support or carry the steel. This can consist of refractory materials or an arrangement of metallic supports that may be water-cooled.
  + Burners that use liquid or gaseous fuels to raise and maintain the temperature in the chamber. Coal or electricity can be used for reheating. A method of removing the combustion exhaust gases from the chamber.
  + A method of introducing and removing the steel from the chamber.
  + These facilities depend on the size and type of furnace, the shape and size of the steel being processed, and the general layout of the rolling mill.
  + Common systems include roller tables, conveyors, charging machines and furnace pushers.

**Heat Transfer in Furnaces**

Heat transfer in furnaces is mainly dependent on the temperature achieved inside the furnace. If the temperature is high enough, then the dominant mode of heat transfer is by radiation. Heat is transferred to the material by convection and radiation. Convection heat transfer is mainly due to to the movement of hot gases over the stock surface while heat is transferred to the material by radiation from the flame, hot combustion products and the furnace walls and roof. [1]

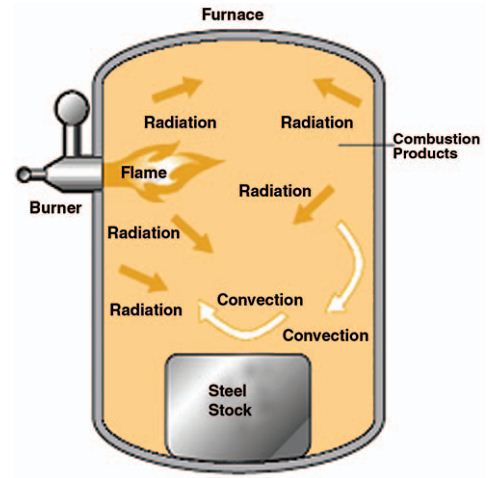


Fig: Heat transfer inside the furnace to the steel material

**Types of Continuous Reheating Furnace**

Continuous reheating furnaces are primarily categorised by the method by which stock is transported through the furnace. There are two basic methods:

* Stock is butted 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. Such types include walking beam, walking hearth, rotary hearth and continuous recirculating bogie furnaces.

The major consideration with respect to furnace energy use is that the inlet and outlet apertures should be minimal in size and designed to avoid air infiltration.

1. **Pusher Type Furnaces**

This type of furnace is widely used in steel industry because of relatively low installation and maintenance costs compared to moving hearth furnaces. The furnace may have a solid hearth, but it is also possible to push the stock along skids with water-cooled supports that allow both the top and bottom faces of the stock to be heated. Pusher type furnace is shown in figure below

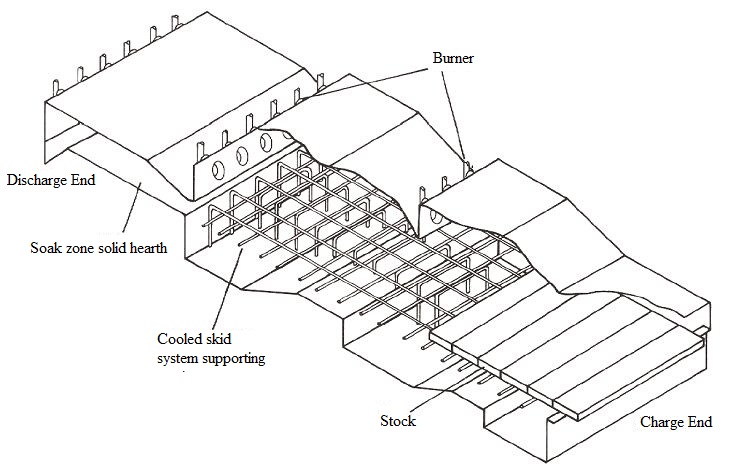


Fig: Pusher type furnace

Disadvantages

* Frequent damage of refractory hearth and skid marks on material.
* Water cooling energy losses from the skids and stock supporting structure in top and bottom fired furnaces have a detrimental effect on energy use;
* Discharge must be accompanied by charge:
* Stock sizes and weights and furnace length are limited by friction and the possibility of stock pile-ups.
* All round heating of the stock is not possible [1]

**ii) Walking Hearth Furnaces**

The purpose of the walking hearth furnace allows to heat cold material from the billet yard and hot product from the caster. Walking hearth furnaces are a highly flexible alternative compared to pusher type reheating furnaces. Smaller product size can be heated by this type of furnace. Less scale production, less decarburization and no product remains in the furnace when the furnace has to stop operation, are some of the advantages of this type of furnace. Bottom face of the material cannot be heated. This can be alleviated to some extent by maintaining large spaces between pieces of stock. Small spaces between the individual stock pieces limits the heating of the side faces and increases the potential for unacceptable temperature differences within the stock at discharge. Consequently, the stock residence time may be long, possibly several hours; this may have an adverse effect on furnace flexibility and the yield may be affected by scaling. Lower exhaust emission can be seen in this furnaces because furnace required very little water which results in low fuel consumption.

