NATIONAL INSTITUTE OF TECHNOLOGY DURGAPUR

DEPARTMENT OF Mechanical Engineering .... PAGE NO 1

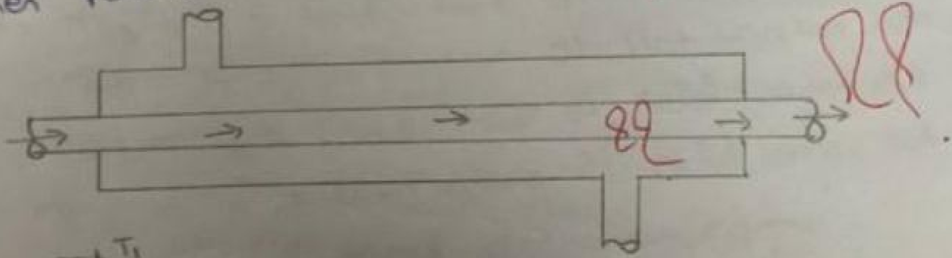
Aim:- Determination of LMTD and ~~Heat~~ effectiveness with Help of Parallel flow and Counter flow Heat Exchangers

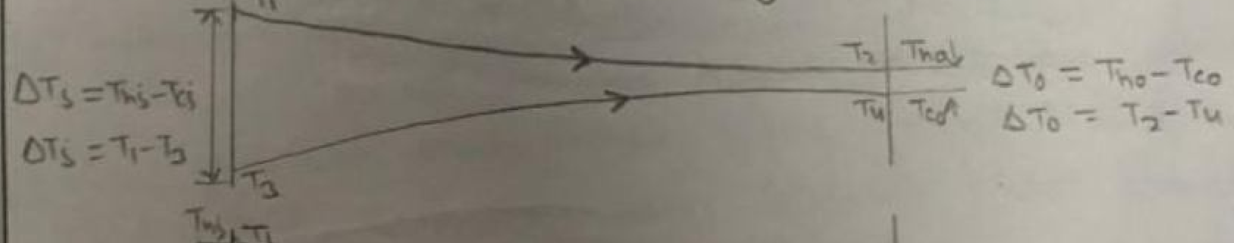
Theory:- A Heat exchanger is a steady flow Adiabatic open system in which two flowing fluid exchang Heat between them without losing or gaining any Heat to or from the Ambient.

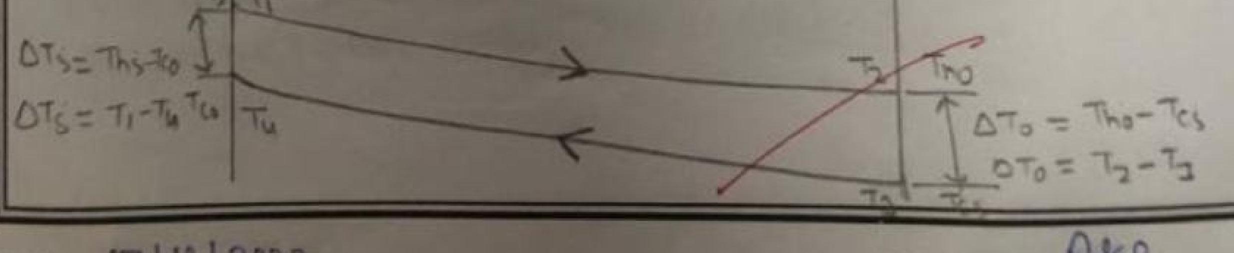
On the basis of flow Arrangement, Heat exchanger may be classified as:-

(1) Parallel flow Heat exchanger:- In a parallel flow Heat exchanger, ~~bond~~ both the Hot and cold fluid flow In the same Direction.

(ii) Counter flow Heat exchanger:- In a counter flow Heat exchanger, the Direction of flow of one working fluid is opposite to the Direction of flow of the other fluid.







