Chapter 4.4: Heat Exchangers

Short type Questions

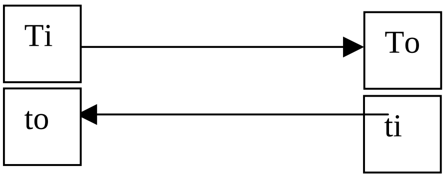
1.	Define effectiveness of heat exchanger? **Ans.** Effectiveness = $\frac{t_o - t_i}{(T_i - t_i)} = \frac{\text{Cold fluid temp.range}}{\text{Inlet temp. diff. of hot \& cold fluid}}$ Where, t_o = Cold fluid outlet temperature t_i = Cold fluid inlet temperature T_i = Hot fluid inlet temperature
2.	What do you mean by heat duty of a heat exchanger? **Ans.** Heat duty of a heat exchanger is defined as the heat that is transferred from hot fluid to cold fluid per unit time.
3.	Mention 2 basic parameters that have to be measured at site to evaluate the performance of a heat exchanger? **Ans.** 1. Hot and cold fluid in let and outlet temperatures 2. Mass flow rate of cold and hot fluids
4.	What do you mean by capacity ratio in a heat exchanger? **Ans.** R = $\frac{T_i - T_o}{t_o - t_i} = \frac{\text{Temp. range of hot fluid}}{\text{Temp. range of Cold fluid}}$ Where, t_o = Cold fluid outlet temperature t_i = Cold fluid inlet temperature T_i = Hot fluid inlet temperature T_o = Hot fluid outlet temperature
5.	Find the Overall heat transfer coefficient for a shell and tube counter flow heat exchanger where the heat exchanged is 11.27 GJ/hour with the heat transfer area of 96 m^2. Assume the LMTD as 76 ^oC. **Ans.** Heat Transfer Co-efficient Overall HTC, U = Q/ (A x LMTD) = 11.27 x 10^6 / (3600 x 96 x 76) = 0.43 kW/m^2. K
6.	Give the equation to calculate the Overall heat transfer coefficient. **Ans.** Heat exchanger performance is normally evaluated by the overall heat transfer coefficient *U that* is defined by the equation **U=Q/ (A x LMTD)** Where **Q** = Heat transferred in **kCal/hr** **A** = Heat transfer surface area in **m²** **LMTD** = Log Mean Temperature Difference in **⁰C** **U** = Overall heat transfer Coefficient **kCal/hr/m²/⁰C**

7.	Give the equation to Calculate LMTD for a counter flow heat exchanger **Ans.** LMTD Counter current Flow = ((Ti-to) – (To-ti)) / ln ((Ti-to)/(To-ti)) Where, Ti- Hot fluid inlet temperature, ti- Cold fluid inlet temperature To- Hot fluid outlet temperature, to- Cold fluid outlet temperature
8.	Give the equation to Calculate LMTD for a parallel flow heat exchanger **Ans.** LMTD Parallel Flow = ((Ti-ti) – (To-to)) / ln ((Ti-ti)/(To-to)) Where, Ti- Hot fluid inlet temperature, ti- Cold fluid inlet temperature To- Hot fluid outlet temperature, to- Cold fluid outlet temperature
9.	Write the equation to calculate heat duty for a heat exchanger. **Ans.** Heat Duty, Qh = Wx Cph x (Ti-To) ....Eqn-1 Heat Duty, Qc = Wx Cpc x (ti-to) Eqn-2
10.	What do you mean by overall heat transfer coefficient? **Ans.** The ratio of heat flux per unit difference in approach across heat exchange equipment considering the individual coefficient and heat exchanger metal surface conductivity. The magnitude indicates the ability of heat transfer for a given surface. Higher the coefficient lesser will be the heat transfer surface requirement

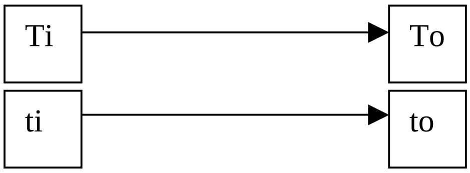
Long type questions

1.	Explain the following a) Over all heat transfer coefficient b) Log mean temp difference c) Co-current and counter current flow d) Heat duty of heat exchanger **Ans.** a) Over all heat transfer coefficient: Heat exchanger performance is normally evaluated by the overall heat transfer coefficient *U that* is defined by the equation **Q=U x A x LMTD** Where **Q** = Heat transferred in **kCal/hr** **A** = Heat transfer surface area in **m^2** **LMTD** = Log Mean Temperature Difference in **^0C** **U** = Overall heat transfer Coefficient **$kCal/hr/m^2/^0C$** When the hot and cold stream flows and inlet temperatures are constant, the heat transfer coefficient may be evaluated using the above formula. It may be observed that the heat pick up by the cold fluid starts reducing with time. b) Log mean temp difference

a) Counter current Flow



b) Co-current flow



LMTD Counter current Flow = ((Ti-to) – (To-ti)) / ln ((Ti-to)/(To-ti))