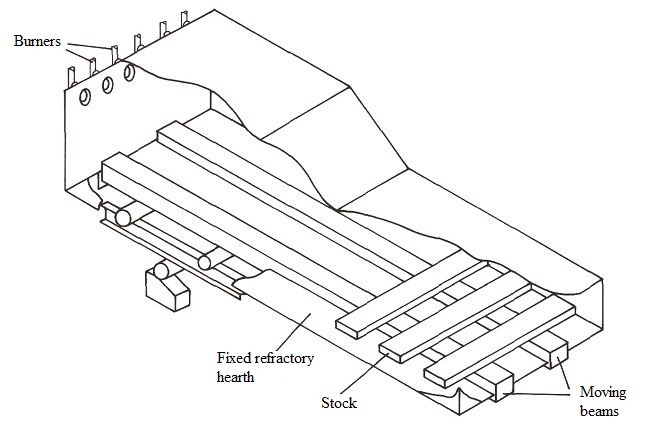


Fig: Walking hearth furnace

**iii) Rotary Hearth Furnace**

Rotary hearth furnace are continuous type furnace. The name itself depicts that the hearth is a rotating one which rotates along the vertical axis. Opening is provided for charging the material. Discharging of the heat treated material from the furnace is done through the same opening. The speed of rotation is adjusted in such a manner that heat treatment cycle is completed by the time the hearth undergoes one complete rotation.

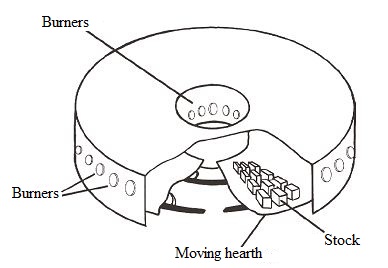


Fig: Rotary hearth furnace

**iv) Continuous Recirculating Bogie type Furnaces**

Smaller size stock material can be heat treated by this type of furnace. In bogie furnaces, the material (stock) is charged from the charging end on the bogie which helps to travel the material from the charge end to the discharging end while passing through the burners placed on the furnace as shown in figure. Bogies always occupies the entire length of the furnace. Bogie furnaces tend to be long and narrow and to suffer from problems arising from inadequate sealing of the gap between the bogies and furnace shell, difficulties in removing scale, and difficulties in firing across a narrow hearth width [1]

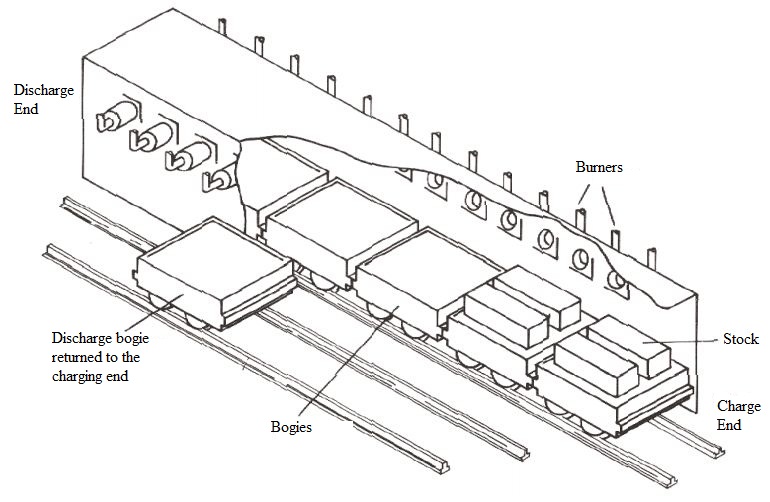
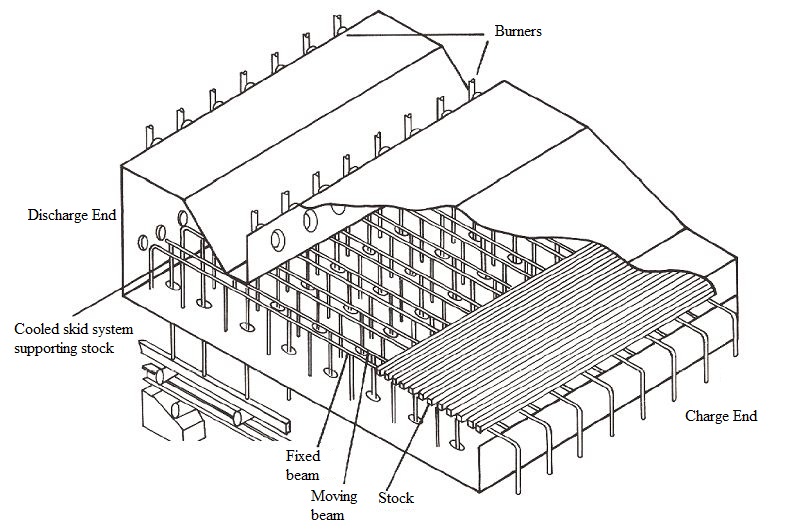


Fig: **Continuous Recirculating Bogie type Furnaces**

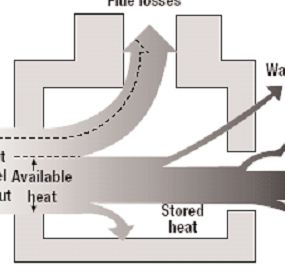
**v) Walking Beam Furnaces**

The main drawback of pusher type furnace is that the bottom face of the charge (slabs, blooms or ingots) cannot be heat treated which is solved by introducing walking beam furnace where heating of the bottom face of the charge is done. Here the charge is transferred from the charging end to the discharging end by placing the charge(stock) on the skid system. This reduces the heating time of the charge and furnace lengths and thus better control of heating rates, uniform stock discharge temperatures and operational flexibility. In common with top and bottom fired pusher furnaces, however, much of the furnace is below the level of the mill; this may be a constraint in some applications [1]

Fig: Walking Beam Furnaces

**4.2 Performance Evaluation of a Typical Furnace**

Thermal efficiency of process heating equipment, such as furnaces, ovens, heaters, and kilns is defined as the ratio of heat delivered to a material and heat supplied to the heating equipment. The purpose of heating the material is to change its properties. Total energy losses from the process are shown by Sankey diagram. A large amount of heat supplied is wasted with the exhaust gases.