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⇒ Logarithmic Mean Temprature Difference (LMTD):-

LMTD is a logarithmic Average of the temprature Difference between the Hot and cold fluids feed at each end of a Heat exchanger.

$$LMTD = \frac{\Delta T_i - \Delta T_o}{\ln(\Delta T_i / \Delta T_o)}$$

where, ΔT_i = temprature difference at Inlet
ΔT_o = temperature Difference at outlet

⇒ for parallel flow Heat exchanger,

$\Delta T_i = T_{hi} - T_{ci} = T_1 - T_3$

$\Delta T_o = T_{ho} - T_{co} = T_2 - T_4$

⇒ for counter flow Heat exchanger,

$\Delta T_i = T_{hi} - T_{co} = T_1 - T_4$

$\Delta T_o = T_{ho} - T_{co} = T_2 - T_3$

where, $T_{hi} = T_1$ = temprature of Hot water at Inlet
$T_{ho} = T_2$ = Temprature of Hot water at outlet
$T_{ci} = T_3$ = Temprature of cold water at Inlet
$T_{co} = T_4$ = Temprature of cold water at outlet

⇒ effectiveness of Heat exchanger (ϵ):-

It is Define As the Ratio b/w actual Heat transfer that takes place between HOT and cold fluid, and maximum Possible Heat Transfer Rate between the two fluid.

Date 07/11/2022 Signature ASK

$$\epsilon = \frac{q_{act}}{q_{max}}$$

where, q_{act} = Rate of chang of enthalpy of either of the fluids,

$$\text{ie } q_{act} = \dot{m}_h c_{ph}(T_{hi} - T_{ho}) = \dot{m}_c c_{pc}(T_{co} - T_{ci})$$

and $q_{max} = (\dot{m} c_p)_{small}(T_{hi} - T_{ci})$

where $(\dot{m} c_p)_{small}$ is the smaller Heat capacity between Hot and cold fluid ie smaller value between $\dot{m}_h c_p$ and $\dot{m}_c c_{pc}$

Here, $\dot{m}_h$ = mass flow Rate of Hot fluid (Kg/s)

$\dot{m}_c$ = mass flow Rate of cold fluid (Kg/s)

c_{ph} = Specific Heat capacity of Hot fluid (KJ/Kg-K)

c_{pc} = Specific Heat capacity of cold fluid (KJ/Kg-K)

If $\dot{m}_c c_{pc} < \dot{m}_h c_{ph}$ then,

$$\epsilon = \frac{\dot{m}_c c_{pc}(T_{co} - T_{ci})}{\dot{m}_c c_{pc}(T_{hi} - T_{ci})} = \frac{T_{co} - T_{ci}}{T_{hi} - T_{ci}} = \frac{T_4 - T_3}{T_1 - T_3}$$

If $\dot{m}_h c_{ph} < \dot{m}_c c_{pc}$ then,

$$\epsilon = \frac{\dot{m}_h c_{ph}(T_{hi} - T_{ho})}{\dot{m}_h c_{ph}(T_{hi} - T_{ci})} = \frac{T_{hi} - T_{ho}}{T_{hi} - T_{ci}} = \frac{T_1 - T_2}{T_1 - T_3}$$

mass flow Rate $\dot{m} = \rho V / t$

where ρ = Density of fluid (Kg/m^3), t = time (sec)

V = volume of fluid (m^3)

