HEAT TRANSFER STUDIES IN LAMINAR FLOW

AIM

To determine overall heat transfer coefficient making use of transferred heat and logarithmic mean temperature difference. From overall heat transfer coefficient, determine the individual film heat transfer coefficient and verify the Sieder-Tate equation for laminar flow.

APPARATUS

1. Stainless steel double pipe heat exchanger with facility to measure inlet and the outlet temperature of hot fluid by electronic thermometers of 0.1^0C accuracy.
2. A stainless steel insulated tank with a heater, bottom discharge and fluid charging line at the top.
3. Hot and cold fluid circulation pump with speed variation mechanism.
4. A rotameter to measure the flow rate.

PROCEDURE

1. Connect 15 amp. And 5 amp. plug pins to stable 230 V A.C. electric supply. Care should be taken to connect these two pins in different phases of the power supply.
2. Check the set point of the controller. The set point should be set around 60 to 80°C.
3. Connect the suction line of cold fluid circulation pump to cold water supply line.
4. We will keep cold flow rate constant and minimum as 100 LPH. It is essential for rise in temperature at least 2-4°C. The lesser we go (<100 LPH) fluctuation in flow rate is noticed. Similarly, for higher cold flow rate, it becomes difficult to reasonable temperature difference
5. As the temperature starts reaching the set value, the flow rate of hot fluid increases. Thus, it is better to wait till the temperature is close to set value.
6. Adjust the flow rate of hot fluid (known through rotameter reading) through the heat exchanger by adjusting the speed of hot fluid circulation pump. (The minimum flow rate of hot fluid should be at least being 300 LPH).
7. Note down the inlet and outlet temperatures indicated by digital thermometer on the control panel after steady state is reached. Also note down the inlet and outlet temperatures of cooling water.
8. Repeat step 7 for at least three different flow rates of hot fluid at particular set temperature.
9. Repeat the experiment again at three different set temperature

THEORY

In a heat exchanger, heat is transferred from hot fluid to cold fluid through the metal wall. Heat transferred through the metal wall is always by conduction while on the both side of metal by convection. Generally, resistance offered to heat transfer by metal wall is negligible as compared to resistance offered by convection. The wall temperature should always be between local temperatures of the two fluids.

At low Reynolds number (Re<2100) the flow pattern is laminar and the fluid flows in an ordered manner along generally parallel "Filament like" streams which do not mix. It followsthat in this type of flow that the heat transferred to and through is essentially by convection.

When heat transferred through resistance in series, the total resistance to heat transfer is the sum of individual resistance in series. The overall heat transfer resistance in a heat exchanger can write,

$$\left(\frac{1}{U_iA_i}\right) = \left(\frac{1}{h_iA_i}\right) + \left(\frac{\Delta x}{KA_{lm}}\right) + \left(\frac{1}{h_oA_o}\right) \quad (1)$$

OR

$$\left(\frac{1}{U_i}\right) = \left(\frac{1}{h_i}\right) + \left(\frac{\Delta x A_i}{KA_{lm}}\right) + \left(\frac{A_i}{h_oA_o}\right) \dots\dots\dots\dots \quad (2)$$

In the above equation $h_i$is the heat transfer coefficient of hot fluid flowing through the inner tube. Since the test fluid is highly viscous and has very low thermal conductivity the inside heat transfer coefficient is expected to be very low and hence it will become controlling resistance for heat transfer. Thus, even if overall heat transfer coefficient is considered equal to inside heat transfer coefficient it will not be much in error. If flow through inner tube is in laminar flow regime h_i can be predicted from Sieder-Tate equation given below.

$$\mathbf{Nu = 1.86Re^{\frac{1}{3}}Pr^{\frac{1}{3}}\left(\frac{D}{L}\right)^{\frac{1}{3}}} \quad (3)$$

$$\mathbf{Nu = hd/K} \quad (4)$$

On simplifying equation, we will get

$$\mathbf{h_i = C * m^{\frac{1}{3}}} \dots\dots\dots\dots. \quad (5)$$

Where C is constant and m is mass flow rate of hot fluid.