****

Losses from the furnace include [1]

* Heat storage in the furnace structure
* Losses from the furnace outside walls or structure
* Heat transported out of the furnace by the load conveyors, fixtures, trays, etc.
* Radiation losses from openings, hot exposed parts, etc.
* Heat carried by the cold air infiltration into the furnace
* Heat carried by the excess air used in the burners.

**Stored Heat Loss:**

First, the metal structure and insulation of the furnace must be heated so their interior surfaces are about the same temperature as the product they contain. This stored heat is held in the structure until the furnace shuts down, then it leaks out into the surrounding area. The more frequently the furnace is cycled from cold to hot and back to cold again, the more frequently this stored heat must be replaced. Fuel is consumed with no useful output.

**Wall losses:**

Heat losses from the furnace takes place by conduction, convection, cooling losses. During furnace operation losses takes place through walls that are caused by the conduction of heat through the walls, roof, and floor of the furnace. When the temperature of the outside furnace walls are more than the atmospheric temperature, heat is radiated to the surrounding area or is carried by the air until equilibrium is reached.

**Material Handling Losses**

The material to be processed is charged and discharged from inside the furnace by means of equipments such as conveyor belts or product hangers, which may also lead to heat losses by entering the equipment at atmospheric temperature and leaves the furnace at higher temperature. In car bottom furnaces, the hot car structure gives off heat to the room each time it rolls out of the furnace to load or remove work. This lost energy must be replaced when the car is returned to the furnace [1].

**Cooling Losses**

Water or air cooling protects rolls, bearings, and doors in hot furnace environments, but at the cost of lost energy. These components and their cooling media (water, air, etc.) become the conduit for additional heat losses from the furnace. Maintaining an adequate flow of cooling media is essential, but it might be possible to insulate the furnace and load from some of these losses [1].

**Radiation (Opening) Losses**

When temperature of the furnace reaches 5400C, losses due to radiation takes place. Hot surfaces radiate energy to nearby colder surfaces, and the rate of heat transfer increases with the fourth power of the surface's absolute temperature. Anywhere or anytime there is an opening in the furnace enclosure, heat is lost by radiation, often at a rapid rate. [1]

**Waste-gas Losses**

Waste-gas loss, also known as flue gas or stack loss, is made up of the heat that cannot be removed from the combustion gases inside the furnace. The reason is heat flows from the higher temperature source to the lower temperature heat receiver [1].

**Air Infiltration**

Excess air does not necessarily enter the furnace as part of the combustion air supply. It can also infiltrate from the surrounding room if there is a negative pressure in the furnace. Because of the draft effect of hot furnace stacks, negative pressures are fairly common, and cold air slips past leaky door seals, cracks and other openings in the furnace. Every time the door is opened, considerable amount of heat is lost. Economy in fuel can be achieved if the total heat that can be passed on to the stock is as large as possible [1].

**Direct method**

The efficiency of furnace can be judged by measuring the amount of fuel needed per unit weight of material.

Thermal efficiency of the furnace =

**Quantity of heat to be imparted by the stock is calculated by**

-

Where Q = quantity of heat carried out by the stock, kCal

m = mass of the stock, kg

mean specific heat of the stock, kCal/kg 0C

final desired temperature of the stock, 0C

initial temperature of the stock before entering to the furnace, 0C

**Indirect Method**

Furnace efficiency can be calculated by subtracting the various losses that occurred during the operation of the furnace. The different losses are

1. Sensible heat loss in the flue gas
2. Loss due to moisture in the flue gas
3. Heat loss due to opening in the furnace
4. Heat loss through furnace wall
5. Other unaccounted losses

For finding out the furnace efficiency, parameters that are required to be observed during the process are

1. Furnace oil consumption in hour basis
2. Material output
3. Excess air quantity
4. Temperature of the flue gas
5. Temperature of the furnace at various zones
6. Wall temperature
7. Hot combustion air temperature

The above parameters can be measured by instruments like infrared thermometer, fuel efficiency monitor, surface thermocouple and other measuring devices.

Furnace efficiency of some known industrial furnaces are shown below in table

|  |  |
| --- | --- |
| **Table: Thermal efficiencies for common industrial furnaces** | |
| **Furnace Type** | **Typical thermal efficiencies (%)** |
| **1. Low temperature furnces** |  |
| a. 540 -9800C (Batch type) | 20 -30 |
| b. 540 -9800C (Continuous type) | 15 -25 |
| c. Coil Anneal (Bell) radiant type | 5 to 12 |
| d. Strip Anneal Muffle | 7 to 12 |
| **2. High temperature furnaces** |  |
| a. Pusher, Rotary | 7 to 15 |
| b. Batch forge | 5 to 10 |
| **3. Continuous Kiln** |  |
| a. Hoffman | 25 to 90 |
| b. Tunnel | 20 to 80 |
| **4. Ovens** |  |
| a. Indirect fired ovens (20 0C - 370 0C) | 35 to 40 |
| b. Direct fired ovens (20 0C - 370 0C) | 35 to 40 |
| *Source : Bureau of Energy Efficiency* |  |

Question:

*An oil-fired reheating furnace has an operating temperature of around 1340°C. Average fuel consumption is 400 litres/hour. The flue gas exit temperature is 750 °C after air preheater. Air is preheated from ambient temperature of 40 °C to 190 °C through an air pre-heater. The furnace has 460 mm thick wall (x) on the billet extraction outlet side, which is 1 m high (D) and 1 m wide. The other data are as given below. Find out the efficiency of the furnace by both indirect and direct method.*