NATIONAL INSTITUTE OF TECHNOLOGY DURGAPUR

DEPARTMENT OF Mechanical Engineering .... PAGE NO 4

Experimented Set UP:-

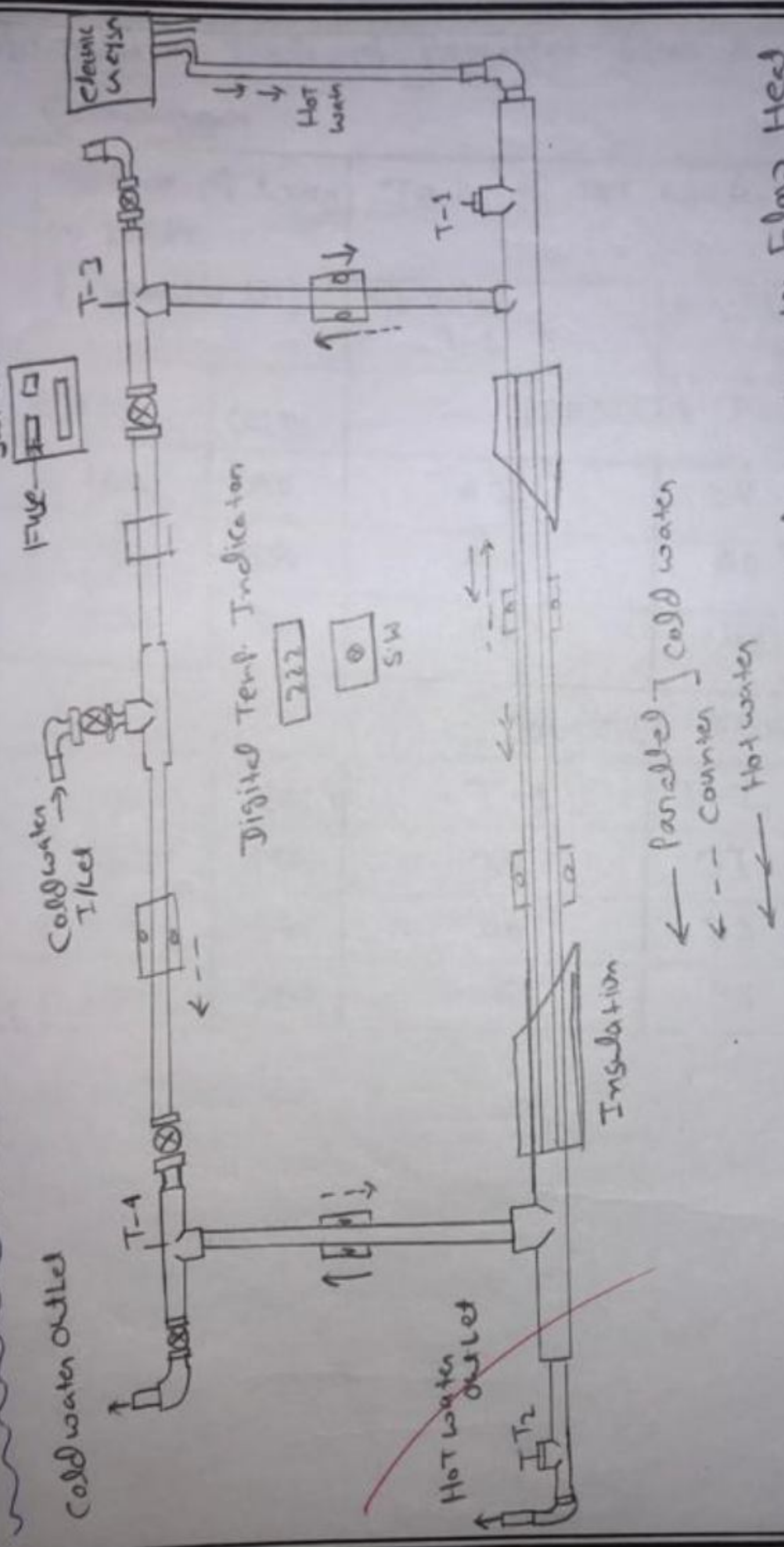

Fig:-> Schematic Diagram of Parallel Flow, counter Flow Heat Exchanger

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DEPARTMENT OF Mechanical Engineering PAGE NO 5

⇒ Observation Table of Parallel flow & Counter flow Heat Exchangers

Obs. No	Volume of water in 10 Sec [in milli Lit]		Temp. of Hot water		Temp. of cold water	
			At Inlet T-1	At Outlet T-2	At Inlet T-3	At Outlet T-4
-	HOT	COLD	PARALLEL FLOW			
1	500	940	42	38	28	30
2	390	500	43	40	28	31
3	240	300	57	48	28	34
-	COUNTER FLOW					
-	HOT	COLD	T-1	T-2	T4	T-3
1	680	650	38	37	28	29
2	610	570	40	38	28	30
3	290	340	51	45	28	32

