Chapter 4.2: Furnaces

Short type questions

1.	Write the formula to calculate the thermal efficiency of a furnace by direct method? **Ans.** 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 to be imparted (Q) to the stock can be found from $Q = m \times C_p (t_1 - t_2)$ kcal/h 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 desired, ^oC t_2 = Initial temperature of the stock before it enters the furnace, ^oC Heat in the fuel consumed for heating the stock (kcal/h) $= \frac{\text{GCV of fuel (kcal/kg)}}{\text{Fuel consumption rate (kg/h)}}$
2.	What are the instruments required to measure billet temperature in a billet reheating furnace? **Ans.** Instruments like infrared pyrometer or optical pyrometer is used to measure billet temperature in a billet reheating furnace.
3.	List any five factors which affect the performance of furnace **Ans.** a Lower capacity utilisation of furnace b Insufficient draft c Use of inefficient burner d High stack loss e Inadequate insulation
4.	What is the equation used to calculate the % of excess air in a furnace? **Ans.** The excess air equation is given by = $(\%O_2 \times 100) / (21 - \%O_2)$
5.	What is the equation used to estimate the sensible heat loss in flue gas at furnace exit? **Ans.** Sensible heat loss in flue gas at furnace exit is given by the equation = $m \times C_p \times \Delta T$ Where, M = Mass of flue gas in kg C_p = Specific heat of flue gas in kcal/kg/°C

	ΔT = (Flue gas Temperature - ambient temperature) in °C
6.	Name any three instruments required for performance evaluation of a furnace **Ans.** The instruments used for performance evaluation of a furnace are Flue gas analyser, infrared pyrometer and draft gauge.
7.	What happens if the flames impinge on refractories in a furnace? **Ans.** If the flames impinge on refractories, the incomplete combustion products can settle and react with the refractory constituents at high flame temperatures resulting in damage to refractories.
8.	What should be the Optimum Operating Temperature of rolling mill furnace and what happens if the charge is heated above the optimum temperature? **Ans.** The optimum temperature of the rolling mill furnace is 1200°C Operating at too high temperatures than optimum causes heat loss, excessive oxidation, de-carbonization as well as over-stressing of the refractories.
9.	What are the locations in which stock should not be placed inside the furnace? • 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.
10.	The heat losses from furnace walls affect the fuel economy considerably. Name the parameters on which wall losses depend on? – Emissivity of wall – Thermal conductivity of refractories – Wall thickness – Whether furnace is operated continuously or intermittently

Long type questions

1.	What are the characteristics of an Efficient Furnace? Furnace should be designed so that in a given time, as much of material as possible can be heated to a uniform temperature as possible with the least possible fuel and labour. To achieve this, the following parameters can be considered. ▪ Determination of the quantity of heat to be imparted to the material or charge. ▪ Liberation of sufficient heat within the furnace to heat the stock and overcome all heat losses. ▪ Transfer of available part of that heat from the furnace gases to the surface of the heating stock. ▪ Equalization of the temperature within the stock. ▪ Reduction of heat losses from the furnace to the minimum possible extent.

2.	List at least six 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

Numerical type questions

1.	An oil-fired reheating furnace has an operating temperature of around 1150°C. Average fuel (FO) consumption is 400 litres/hour. The flue gas exit temperature after the air pre heater is 300 °C. Combustion air is preheated from ambient temperature of 40 °C to 190 °C through an air pre-heater. The other data are as given below. Find out the heat carried away by the exhaust gases (in kcal/h and also as % of the energy input) and heat recovered by the combustion air (in kcal/h and also as % of the energy input).		
	Specific gravity of oil	=	0.92
	Calorific value of oil	=	9200 kCal/kg
	Average O_2 percentage in flue gas	=	12%
	Theoretical air required	=	14 kg of air to burn 1 kg of oil
	Specific heat of air	=	0.24 kcal/kg°C
	Specific heat of flue gas	=	0.25 kcal/kg°C
	A. Energy Input		
	FO consumption	=	400 lph
		=	400 x 0.92 =368 kg/hr
		=	368 x 9200 = 3385600 kcal/h
	Sensible Heat Loss in Flue Gas:		
	Corresponding excess air	=	$(\%O_2 \times 100) / (21 - \%O_2)$
		=	133% excess air
	Theoretical air required	=	14 kg of air to burn 1 kg of oil
	Total air supplied	=	14 x 2.33 kg / kg of oil
		=	32.62 kg / kg of oil
	Sensible heat loss in flue gas	=	$m \times C_p \times \Delta T$
	m	=	Mass of flue gas
		=	32.62 + 1.0 = 33.62 kg / kg of oil.
	C_p	=	Specific heat of flue gas

	ΔT	=	Temperature of flue gas – ambient temperature
	Heat loss	=	33.62 x 0.25 x (300– 40)
		=	2185 kcal / kg of oil
		=	2185 x 368 kcal/h
		=	804080 kcal/h
	Sensible heat loss in flue gas as % heat loss to input energy	=	804080 x100/3385600 = 23.75%
	Heat gained by combustion air:		
	Heat gain by combustion air	=	32.62 x 0.24 x (190 – 40) x 368
		=	432150 kcal/h
	Heat gain by combustion air as % heat to input energy	=	432150 x100/3385600 = 12.76%