*Exit flue gas temperature = 750°C*

*Ambient temperature = 40°C*

*Preheated air temperature = 190°C*

*Specific gravity of oil = 0.92*

*Average fuel oil consumption = 400 Litres / hr = 400 × 0.92 =368 kg/hr*

*Calorific value of oil = 10000 kCal/kg*

*Average O2 percentage in flue gas = 12%*

*Weight of stock = 6000 kg/hr*

*Specific heat of Billet = 0.12 kCal/kg/°C*

*Average surface temperature of heating + soaking zone = 122 °C*

*Average surface temperature of area other than heating and soaking zone = 80 °C*

*Area of heating + soaking zone = 70.18 m2*

*Area other than heating and soaking zone = 12.6 m2*

***Solution:***

1. **Sensible Heat Loss in Flue Gas:**

Excess air =

=

= 133 %

Theoretical air required to burn 1 kg of oil = 14 kg

Total air supplied = 14 2.33 kg/ kg of oil

Sensible heat loss = -

where m = weight of the flue gas (air + fuel)

= 32.62 + 1 = 33.62 kg / kg of oil.

Sensible heat loss = -

= 33.62 × 0.24 × (750- 40)

= 5729 kCal / kg of oil

Therefore % heat loss in flue gas = = 57.29%

1. **Loss Due to Evaporation of Moisture Present in Fuel**

% Heat Loss =

Where

M = kg of Moisture in 1 kg of fuel oil (0.15 kg/kg of fuel oil)

= flue gas temperature, OC

= Ambient temperature, OC

GCV - Gross Calorific Value of Fuel, kCal/kg

Therefore % Heat Loss = =1.36 %

1. **Loss Due to Evaporation of Water Formed due to Hydrogen in Fuel**

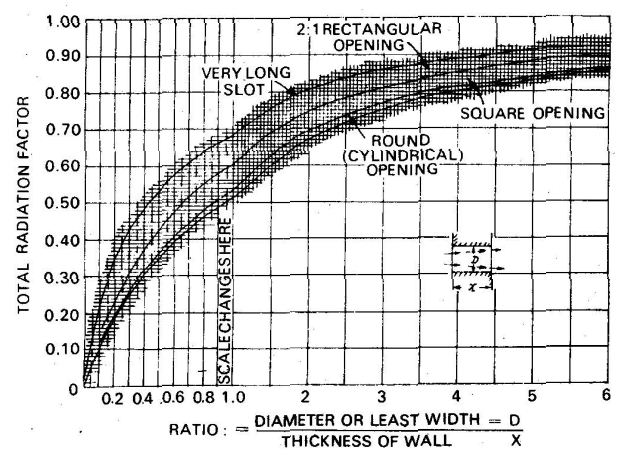
% Heat Loss =

=

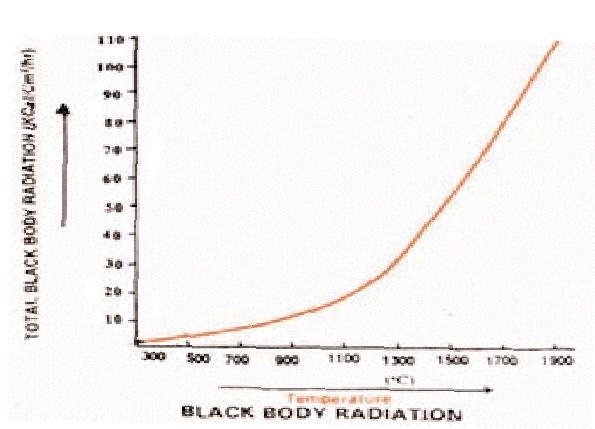
= 9.13 %

1. **Heat Loss due to Openings**

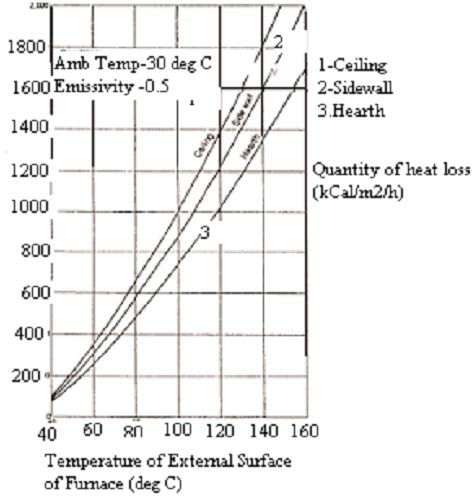
If a furnace body has an opening on it, the heat in the furnace escapes to the outside as radiant heat. Heat loss due to openings can be calculated by computing black body radiation at furnace temperature, and multiplying these values with emissivity (usually 0.8 for furnace brick work), and the factor of radiation through openings. Factor for radiation through openings can be determined with the help of graph as shown in figure (a) The black body radiation losses can be directly computed from the curves as given in the figure (b) below. The reheating furnace in example has 460 mm thick wall (X) on the billet extraction outlet side, which is 1m high (D) and 1m wide. With furnace temperature of 1340°C, the quantity (Q) of radiation heat loss from the opening is calculated as follows:

****

**Fig (a)** Factor for Determining the Equivalent of Heat Release from Openings to the Quality of Heat Release from Perfect Black Body

****

**Fig (b)**  Graph for Determining Black Body Radiation at a Particular Temperature

****

**Fig ( c )** Quantity of Heat Release at Various Temperatures

1. **Heat Loss through Furnace walls**
2. Heat loss through roof and sidewalls:

Total average surface temperature = 122°C

Heat loss at 122 °C (Refer Fig c) = 1252 kCal / m2

Total area of heating + soaking zone = 70.18 m2

Total heat loss = 1252 kCal / m2 / hr × 70.18 m2= 87865 kCal/hr

Equivalent oil loss (a) = 8.78 kg / hr

Total average surface temperature of area other than heating and soaking zone = 80°C Heat loss at 80°C = 740 kCal / m2 / hr

Total area = 12.6 m2

Total heat loss = 740 kCal / m × 12.6 m2= 9324 kCal/hr

Equivalent oil loss (b) = 0.93 kg / hr

Total loss of fuel oil = a + b = 9.71 kg/hr

Total percentage loss = = 2.64%

1. **Unaccounted Loss**

These losses comprises of heat storage loss, loss of furnace gases around charging door and opening, heat loss by incomplete combustion, loss of heat by conduction through hearth, loss due to formation of scales.

Furnace Efficiency

**(Direct Method)**

Heat input = 400 litres / hr = 368 kg/hr

Heat output = m × Cp × ∆T

= 6000 kg × 0.12 × (1340 – 40)

= 936000 kCal

Efficiency = 936000 × 100 / (368 × 10000)

= 25.43 %

Losses = (100 -25.43) % = 74.57 %

**Furnace Efficiency (Indirect Method)**

1. Sensible Heat Loss in flue gas = 57.29%

2. Loss due to evaporation of moisture in fuel = 1.36 %

3. Loss due to evaporation of water in fuel = 9.13 %

4. Heat loss due to openings = 5.56 %

5. Heat loss through wall = 2.64%

Total losses = 75.98%

Furnace Efficiency = 100 – 75.98 = 24.02 %

The instruments required for carrying out performance evaluation in a furnace can be carried out by the following instruments as tabulated below

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Sl.No. | **Parameters to be measured** | **location of measurement** | **Instruments required** | **Required Value** |
| 1 | Furnace soaking zone temperature (reheating furnace) | Soaking zone side wall | Pt/ Pt - Rh thermocouple with indicator and recorder | 1200–1300°C |
| 2 | Flue gas | Flue gas exit from furnace and entry to re- cuperator | Chromel Alummel Thermocouple with indicator | 700°C max. |
| 3 | Flue gas | After recuperator | Hg in steel thermometer | 300°C (max) |
| 4 | Furnace hearth pressure in the heating zone | Near charging end side wall over hearth level | Low pressure ring gauge | +0.1 mm. of Wg |
| 5 | Flue gas analyser | Near charging end side wall end side | Fuel efficiency monitor for oxygen and temperature | t = 700°C (max) O2 % = 5 |
| 6 | Billet temperature | Portable | Infrared pyrometer or Optical pyrometer | - |
| *Source: Bureau of Energy Efficiency* | |  |  |  |

**4.3 General Fuel Economy Measures in Furnaces**

Typical energy efficiency measures for an industry with furnace are:

1) Complete combustion with minimum excess air

2) Correct heat distribution

3) Operating at the desired temperature

4) Reducing heat losses from furnace openings

5) Maintaining correct amount of furnace draught

6) Optimum capacity utilization

7) Waste heat recovery from the flue gases

8) Minimum refractory losses

9) Use of Ceramic Coatings

1. **Complete Combustion with Minimum Excess Air**

Amount of excess air in the furnace determines the amount of heat loss in the flue gas. Percentage of heat loss from the furnace when the temperature of the flue gas is 900°C is tabulated below

|  |  |
| --- | --- |
| Table: Heat loss in Flue gas based on excess air level | |
| Excess Air | % of total heat in the fuel carried away by waste gases ( flue gas temperature 9000C) |
| 25 | 48 |
| 50 | 55 |
| 75 | 63 |
| 100 | 71 |
| *Source: Bureau of Energy Efficiency* | |
| There are several ways by which air quantity can be controlled for complete combustion of fuel. By controlling air infiltration, maintain pressure of combustion air, fuel quality and excess air monitoring, quantity of air can be controlled. Too much excess air can cause the flame temperature, furnace temperature, heating rate reduce by some extent. Again lowering the excess air will increase the amount of unburnt component in the flue gases which will pass through stack. Energy can be conserved by optimizing the amount of air required for combustion inside the furnace and hence an economical measure in furnace. The impact of this measure is higher when the temperature of furnace is high [1].  If a reheating furnace is not equipped with an automatic air/fuel ratio controller, it is necessary to periodically sample gas in the furnace and measure its oxygen contents by a gas analyzer. Scale losses are more if the amount of air is in excess.   1. **Proper Heat Distribution**   Furnace design should be such that in a given time, as much of the stock could be heated uniformly to a desired temperature with minimum fuel firing rate. Following care should be taken when using burners, for proper heat distribution:   1. The position of the flame should be such that it does not touch the wall and should propagate clear of any solid object. Any obstruction will deatomise the fuel particles thus affecting combustion and create black smoke. If flame impinges on the stock, there would be increase in scale losses.   uygyug.JPG  Fig: Heat Distribution in Furnace   1. If the flames impinge on refractories, the incomplete combustion products can settle and react with the refractory constituents at high flame temperatures. 2. The flames of different burners in the furnace should stay clear of each other. If they intersect, inefficient combustion would occur. It is desirable to stagger the burners on the opposite sides.   tyttttt.JPG  Fig: Alignment of Burners in Furnace   1. The burner flame has a tendency to travel freely in the combustion space just above the material. In small furnaces, the axis of the burner is never placed parallel to the hearth but always at an upward angle. Flame should not hit the roof. 2. The larger burners produce a long flame, which may be difficult to contain within the furnace walls. More burners of less capacity give better heat distribution in the furnace and also increase furnace life. 3. For small furnaces, it is desirable to have a long flame with golden yellow colour while firing furnace oil for uniform heating. The flame should not be too long that it enters the chimney or comes out through the furnace top or through doors. In such cases, major portion of additional fuel is carried away from the furnace. | |
|  | |

