## Solution Paper - I

### Question1:-

**The steady state temperature distribution in a wall is , where x (in meter) is the position in the wall and T is the temperature (in $^oC$). The thickness of the wall is 0.2 m and the thermal conductivity of the wall is 1.2 (W/m·$^oC$). The wall dissipates the heat to the ambient at 30 $^oC$. Calculate the heat transfer coefficient at the surface of the wall at 0.2 m.**

### Answer:-

The rate of heat transfer through the wall by conduction will be equal to the rate of heat transfer from the surface to the ambient by convention at steady state,

Rate of heat transfer by conduction at x=0.2 is given by,

$$-kA\frac{dT}{dx} = hA(T_x - T_a)$$

where $T_a$ is the ambient temperature.

$$T = 300 - 3050x^2$$

$$T_{x=0.2} = 300 - 3050(0.2^2) = 178\ °C$$

$$\frac{dT}{dx} = -6100x$$

$$h = \frac{-kA\frac{dT}{dx}}{A(T_x - T_a)}$$

$$= \frac{(-k)(-6100x)}{T_x - T_a}$$

On putting the values and solving,

$$= \frac{(1.2)(6100)(0.2)}{178-30}$$

$$h = 9.89\ \mathrm{W/(m^2 \cdot {}^oC)}$$

**Question2:-**

**What is Thermal Conductivity?**

**Answer:-**

Thermal conductivity (λ) is the intrinsic property of a material which relates its ability to conduct heat. Heat transfer by conduction involves transfer of energy within a material without any motion of the material as a whole. Conduction takes place when a temperature gradient exists in a solid (or stationary fluid) medium. Conductive heat flow occurs in the direction of decreasing temperature because higher temperature equates to higher molecular energy or more molecular movement. Energy is transferred from the more energetic to the less energetic molecules when neighboring molecules collide.

Thermal conductivity is defined as the quantity of heat ($Q$) transmitted through a unit thickness ($L$) in a direction normal to a surface of unit area ($A$) due to a unit temperature gradient ($\Delta T$)under steady state conditions and when the heat transfer is dependent only on the temperature gradient. In equation form this becomes the following:

Thermal Conductivity = heat × distance / (area × temperature gradient)

$$\lambda = Q \times L / (A \times \Delta T)$$

**Question3:-**

**What is Wein's law?**

**Answer:-**

The temperature increases the peaks of the curve also increases and it shift towards the shorter wavelength. It can be easily found out that the wavelength corresponding to the peak of the plot ($\lambda max$) is inversely proportional to the temperature of the blackbody (Wein's law) as shown in eq. 7.11.

$$\lambda max\ T = 2898 \qquad (7.11)$$

Now with the Wien's law or Wien's displacement law, it can be understood if we heat a body, initially the emitted radiation does not have any colour. As the temperature rises the λ of the radiation reach the visible spectrum and we can able to see the red colour being height λ (for red colour). Further increase in temperature shows the white colour indicating all the colours in the light.

**Question4:-**

**Warm methanol flowing in the inner pipe of a double pipe heat exchanger is being cooled by the flowing water in the outer tube of the heat exchanger. The thermal conductivity of the exchanger, inner and outer diameter of the inner pipe are 45 W/(m·oC), 26 mm, and 33 mm, respectively. The individual heat transfer coefficients are:**

| | **Coefficient (W/(m2·oC))** |
|---|---|
| **Methanol, hi** | **1000** |
| **Water, ho** | **1750** |

**Calculate the overall heat transfer coefficient based on the outside area of the inner tube.**

**Answer:-**

Using following equation,

$$U_o = \frac{1}{\frac{r_o}{r_i h_i} + \frac{r_o \ln (r_o/r_i)}{k} + \frac{1}{h_o}}$$

It is apparent that all the values are known. Thus, on putting the values the $U_o$ is 519 W/(m$^2$·°C).

**Question5:-**

**Write short notes on the following:-**

- **a) Thermal design of heat exchangers**
- **b) Fouling factor or dirt factor**

**Answer:-**

### a) Thermal design of heat exchangers

The mechanical design is done by the mechanical engineers on the inputs of chemical engineers and using the codes. The most widely used code in Tubular Exchanger Manufactures Associations (TEMA). This USA code along with ASME selection VIII (unfired pressure vessel) code is used together for the mechanical design of the heat exchanger. The Indian code for the heat exchanger design IS 4503.

Here we would discuss about the process design (or thermal design) leading to the sizing of the heat exchanger. Before understanding design steps, it is necessary to understand the following for the heat exchanger.