2. In an engineering industry, resistance heating type furnace was used for heat treatment of the product. The power consumption of the furnace at 1/3rd loading and full loading is 860 kWh and 1600 kWh per cycle respectively. The furnace heat treatment cycle and loading of the furnace was analysed. The details are as follows:

Furnace capacity	: 180 kW
Rated loading capacity of furnace	: 10 Tons
Heat treatment cycle	: Heating up to 650 °C – 6 hours
	: Soaking at 650 °C – 8 hours
	: Cooling in furnace – 4 hours
Quantity of the stock to be treated	: 1000T/year

Evaluate the specific energy consumption (kWh/ton) at 1/3rd loading and full loading. Calculate the energy savings by improving the loading of furnace from 1/3rd load to full load (cost of electricity is Rs. 5.00 per kWh).

Ans.

Sp. Power consumption of stock:

i)	Load in furnace (1/3rd)	: 10 x 1/3rd = 3.3 MT
	Power consumption for 1/3rd load	: 860 kWh/cycle
	Sp. Power consumption at 1/3rd load	: 860/3.3 = 260.6 kWh/MT
ii)	Load in the furnace (full load)	: 10 MT
	Power consumption at full load	: 1600 kWh/cycle
	Sp. Power consumption at full load	: 1600/10 = 160 kWh/MT
	Reduction in power consumption at optimum load (full load)	: 260.6 – 160 = 100.6 kWh/MT
	Annual stock production	: 1000 T
	By operating furnace with each batch of 10T (full load)	
	Reduction in power consumption	: 1000 x 100.6
		: 100600 kWh/year
	Annual cost saving	: Rs. 5.03 lakh

3.	Find the theoretical energy required to melt one ton of steel from ambient temperature of 20°C. Data: Specific heat of steel = 0.186 Wh/kg/°C, Latent heat for melting of steel = 40 Wh/kg/°C. Melting point of steel = 1600 °C. If the melting furnace consumed 700 kWh to melt one ton of steel, what is the efficiency of the furnace. **Ans.** Theoretical Total heat required to melt on ton of steel = Sensible heat + Latent heat Sensible Heat =(1000kg x 0.186 Wh /kg °C x (1600-20)°C)/1000=294 kWh Latent heat = (40 Wh/ kg x 1000 kg)/1000 = 40 kWh Total Heat = 294 + 40 = 334 kWh. So the theoretical energy needed to melt one tone of steel from 20°C = 334 kWh. Actual Energy used to melt to 1600 °C is 700 kWh Therefore, Efficiency = 334 kWh x 100/ 700 kWh = 48%
4.	One heat treatment furnace (resistance heating type) having 150 kW heating capacity. The measured surface temperature was about 120 °C, which is on higher side. The plant has replaced the inside refractory with ceramic fibre. After replacing with ceramic fibre the surface temperature was reduced to 60 °C. Evaluate the energy savings, cost savings and pay back period achieved by the plant. The surface area of the furnace is 20 m². The cost of insulation was Rs. 8000 per m² the operating hours of the furnace is 4000 hours per year. Evaluate the losses before the insulation and after the insulation. Consider ambient temperate as 30° C. Cost of energy Rs. 4.50 per kWh. Assume heat transfer factor as 2.2 to calculate the convective heat loss. **Ans.** The surface heat loss (kcal/h/m²) is given by the equation: $= Q = \left\{a \times (t_1 - t_2)^{\frac{5}{4}}\right\} + \left\{4.88 \times \in \times \left[\left(\frac{t1 + 273}{100}\right)^4 - \left(\frac{t2 + 273}{100}\right)^4\right]\right\}$ Where, a = heat transfer factor t1 = Wall surface temperature, °C t2 = Ambient temperature, °C ε = Emissivity of the wall surface (assumed as 0.7) Therefore, the surface heat loss at 120°C, $Q_{120} = \left\{2.2 \times (120 - 30)^{5/4}\right\} + \left\{4.88 \times 0.7 \times \left[\left(\frac{120 + 273}{100}\right)^4 - \left(\frac{30 + 273}{100}\right)^4\right]\right\}$ Q_{120} = 1136.75 kcal/h/m² ∴ for 20 m² surface area Q_{120} = 22735 kcal/h = 26.43 kW

	Similarly for 60°C surface temperature after insulation.			
	Q_{60}	=	286.55 kcal/h/m²	
	$\therefore$ for 20 m² surface area Q_{60}	=	5731 kcal/h	
		=	6.66 kW	
	Therefore net energy savings	=	26.43 – 6.66	= 19.76 kW
	Annual energy savings for 4000 hrs of operation	=	79040 kWh	
	Annual cost savings @ Rs. 4.50/kWh	=	Rs. 3.56 lakh	
	Cost of investment @ Rs. 8000 / m²	=	Rs. 1.60 lakh	
	Simple payback period	=	0.45 year.	