07/11/22

Date 07/11/2022 Signature

⇒ Calculations (LMTD):→

for Parallel flow:→

(a) observation No:→1

$T_{hi} = T_1 = 42°c$, $T_{ho} = T_2 = 38°c$, $T_3 = 28°c$; $T_{co} = T_4 = 30°c$

$\Delta T_i = T_{hi} - T_{ci} = 42 - 28 = 14°c$

$\Delta T_o = T_{ho} - T_{co} = 38 - 30 = 8°$

$\therefore (LMTD)_1 = \frac{\Delta T_i - \Delta T_o}{\ln\left(\frac{\Delta T_i}{\Delta T_o}\right)} = \frac{14-8}{\ln(14/8)} \Rightarrow \boxed{(LMTD)_1 = 10.72}$

(b) observation No:→2

$T_{hi} = T_1 = 43°c$, $T_{ho} = T_2 = 40°c$, $T_{c1} = T_3 = 28°c$, $T_{co} = T_4 = 31°c$

$\Delta T_i = T_{hi} - T_{ci} = 43 - 28 = 15°c$

$\Delta T_o = T - T_{co} = 40 - 31 = 9°c$

$\therefore (LMTD)_2 = \frac{\Delta T_i - \Delta T_o}{\ln(\Delta T_i/\Delta T_o)} = \frac{15-9}{\ln(15/9)} \Rightarrow \boxed{(LMTD)_2 = 11.74°c}$

(c) observation No:→3

$T_{hi} = T_1 = 57°c$, $T_{ho} = T_2 = 48°c$, $T_{c1} = T_3 = 28°c$, $T_{co} = T_4 = 34°c$

$\Delta T_i = T_{hi} - T_{ci} = 57 - 28 = 29°c$

$\Delta T_o = T_{ho} - T_{co} = 48 - 34 = 14°c$

$(LMTD)_3 = \frac{\Delta T_i - \Delta T_o}{\ln(\Delta T_i/\Delta T_o)} = \frac{29-14}{\ln(29/14)} \Rightarrow \boxed{(LMTD)_3 = 20.60°c}$

$\therefore$ Average value of LMTD for Parallel flow Heat exchanger

is, $LMTD = \frac{(LMTD)_1 + (LMTD)_2 + (LMTD)_3}{3}$

$= \frac{10.72 + 11.74 + 20.60}{3} \Rightarrow \boxed{LMTD = 14.35°c}$

Date 07/11/2022 Signature ASK

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DEPARTMENT OF Mechanical Engineering PAGE NO 7

⇒ For ~~calcula~~ counter flow:-

ⓐ Observation No:→1

$T_{hi} = T_1 = 38°c$, $T_{ho} = T_2 = 37°c$, $T_{ci} = T_4 = 28°c$, $T_{co} = T_3 = 29°c$

$\Delta T_i = T_{hi} - T_{co} = 38 - 29 = 9°c$

$\Delta T_o = T_{ho} - T_{ci} = 37 - 28 = 9°c$

$\because \Delta T_i = \Delta T_o$ $\therefore \boxed{(LMTD)_1 = 9°c}$

ⓑ Observation No:→2

$T_{hi} = T_1 = 40°c$, $T_{ho} = T_2 = 38°c$, $T_{ci} = T_4 = 28°c$, $T_{co} = T_3 = 30°c$

$\Delta T_i = T_{hi} - T_{co} = 40 - 30 = 10°c$

$\Delta T_o = T_{hi} - T_{ci} = 38 - 28 = 10°c$

$\therefore \Delta T_i = \Delta T_o$ $\therefore \boxed{(LMTD)_2 = 10°c}$

ⓒ Observation No:→3

$T_{hi} = T_1 = 51°c$, $T_{ho} = T_2 = 45°c$, $T_{ci} = T = 28°c$, $T_{co} = T_3 = 32°c$