LMTD Co current Flow = ((Ti-ti) – (To-to)) / ln ((Ti-ti)/(To-to))

c) co current and counter current flow

If the flow of hot and cold fluids is in the same direction then the flow is described as co current flow. If the flow is in opposite direction then it is called as counter current flow.

d) Heat duty of heat exchanger

The capacity of the heat exchanger equipment expressed in terms of heat transfer rate, viz. magnitude of energy or heat transferred per time. It means the exchanger is capable of performing at this capacity in the given system.

2. Explain with equations the procedure for calculating the overall heat transfer co-efficient for heat exchangers

Ans. 1. Heat Duty, Q = qs + ql

qs is the sensible heat and ql is the latent heat

qs = Wx Cph x(Ti- To)/1000/3600

(or)

qs = w x Cpc x (to-ti)/1000/3600 in kW

ql= W x λ_h ,

λ_h – Latent heat of Condensation of a hot condensing vapour

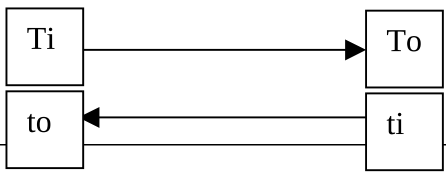
(or)

= w x λ_c ,

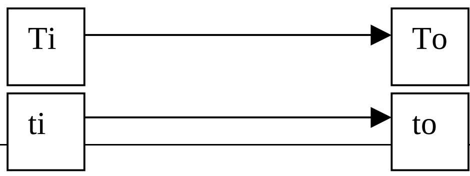
λ_c - Latent heat of Vaporization

2. Hot Fluid Pressure Drop, ΔPh = Pi – Po
3. Cold fluid pressure drop, ΔPc = pi- po
4. Temperature range hot fluid, ΔT = Ti- To
5. Temperature range cold fluid, Δt = to – ti
6. Capacity ratio, R = W x CPh / w Cpc (or) (Ti- To) / (to- ti)
7. Effectiveness, S = (to- ti) / (Ti – ti)
8. LMTD

a) Counter current Flow



b) Co-current flow



LMTD Counter current Flow = ((Ti-to) – (To-ti)) / ln ((Ti-to)/(To-ti))

LMTD Co current Flow = ((Ti-ti) – (To-to)) / ln ((Ti-ti)/(To-to))

b) Correction factor for LMTD to account for Cross flow

$$F = \frac{(R+1)^{1/2} \ x \left[\ln\left(\frac{1-SR}{1-S}\right)\right]}{(1-R) \ x \ \ln\left\{\frac{2-S(R+!-(R+1)^{1/2}}{\{2-S(R+1)+(R+1)^{1/2}\}}\right\}}$$

9. Corrected LMTD

= F x LMTD

10. Heat Transfer Co-efficient

U = Q / (A x Corrected LMTD)

Numerical type questions

1. In a double pipe heat exchanger hot fluid is entering at 220°C and leaving at 115°C. Cold fluid enters at 10 deg c and leaves at 75°C. Mass flow rate of hot fluid 100 kg/hr, cp of hot fluid 1.1 kcal/kg°C. Cp of cold fluid 0.95kcal/kg°C. Calculate LMTD

i) If the flow is parallel

ii) If the flow is counter current.

iii) Find the mass flow rate of cold fluid if the heat loss during the exchange is 5%.

i. LMTD Parallel flow

$$\textbf{LMTD} = \frac{\Delta t1 - \Delta t2}{\ln \frac{\Delta t1}{\Delta t2}}$$

