HEAT TRANSFER STUDIES IN TURBULENT FLOW

AIM

To determine the overall heat transfer coefficient making use of logarithmic mean temperature difference. From overall heat transfer coefficient, determine the individual film heat transfer coefficients and verify the Turbulent flow equation for heat transfer.

APPARATUS

- Stainless steel double pipe heat exchanger with facility to measure inlet and outlet temperatures of hot fluid with electronic thermometers of accuracy 0.1°C. The inlet and outlet temperatures of cold fluid are also measured with electronic thermometers of accuracy of 0.1°C.
- A stainless steel insulated tank with a heater, bottom discharge and fluid charging line at the top. It is also provided with temperature indicator cum controller to control the hot fluid temperature.
- Hot fluid circulation pump with speed variation mechanism. Hot fluid circulation line has a rotameter to measure flow rate of hot fluid.
- Cold fluid circulation pump, with speed variation mechanism. Cold fluid circulation line has a rotameter to measure flow rate of cold fluid.

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. Switch on the dual temperature indicator cum controller. Check the set point of the controller. The set point should be set around 60 to 80°C.
3. Ensure that the valve at the bottom of measuring tank is open. Open the valve on the outlet line of the hot fluid tank. Switch on the power supply to hot fluid circulation pump and slowly increase the speed of the pump by regulating the voltage supplied to it. Initially run the pump at slow speed. Check the inlet and outlet temperatures of the fluid indicated by digital thermometer. Note down the temperature difference between inlet and outlet temperatures, which gives zero error (Digital thermometers can give errors up to 1°C which is generally very difficult to bring down). After noting down the zero error in the digital thermometer, switch on all the (three) heaters of the hot fluid tank by switching on their respective main switches.
4. Connect the suction line of cold fluid circulation pump to cold water supply line.
5. 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
6. 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.
7. 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).

8. 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.
9. Repeat step 7 for at least three different flow rates of hot fluid at particular set temperature.
10. Repeat the experiment again at three different set temperature

THEORY

In a heat exchanger, heat is transferred from hot fluid to cold fluid through metal wall which generally separates those two fluids. Heat transfer through metal wall is always by conduction while on both sides of metal wall it is generally by convection. Generally, resistance offered to heat transfer by the metal wall is negligible as compared to resistance offered by convection. The wall temperature is always between local temperatures of the two fluids. The actual value depends upon individual film heat transfer coefficient on either side.

At higher Reynolds number, the ordered flow pattern of laminar flow regime is placed by randomly moving eddies thoroughly mixing the fluid and greatly assisting heat transfer. However, this enhancement of film heat transfer coefficient is accompanied by much higher pressure drop which demands higher pumping power. Thus, although desirable, turbulent flow is usually restricted to fluids of low viscosity.

When heat is transferred through resistances in series, the total resistance to heat transfer is the sum of individual resistances in series. Thus, for heat exchanger, one can write,

$$\frac{1}{U_i \cdot A_i} = \frac{1}{h_i \cdot A_i} + \frac{\Delta X}{K \cdot A_{lm}} + \frac{1}{h_o \cdot A_o} \qquad (1)$$

OR

$$\frac{1}{U_i} = \frac{1}{h_i} + \frac{\Delta X \cdot A_i}{K \cdot A_{lm}} + \frac{A_i}{h_o \cdot A_o} \qquad (2)$$

Once the heat exchanger material and its geometry are fixed, then the metal wall resistance $\left[\frac{\Delta X}{K \cdot A_{lm}}\right]$ becomes constant. Similarly, if the flow rate of cold fluid is fixed and its mean temperature does not differ much for different flow rates of hot fluid, then the resistance by the outside film will remain almost constant. Thus, the overall heat transfer coefficient will depend upon the value of inside film heat transfer coefficient alone. If flow through inner tube is in the turbulent flow regime and Pr (0.6-100), then Dittus-Boelter equation can be used to find out inside film heat transfer coefficient.

$$Nu = 0.023 * Re^{0.8} * Pr^{n} \qquad (3)$$

If Pr>100, we have to use the following turbulent flow equation

$$Nu = 3.66 + \frac{0.0668(\frac{D}{L}) \times Re \times Pr}{1 + 0.04(\frac{D}{L}) \times Re \times Pr^{\frac{2}{3}}}$$