**3. Maintaining Optimum Operating Temperature of Furnace**

It is important to operate the furnace at optimum temperature. The operating temperatures of various furnaces are given in Table

|  |  |  |
| --- | --- | --- |
| Operating temperature of various furnaces | | |
| Slab reheating furnaces | 12000C | |
| Rolling Mill furnaces | 12000C | |
| Bar furnace for sheet mill | 8000C | |
| Bogie type annealing furnace | 6500C - 7500C | |
| *Source: Bureau of Energy Efficiency* | |

Excessive high temperatures than optimum causes heat loss, excessive oxidation, decarbonization as well as over-stressing of the refractories. These controls are normally left to operator judgment, which is not desirable. To avoid human error, on/off controls should be provided.

1. **Prevention of Heat Loss through Openings**

Heat loss through openings consists of the heat loss by direct radiation through openings and the heat loss caused by combustion gas that leaks through openings. The heat loss from an opening can also be calculated using the following formula:

Where

T = absolute temperature, 0C

a = factor of total radiation

A = area of the opening, m2

H = time, hr

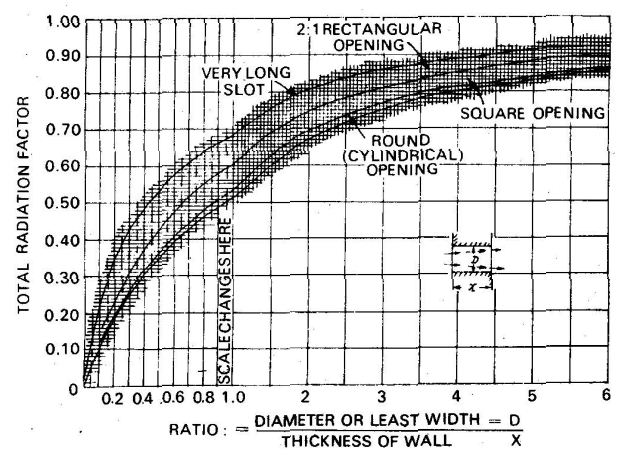
During furnace operation if the furnace pressure is slightly higher than ambient pressure (as in case of reheating furnace), there will be leakage of the burnt gases and may blow off through openings and heat is lost with that. But damage is more, if outside air intrudes into the furnace, making temperature distribution uneven and oxidizing billets. This heat loss is about 1% of the total quantity of heat generated in the furnace, if furnace pressure is controlled properly.

***Question:***

*A reheating furnace with walls 460 mm thick (X) has a billet extraction outlet, which is 1 m high (D) and 1 m wide. When the furnace temperature is 1,340°C. Calculate the quantity (Q) of radiation heat loss from this opening.*

Solution: The shape of opening is square, and D/X = l/0.46 = 2.17.

Thus, the factor for total radiation is calculated from the figure, a= 0.71



Therefore we get,

= 234539 kCal /hr

1. **Control of furnace draf**t

If negative pressures exist in the furnace, air infiltration is liable to occur through the cracks and openings thereby affecting air-fuel ratio control. Tests conducted on apparently airtight furnaces have shown air infiltration up to the extent of 40%. Neglecting furnaces pressure could mean problems of cold metal and non-uniform metal temperatures, which could affect subsequent operations like forging and rolling and result in increased fuel consumption. For optimum fuel consumption, slight positive pressure should be maintained in the furnace as shown in Figure

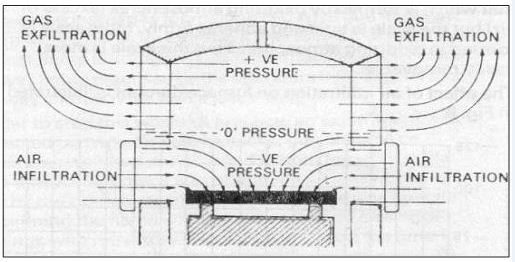


Fig: Effect of Pressure on the Location of Zero Level and Infiltration of Air

Ex-filtration is less serious than infiltration. Some of the associated problems with ex filtration are leaping out of flames, overheating of the furnace refractories leading to reduced brick life, increased furnace maintenance, burning out of ducts and equipments attached to the furnace, etc. In addition to the proper control on furnace pressure, it is important to keep the openings as small as possible and to seal them in order to prevent the release of high temperature gas and intrusion of outside air through openings such as the charging inlet, extracting outlet and peephole on furnace walls or the ceiling.

1. **Optimum Capacity Utilization:**

Loading is one of the most important factors which affect the furnace efficiency. Maximum thermal efficiency can be achieved by proper loading (quantity). If the furnace is under loaded a smaller fraction of the available heat in the working chamber will be taken up by the load and therefore efficiency will be low. The best method of loading is generally obtained by trial-noting the weight of material put in at each charge, the time it takes to reach temperature and the amount of fuel used. Every endeavour should be made to load a furnace at the rate associated with optimum efficiency although it must be realised that limitations to achieving this are sometimes imposed by work availability or other factors beyond control.

The loading of the charge 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 the flames produced.

• The hot gases are efficiently circulated around the heat receiving surfaces

Stock should not be placed in the following position

• In the direct path of the burners or where flame impingement is likely to occur.

• In an area which 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.