$\Delta t1$ = 210°C

$\Delta t2$ = 40°C

$$\text{LMTD} = \frac{210-40}{\ln \frac{210}{40}} = 102.5°C$$

ii. LMTD Counter current flow

$\Delta t1$ = 145°C

$\Delta t2$ = 105°C

	LMTD = $\dfrac{\Delta t1 - \Delta t2}{\ln \dfrac{\Delta t1}{\Delta t2}}$ = $\dfrac{145 - 105}{\ln \dfrac{145}{105}}$ = 123.9°C **iii. Mass flow rate of cold fluid** Data: m. Mass flow rate of hot fluid = 100 kg/hr cph. = 1.1 kcal/kg°C CPC = 0.95 kcal/kg°C Cold fluid inlet temperature = 10°C Cold fluid outlet temperature = 75°C Hot fluid inlet temperature = 220°C Hot fluid outlet temperature = 115°C $Q = m_{.h} x CP_h \ X \ \Delta t_h \ x \ 0.95$ = $m_c \ x \ CPC \ x \ \Delta t_c$ Mass flow rate of cold fluid m_c = $\dfrac{m_h \ \ cP_h \ \Delta T_h \ \ x \ \ 0.95}{cP_h \ \ x \ \ \Delta t_c}$ = $\dfrac{100 x \ 1.1 x (220 - 115) x \ 0.95}{0.95 \ x \ (75 - 10)}$ = 177.7 kg/hr
2.	When a heat exchanger was designed its overall heat transfer co-efficient was 600 kcal/hr mt²°C. The heat transfer area provided = 10mt². Over a period of time, its overall heat transfer co-efficient has fallen to 450 kcal/hr mt²°C due to fouling. Data: Specific heat of hot fluid = 1 kcal/kg °C Hot fluid entering temperature = 80°C Hot fluid leaving temperature = 60°C Cold fluid entering temperature = 25 °C Cold fluid leaving temperature = 40°C Calculate: How much additional area is to be added to maintain the same rate of heat transfer? Assumption: Flow is assumed in counter current direction Q = $A \ U \ \Delta T_{LM}$ ΔT_{LM} = $\dfrac{\Delta t1 - \Delta t2}{\ln \dfrac{\Delta t1}{\Delta t2}}$ = 37.4°C

	ΔT_1 = 40°C ΔT_2 = 35°C Q = 10 X 600 X 37.4 = 224400 kcal/hr After fouling area required = $A = \frac{224400}{450 \text{ X } 37.4} = 13.3 \text{ mt}^2$ Additional heat transfer area to be provided is 3.3 m2
3.	An after cooler of shell and tube type with single pass is used for cooling compressed air from 85 °C to 35 °C. The compressed air generated is 1350 m^3/h at mean air temperature. Calculate: 1) The amount of cooling water to be circulated at a temperature of 30 °C. Assume the cooling water outlet temperature as 35 °C. 2) The LMTD and no of tubes if the dia of the tube is 25.4 mm and 2500 mm length. Assume overall heat transfer coefficient for air to water is 150 W/m^2.K. 3) The hp of the pump required if the pressure required is 3.5 kg/cm^2.g. Indicate all assumptions clearly. Ans: 1) Inlet compressed air temperature = 85 °C Exit compressed air temperature = 35 °C Cooling water temperature = 30 °C Cooling water outlet temperature = 35 °C Density of air at 60 °C = 1.06 kg/m^3 Mass of compressed air = 1350 x 1.06 = 1431 kg/hr Specific heat of water at 30 °C = 4.178 kJ/kg °K Heat duty: Hot fluid: = m Cp deta.T = 1431 x 1.005 x (85-35)/ 3600 = 19.974 kW Mass of water to be circulated = 19.974/(4.178 x (35-30) = **3442 kg/hr (Ans)** 2) LMTD = $\frac{(85-35)-(35-30)}{\text{In } (50/5)}$ = **19.54°C (Ans)** Heat transfer area = 19.974/(0.15 x 19.54) = 6.81 m^2 No of tubes = 6.81/ (3.14 x 0.0254 x 2.5) = **35 tubes (Ans)** 3) Theoretical power required for the pump= 3442 x 9.81 x 35 / (3600 x 1000) = 0.33 kW Assuming pump efficiency of 70% and motor efficiency of 85%, the required pump Motor power = 0.33/ (0.7 x 0.85) = 0.555 kW

	Motor required = **1 hp (Ans)**
4.	Hot air is to be generated at the rate of 30,000 m^3/h at 120 ^oC from 35 ^oC for pocket ventilation purpose in a high speed paper machine. Steam is used in indirect heat exchanger steam coils to produce hot air at 120 ^oC. Steam is available at a pressure of 5.0 bar at the user side header. Find out the quantity of steam required. Calculate LMTD. Data: Total enthalpy of steam at 5 bar = 2757 kJ of kg Latent heat of steam at 5 bar = 2086 kJ/kg Note: Assume that condensate is leaving at a temperature of 100°C. **Ans.** Inlet air temperature = 35 ^oC Outlet air temperature = 120 ^oC Steam pressure = 5.0 bar Total heat of steam at 5 bar = 2757 kj/kg Latent heat of steam at 5 bar = 2086 kJ/kg Saturation temperature of steam = 159 ^oC Mass of hot air required = 30,000 x 0.898 = 26940 kg/hr Specific heat of air at 120 ^oC = 1.009 kJ/kg ^oK Heat duty: Cold fluid: = m Cp delta.T = 26940 x 1.009 x (120-35)/ 3600 = 641.8 kW Mass of steam to be circulated = 641.8 x 3600/ 2086 = **1107 kg/hr (Ans)** LMTD = $\dfrac{(159-35)-(159-120)}{\text{In }(124/39)}$ = 26.73 ^oC