$$\mathbf{C} = \frac{\mathbf{1.86}K^{\frac{2}{3}}C_p^{\frac{1}{3}}}{(ADL)^{\frac{1}{3}}} \quad (6)$$

Taking log both sides for equation 5

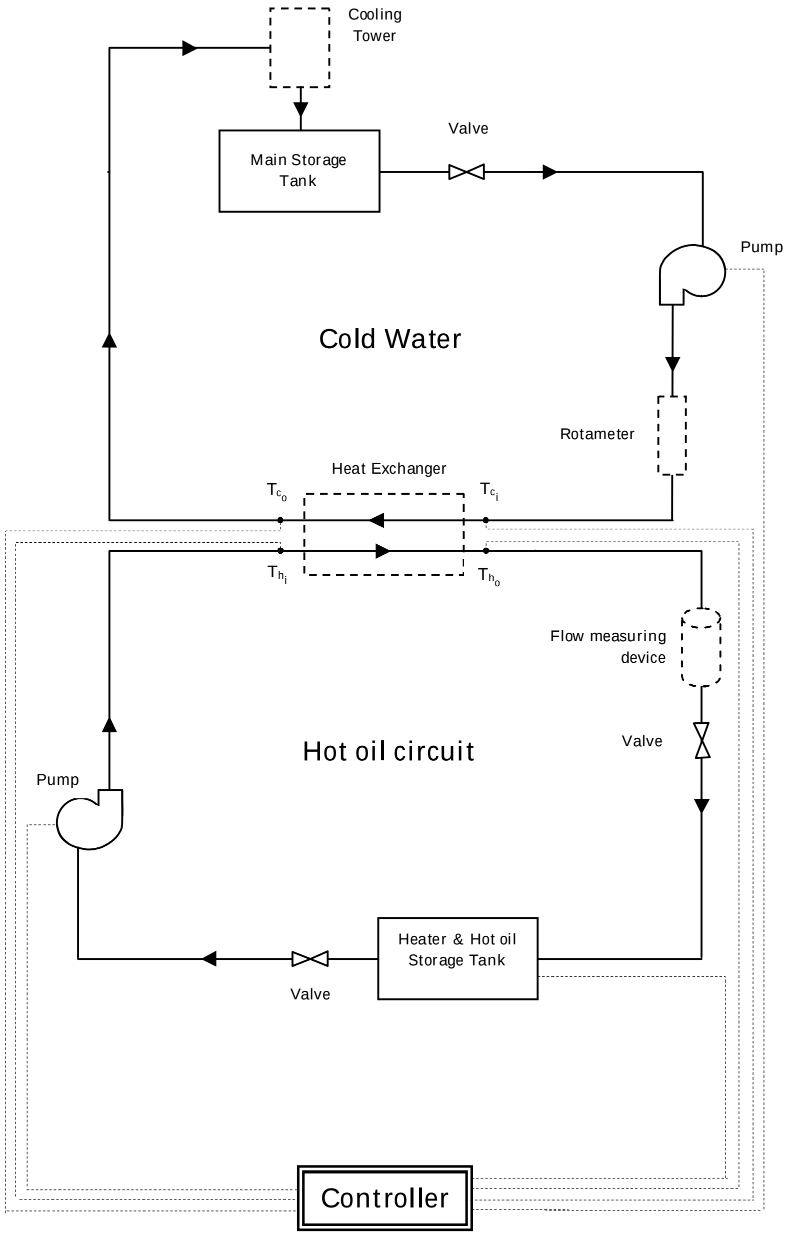
$$\mathbf{\log(h_i) = \log(C) + \left(\frac{1}{3}\right)\log(m)} \quad (7)$$

OBSERVATIONS

1. Outside diameter of inner tube(d_2)= 0.01 m
2. Inside diameter of inner tube(d_i)=0.007 m
3. Length of heat exchanger (L)= 0.8 m