The other reason for not operating the furnace at optimum loading is the mismatching of furnace dimension with respect to charge and production schedule.

In the interests of economy and work quality the materials comprising the load should only remain in the furnace for the minimum time to obtain the required physical and metallurgical requirements. When the materials attain these properties they should be removed from the furnace to avoid damage and fuel wastage. The higher the working temperature, higher is the loss per unit time. The effect on the materials by excessive residence time will be an increase in surface defects due to oxidation. The rate of oxidation is dependent upon time, temperature, as well as free oxygen content. The possible increase in surface defects can lead to rejection of the product. It is therefore essential that coordination between the furnace operator, production and planning personnel be maintained.

Optimum utilization of furnace can be planned at design stage. Correct furnace for the jobs should be selected considering whether continuous or batch type furnace would be more suitable. For a continuous type furnace, the overall efficiency 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.

1. **Waste Heat Recovery from Furnace Flue Gases**

In any industrial furnace the products of combustion leave the furnace at a temperature higher than the stock temperature. Sensible heat losses in the flue gases, while leaving the chimney, carry 35 to 55 per cent of the heat input to the furnace. The higher the quantum of excess air and flue gas temperature, the higher would be the waste heat availability. Waste heat recovery should be considered after all other energy conservation measures have been taken. Minimizing the generation of waste heat should be the primary objective. The sensible heat in flue gases can be generally recovered by the following methods.

* Charge (stock) preheating,
* Preheating of combustion air,
* Utilizing waste heat for other process (to generate steam or hot water by a waste heat boiler)

**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 gas to reduce fuel consumption rate.

**Preheating of Combustion Air**

For a long time, the preheating of combustion air using heat from exhaust gas was not used except for large boilers, metal-heating furnaces and high-temperature kilns. This method is now being employed in compact boilers and compact industrial furnaces as well. The energy contained in the exhaust gases can be recycled by using it to pre-heat the combustion air. A variety of equipment is available; external recuperators are common, but other techniques are now available such as self-recuperative burners. For example, with a furnace exhaust gas temperature of l,000°C, a modern recuperator can pre-heat the combustion air to over 500°C, giving energy savings compared with cold air of up to 30% [1]

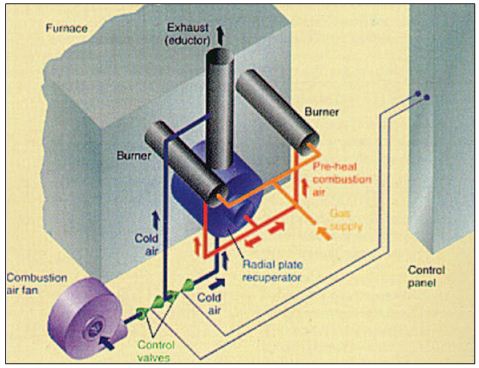


Fig: Preheating the Air for Combustion by a Recuperator

**External Recuperators**

There are two main types of external recuperators:

* Radiation recuperators;
* Convection recuperators

**Radiation Recuperators**

Radiation Recuperators generally take the form of concentric cylinders, in which the combustion air passes through the annulus and the exhaust gases from the furnace pass through the centre. The simple construction means that such recuperators are suitable for use with dirty gases, have a negligible resistance to flow, and can replace the flue or chimney if space is limited. The annulus can be replaced by a ring of vertical tubes, but this design is more difficult to install and maintain. Radiation recuperators rely on radiation from high temperature exhaust gases and should not he employed with exhaust gases at less than about 800°C [1]

**Convection Recuperators**

Convection Recuperators consist essentially of bundles of drawn or cast tubes. Internal and/or external fins can be added to assist heat transfer. The combustion air normally passes through the tubes and the exhaust gases outside the tubes, but there are some applications where this is reversed. For example, with dirty gases, it is easier to keep the tubes clean if the air flows on the outside. Design variations include 'U' tube and double pass systems. Convection recupe rators are more suitable for exhaust gas temperatures of less than about 900°C [1]

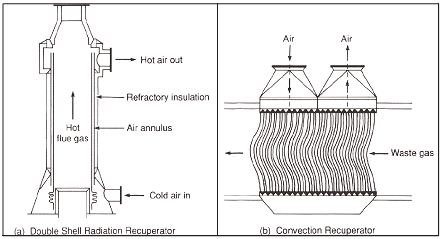


Fig: Metallic Recuperator

**Self-Recuperative Burners**

Self-recuperative burners are based on traditional heat recovery techniques in that the products of combustion are drawn through a concentric tube recuperator around the burner body and used to pre-heat the combustion air. A major advantage of this type of system is that it can be retro-fitted to an existing furnace structure to increase production capability without having to alter the existing exhaust gas ducting arrangements. SRBs are generally more suited to heat treatment furnaces where exhaust gas temperatures are lower and there are no stock recuperation facilities [1]

**Estimation of fuel savings**

By using preheated air for combustion, fuel can be saved. The fuel saving rate is given by the following formula:

where S: fuel saving rate, %

F: Calorific value of fuel (kCal/kg fuel)

P: quantity of heat brought in by preheated air (kCal/kg fuel)

Q: quantity of heat taken away by exhaust gas (kCal/kg fuel)

The above formula can be used for calculating the fuel saving rates for heavy oil and natural gas for various temperatures of exhaust gas and preheated air.

For example, when combustion air for heavy oil is preheated to 400°C by a heat exchanger with an inlet temperature of 800 °C, the fuel conservation rate is estimated to be about 20 percent. When installing a recuperator in a continuous steel reheating furnace, it is important to choose a preheated air temperature that will balance the fuel saving effect and the invested cost for the equipment.