If the bulk mean temperature does not differ much for different flow rates, then all the physical properties will remain nearly the same and equation(3) can be re-written as:

$Nu = constant * v^{0.8}$ (4)

Substituting equation (4) in equation (2), one can write it as:

$\frac{1}{Ui} = \frac{constant1}{V^{0.8}} + constant2$ (5)

Thus, the graph of $\frac{1}{Ui}$ vs $\frac{1}{V^{0.8}}$(which is known as Wilson plot) should be a straight line with a slope equal to constant1 and intercept equal to constant2. From this graph, inside film heat transfer coefficient can be calculated which can be used to verify Dittus-Boelter or any turbulent flow equation.

OBSERVATIONS

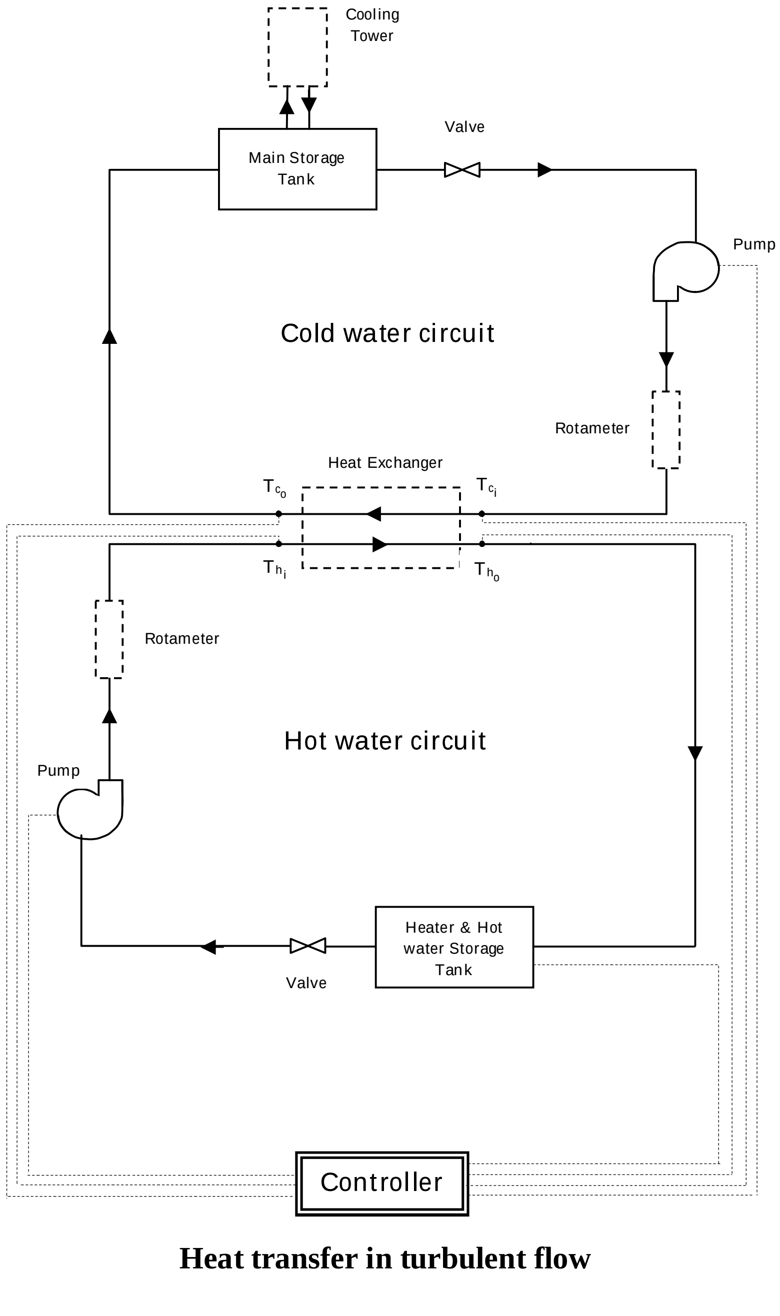
1. Outside diameter of inner tube(d_2)= 0.01 m
2. Inside diameter of inner tube(d_i)=0.007 m
3. Length of heat exchanger (L)= 1 m
4. Specific heat of hot fluid= 0.625 Kcal/kg ^{0}C= 2616.75 J/Kg.K
5. Thermal conductivity of the hot fluid= 0.13 W/mK
6. Kinematic Viscosity (ϑ)

   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 (should be mention in journal).