### b) Fouling factor or dirt factor

Over a time period of heat exchanger operation the surface of the heat exchanger may be coated by the various deposits present in the flow system. Moreover, the surfaces may become corroded or eroded over the time. Therefore, the thickness of the surface may get changed due to these deposits. These deposits are known as scale. These scales provide another resistance and usually decrease the performance of the heat exchangers. The overall effect is usually represented by dirt factor or fouling factor, or fouling resistance, Rf (Table 8.1) which must have included all the resistances along with the resistances due to scales for the calculation of overall heat transfer coefficient.
The fouling factor must be determined experimentally using eq. 8.4,

$$R_f = \frac{1}{U_{dirty}} - \frac{1}{U_{clean}}$$

Thus to determine the Rf, it is very important to know Uclean for the new heat exchanger. TheUclean must be kept securely to obtain the Rf, at any time of the exchanger's life.

**Table:- Fouling factor of a few of the industrial fluids**

| | Fouling factor (or resistance) $\frac{hm^2\,°C}{k\,cal}\times10^3$ |
|---|---|
| **Liquid** | |
| Fuel oil | 1.024 |
| Refrigerant liquids | 0.102 |
| Mono-and di-ethanolamine solution | 0.409 |
| Gasoline , naphtha and kerosene | 0.205 |
| Light gas oil | 0.409 |
| Heavy gas oil | 0.615 |
| **Gases and Vapour** | |
| Solvent vapour | 0.205 |
| Air | 0.102-0.205 |
| Flue gases | 0.205-0.615 |
| Steam (Saturated, oil free) | 0.102-0.307 |
| **Water** | |
| River water (treated, velocity > 0.6 m/s) | 0.205-0.409 |
| Treated boiler feed water | 0.102-0.205 |
| Process water | 0.205-0.409 |

**Question6:-**

**Why we use multi-pass exchangers?**

**Answer:-**

The simplest type of heat exchangers is double pipe heat exchangers, which is inadequate for flow rates that cannot readily be handled in a few tubes. If several double pipes are used in parallel, the metal weight required for the outer tubes becomes so large that the shell and tube construction, such as 1-1 exchanger will be helpful. In that one shell serves for many tubes, is economical. The heat transfer coefficient of tube side and shell side fluid is very important and the individual heat transfer coefficients must be high enough to attain high overall heat transfer coefficient. As the shell would be quite large as compared to the tubes, the velocity and the turbulence of the shell side fluid is important.

In contrast, the 1-1 exchanger has limitations also. When the tube side flow is divided evenly among all the tubes, the velocity may be quite low, resulting in low heat transfer coefficient. There it may be required to increase the area to have the desired heat exchange for this low heat transfer coefficient. The area may be increased by increasing the length of the tube. However, the tube length requirement may be impractical for a given situation. Thus the number of tubes should be increased without increased the tube length. The increased number of tubes would also provide the increased velocity in the shell side resulting in the higher heat transfer coefficient. Therefore, multi-pass construction is needed, which would permit to use the practical and standard tube lengths. However, the disadvantages are that,

a) The construction of the exchangers become complex.
b) Parallel flow cannot be avoided.
c) Additional friction losses may occur.

It should be noted that generally even number of tube passes are used in multi pass exchanger.

## Question7:-

**What are the main differences among evaporation and distillation?**

## Answer:-

Evaporation. The easiest example is water. Water molecules are in constant motion. Some molecules move fast enough to escape into the air on their own. Sweat evaporates from your skin to cool you. When you air dry your hands in a bathroom, it is evaporation that makes the water go away. Many liquids will evaporate into the air, not just water.

Distillation. Lets look at water again, though you can distill most any liquid. When you heat water you can make it boil. The boiling water will go into the air as steam. (In this way evaporation and distillation are similar) That steam can be captured and cooled down again to make liquid water. The cool part is that if there is anything else in the water that you don't want, it will stay behind when you boil the water. So if you are really thirsty and only have a bottle of salt water, you can use distillation to make clean water. Scientist use distillation to separate liquids from impurities, like salt, but also to separate liquids that are mixed in with each other.

## Question8:-

**What is the physical meaning of LMTD?**

## Answer:-

The rise in secondary temperature is non-linear and can best be represented by a logarithmic calculation. A logarithmic mean temperature difference is termed

- Logarithmic Mean Temperature Difference or *LMTD* or $DT_{LM}$

LMTD can be expressed as

$LMTD = (dt_o - dt_i) / \ln(dt_o / dt_i)$ *(1)*

*where*

*LMTD = Logarithmic Mean Temperature Difference* ($^oF$, $^oC$)

For parallel flow:

$dt_i = t_{pi} - t_{si}$ = ***inlet*** *primary and secondary fluid temperature difference* ($^oF$, $^oC$)

$dt_o = t_{po} - t_{so}$ = ***outlet*** *primary and secondary fluid temperature difference* ($^oF$, $^oC$)

For counter flow:

$dt_i = t_{pi} - t_{so}$ = ***inlet*** *primary and outlet secondary fluid temperature difference* ($^oF$, $^oC$)

$dt_o = t_{po} - t_{si}$ = ***outlet*** *primary and inlet secondary fluid temperature difference* ($^oF$, $^oC$)

The Logarithmic Mean Temperature Difference is always less than the Arithmetic Mean Temperature Difference.