Also, the following points should be checked:

* Draft of exhaust gas: When exhaust gas goes through a recuperator, its draft resistance usually causes a pressure loss of 5–10 mm H2O. Thus, the draft of stack should be checked.
* Air blower for combustion air: While the air for combustion goes through a recuperator, usually 100–200 mm H2O pressure is lost. Thus, the discharge pressure of air blower should be checked, and the necessary pressure should be provided by burners.

Since the volume of air is increased owing to its preheating, it is necessary to be careful about the modification of air-duct diameters and blowers. As for the use of combustion gases resulting from high-density oils with a high sulphur content, care must be taken to avoid problems such as clogging with dust or sulphides, corrosion or increases in nitrogen oxides.

1. **Minimising Wall Losses**

About 30–40% of the fuel input to the furnace generally goes to make up for heat losses in intermittent or continuous furnaces. Saving of fuel and heat loss from the furnace can be done by using appropriate choice of refractory and insulation materials. The heat losses from furnace walls affect the fuel economy considerably. The extent of wall losses depend on:

• Emissivity of wall

• Thermal conductivity of refractories

• Wall thickness

• Whether furnace is operated continuously or intermittently

Heat losses can be reduced by increasing the wall thickness, or through the application of insulating bricks. Outside wall temperatures and heat losses of a composite wall of a certain thickness of firebrick and insulation brick are much lower, due to lesser conductivity of insulating brick as compared to a refractory brick of similar thickness. In the actual operation in most of the small furnaces the operating periods alternate with the idle periods. During the off period, the heat stored in the refractories during the on period is gradually dissipated, mainly through radiation and convection from the cold face. In addition, some heat is abstracted by air flowing through the furnace. Dissipation of stored heat is a loss, because the lost heat is again imparted to the refractories during the heat "on" period, thus consuming extra fuel to generate that heat. If a furnace is operated 24 hours, every third day, 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 55 percent of the heat stored in the refractories is dissipated from the cold surface during the 16 hours idle period. Furnace walls built of insulating refractories and cased in a shell reduce the flow of heat to the surroundings [1]

**Prevention of Radiation Heat Loss from Surface of Furnace**

The quantity of heat release from surface of furnace body is the sum of natural convection and thermal radiation. This quantity can be calculated from surface temperatures of furnace. The temperatures on furnace surface should be measured at as many points as possible, and their average should be used. If the number of measuring points is too small, the error becomes large.

The quantity (Q) of heat release from a reheating furnace is calculated with the following formula:

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

is the temperature of external wall surface of the furnace (°C)

is thetemperature of air around the furnace (°C)

E is emissivity of external wall surface of the furnace

The first term of the above formula represents the quantity of heat release by natural convection, and the second term represents the quantity of heat release by radiation.

**Use of Ceramic Fibre**

Ceramic fibre is a low thermal mass refractory used in the hot face of the furnace and fastened to the refractory walls. Due to its low thermal mass the storage losses are minimized. This results in faster heating up of furnace and also faster cooling. Energy savings by this application is possible only in intermittent furnaces. More details about ceramic fibre are given in the chapter on insulation and refractories [1].

**9. Use of Ceramic Coatings**

Ceramic coatings in 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. This outstanding property has been exploited for use in hot face insulation. Ceramic coatings are high emissivity coatings which when applied has a long life at temperatures up to 1350°C. The coatings fall into two general categories-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% have been reported depending on the type of furnace and operating conditions [1]

**4.4 Case Study**

In a rerolling mill, following energy conservation measure was implemented and savings achieved are explained below:

**Saving by Installing a Recuperator**

This plant had a continuous pusher type billet-reheating furnace. Heating zone is having two burners inside the furnace. The total length of the furnace is 40 ft. Furnace consumes around 620 kL annually. Waste heat recovery unit is not present in the furnace. The flue gas temperature is found to be 650°C. Recuperator device should be installed in the furnace to tap this potential heat which can able to preheat the combustion air to 325°C. By resorting to this measure, there was 15% fuel saving which is 93 kL of oil per annum [1]

***Question***

1. *What do you understand by intermittent and continuous furnaces?*
2. *What are the parameters to be considered in the design of an efficient furnace?*
3. *Why do furnaces operate at low efficiency? What are the methods by which furnace efficiencies can be improved?*
4. *What are the major losses in a furnace?*
5. *How is the furnace performance evaluated by direct method?*
6. *How is the furnace performance evaluated by indirect method?*
7. *What are the instruments required for undertaking performance evaluation of the furnace?*
8. *What are the disadvantages of excess air in a furnace?*
9. *What care should be taken when using furnace for proper heat distribution in a furnace?*
10. *What is the impact of flame impingement on the refractory?*
11. *Explain why a flame should not touch the stock.?*
12. *List down the adverse impacts of operating the furnace at temperatures higher than required.*
13. *Discuss how heat loss takes place through openings.*
14. *What are the methods of waste heat recovery in a furnace?*
15. *Explain the term recuperator*
16. *What are the precautions to be taken when retrofitting the recuperator in the existing furnace.*
17. *Give two examples of utilizing furnace waste heat for other processes.*
18. *What are the parameters on which the wall losses depends?*
19. *What are the methods by which wall losses can be reduced?*

**References**

1. *Bureau of Energy efficiency*, [www.bee-india.nic.in](http://www.bee-india.nic.in), accessed on 28 June, 2012.
2. Rajan, T.V., Sharma, C.P. & Sharma A*.; Heat Treatment: Principles and Techniques*, Prentice Hall of India Pvt. Ltd, 2006.