7. Dynamic viscosity = $\mu = \vartheta * \rho$(Kg/m-s)
8. Specific Density= 0.857 g/cm^3 = 857 kg/m^3
9. heat transfer area of heat exchanger (A) = 0.022 m^2

SCHEMATIC FLOWSHEET



Heat transfer in turbulent flow

OBSERVATION TABLE

Obs. No.	Set Temp (°C)	Hot fluid temperature (°C)		Cold fluid temperature (°C)		Oil flow rate (LPH)
		Inlet (T_1)	Outlet (T_2)	Inlet (t_1)	Outlet (t_2)	
1	60					
2	60					
3	60					
4	70					
5	70					
6	70					
7	80					
8	80					
9	81000					

A: TABLE OF CALCULATED RESULTS

Obs. No.	Volumetric flow rate of hot fluid (V)m^3/sec	Amount of heat transferred (Q)W	Velocity of hot fluid (u) m/sec	LMTD (ΔT_{lm}) (K)	Overall heat transfer coefficient (U)W/m^2 K
1					
2					
3					
4					
5					

6					
7					
8					
9					

B: TABLE OF CALCULATED RESULTS

Obs. No.	$(1/v^{0.8})$	(1/U)	Inside film heat transfer coefficient h_i	Nusselt number Nu	Reynolds number Re
1					
2					
3					
4					
5					
6					
7					
8					
9					

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=∏DL = m^2

3. Prandtl number at hot fluid mean temperature:

$$Pr = \frac{C_p\mu}{K}$$ _____________________

4. Volumetric flow rate of hot fluid (V)___________________m^3/sec

5. Velocity of hot fluid

velocity (v) = Volumetric flow rate(V) / Area (S)________________ m/sec

6. Mass flow rate (m) = V * ρ = ________________ Kg/sec

7. Heat Transferred per hour:

Qhot = m CpΔT = (V * ρ) * $C_p \times (T_1 - T_2)$ = _______________ W

Qcold = m CpΔT = (V * ρ) * $C_p \times (t_2 - t_1)$ = _______________ W

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

9. Overall heat transfer coefficient

$U = \frac{Q}{(A \times LMTD)}$ = ________________W/m^2K (Use Qhot or Qcold value whichever is low)

10. Nusselt number: Nu=0.023*(Re)$^{0.8}$*(Pr)$^{0.3}$ (0.6<Pr>100)
Nusselt number

$Nu = 3.66 + \frac{0.0668(\frac{D}{L}) \times Re \times Pr}{1+0.04(\frac{D}{L}) \times Re \times Pr^{\frac{2}{3}}}$ (Pr>100)

- Theoretical value of inside film heat transfer coefficient

$$h_i = \frac{Nu.K}{d_1}$$

- Experimental value of inside film heat transfer coefficient

1/ho =((1/U)-(1/hi)-((ln(r0/ri)*Ai)/(2pi*L*K)))*(Ai/A0)

- h_o=(1/intercept) where the intercept is of the graph of (1/U) vs (1/$v^{0.8}$)

11. Reynolds number:

$Re = \frac{ud_i}{\vartheta}$ = _________________

GRAPHS (Total 3)

1. Plot the graph of $\frac{1}{\text{Ui}}$ vs. $\frac{1}{V^{0.8}}$.
2. Plot the graph of $\log\left(\frac{1}{\text{Ui}}\right)$ vs. $\log\left(\frac{1}{v}\right)$ on linear scale
3. Plot the graph of log(Nu) vs. log (Re) on linear scale.

CONCLUSION/DISCUSSION ON THE RESULT

From calculation, it was observed that inside film heat transfer coefficient was less than overall heat transfer coefficient in most of the reading. The difference between overall and individual heat transfer coefficient is very less which is not significant.

FURTHER READING

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

TEACHING ASSISTANT