4. Specific heat of hot fluid= 0.625 Kcal/kg ^{0}C = 2616.75 J/Kg.K
5. Thermal conductivity of the hot fluid= 0.13 W/mK
6. Kinematic Viscosity (ϑ)
   At 100^{0}C= 5.3 * 10^{-6} m^2/sec
   At 50^{0}C =20.8 * 10^{-6} m^2/sec
   At 40^{0}C =31* 10^{-6} m^2/sec
   At 90^{0}C= 9.583 * 10^{-6} m^2/sec
   At 80^{0}C =13.866 * 10^{-6} m^2/sec
   At 70^{0}C =18.15 * 10^{-6} m^2/sec
   At 60^{0}C =22.43 * 10^{-6} m^2/sec
   To find values Kinematic Viscosity for other than temperatures use linear interpolation or any existing correlation
   Dynamic viscosity = $\mu = \vartheta * \rho$ (Kg/m.s)
7. Specific Density= 0.857 g/cm^3 = 857 kg/m^3
8. Diameter of the measuring cylinder=0.0762 m

SCHEMATIC FLOWSHEET



Heat transfer in laminar flow

OBSERVATION TABLE

Obs. No.	Set Temp (^{0}C)	hot fluid temperature (^{0}C)		cold fluid temperature (^{0}C)		Height (m)	Time (s)
		inlet(T_1)	outlet(T_2)	inlet(t_1)	outlet(t_2)		
1	40						
2	40						
3	40						
4	55						
5	55						
6	55						
7	70						
8	70						
9	70						

CALCULATION

1. Cross section area of inner tube S = $\prod d_i^2/4$= ___________ m^2

2. Inside heat transfer area of the heat exchanger = A=$\prod$DL = m^2

3. Prandtl number at hot fluid mean temperature:
   $Pr = \frac{C_p \mu}{K}$ ____________________

SAMPLE CALCULATION FOR READING NO___________:

1. Velocity of hot fluid
   $u = \frac{Height}{time}$=______________________m/sec
2. Volumetric flow rate of hot fluid:
   V = velocity (u) *Area (S)_________________ m^3/sec
3. Mass flow rate (m) = V * ρ= _________________ Kg/sec
4. Heat Transferred per hour:
   $Q = (V \times \rho \times 3.6) \times C_p \times (T_1 - T_2)$ = ________________ Kcal/hr
   Q = m Cp ΔT = (V * ρ) * $C_p \times (T_1 - T_2)$ = ________________ W

5. $LMTD = \frac{[(T_1-t_1)-(T_2-t_2)]}{\left[ln\left[\frac{(T_1-t_1)}{(T_2-t_2)}\right]\right]}$ = ______________ K

6. Overall heat transfer coefficient
   $U = \frac{Q}{(A \times LMTD)}$ = ___________________W/m^2 K

7. Inside heat transfer coefficient h_i
   $h_i = \frac{1.86K^{\frac{2}{3}}C_p^{\frac{1}{3}}}{(ADL)^{\frac{1}{3}}} * m^{\frac{1}{3}}$ = ____________________________ W/m^2 K

8. Nusselt number:
   $Nu = \frac{h_i d_i}{K}$ = _________________________

9. Reynolds number:
   $Re = \frac{u d_i}{\vartheta}$ = _____________________

RESULT TABLE 1

Obs. No.	Volumetric flow rate of hot fluid (m^3/sec)	Amount of heat transferred Q (W)	Velocity of hot fluid u (m/sec)	LMTD	Overall heat transfer coefficient U (W/m^2 K)
1					
2					
3					
4					
5					
6					
7					
8					
9					

RESULT TABLE 2

Obs. No.	Inside heat transfer coefficient h_i ($W/m^2 K$)	Nusselt number Nu	Reynolds number Re
1			
2			
3			
4			
5			
6			
7			
8			
9			

GRAPHS (Total 4)

1. Plot the graph of log ($1/U_i$) vs. log (1/u) on linear scale.
2. Plot the graph of log(Nu) vs. log(Re) on linear scale.

RESULTS

CONCLUSION/DISCUSSION ON THE RESULT

1. Write down the observations.
2. Try to explain the results from theory studied earlier.

FURTHER READING

Fundamental of Heat and Mass Transfer by Frank P. Incropera and David P. Dewitt, Chapter 8.