$\Delta T_i = T_{hi} - T_{co} = 51 - 32 = 19°c$

$\Delta T_o = T_{ho} - T_{ci} = 45 - 28 = 17°c$

$$\therefore (LMTD)_3 = \frac{\Delta T_i - \Delta T_o}{\ln(\Delta T_i/\Delta T_o)} = \frac{19-17}{\ln(19/17)} \Rightarrow \boxed{(LMTD)_3 = 17.98°c}$$

$\therefore$ Average value of LMTD for counter flow Heat exchanger is,

$$LMTD = \frac{(LMTD)_1 + (LMTD)_2 + (LMTD)_3}{3}$$

$$LMTD = \frac{9 + 10 + 17.98}{3}$$

$$\boxed{LMTD = 12.33°c}$$

Date 07 | 11 | 2022

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Calculations:→

Since, water is used as hot fluid and cold fluid so, $C_{ph} = C_{pc}$ and density, $\rho = 1000\ kg/m^3$

⇒ for Parallel flow:→

(a) observation No:→ 1

for Hot water,

volume of water in 10 sec, $V = 500\,mL = 500 \times 10^{-6}\ m^3$

$\therefore$ mass flow Rate of Hot water, $\dot{m}_h = \frac{\rho V}{t} = \frac{1000 \times 500 \times 10^{-6}}{10}$

$\Rightarrow \dot{m}_h = 0.05\ kg/s$

⇒ for cold water:→

volume of water in 10 sec, $V = 940\,mL = 940 \times 10^{-6}\ m^3$

$\therefore$ mass flow Rate of cold water, $\dot{m}_c = \frac{\rho V}{t} = \frac{1000 \times 940 \times 10^{-6}}{10}$

$\Rightarrow \dot{m}_c = 0.094\ kg/s$

$\because \dot{m}_h < \dot{m}_c$ and $C_{ph} = C_{pc}$

$\therefore \dot{m}_h C_{ph} < \dot{m}_c C_{pc}$

$\therefore \epsilon_1 = \frac{\dot{m}_h C_{ph}(T_{hi} - T_{ho})}{\dot{m}_h C_{ph}(T_{hi} - T_{ci})} = \frac{T_{hi} - T_{ho}}{T_{hi} - T_{ci}}$

from observation table,

$T_{hi} = T_1 = 42°c$, $T_{ho} = T_2 = 38°c$, $T_{ci} = T_3 = 28°c$

$\therefore \epsilon_1 = \frac{42 - 38}{42 - 28} \Rightarrow \boxed{\epsilon_1 = 0.2857}$

(b) observation No:→2

for Hot water,
volume of water in 10 sec, $V = 390\,mL = 390\times10^{-6}\,m^3$

∴ Mass flow Rate of Hot water, $\dot{m}_h = \frac{1000\times390\times10^{-6}}{10}$

$\Rightarrow \dot{m}_h = 0.039\ kg/s$

for cold water,
volume of water in 10 sec, $V = 500\,mL = 500\times10^{-6}\,m^3$

∴ Mass flow Rate of cold water, $\dot{m}_c = \frac{1000\times500\times10^{-6}}{10}$

$\Rightarrow \dot{m}_c = 0.05\ kg/s$

∵ $\dot{m}_h < \dot{m}_c$ and $C_{ph} = C_{pc}$

∴ $\dot{m}_h C_{ph} < \dot{m}_c C_{pc}$

∴ $\epsilon_2 = \frac{\dot{m}_h C_{ph}(T_{hi} - T_{ho})}{\dot{m}_h C_{ph}(T_{hi} - T_{ci})} = \frac{T_{hi} - T_{ho}}{T_{hi} - T_{ci}}$

⇒ from observation table,
$T_{hi} = T_1 = 43^\circ c$, $T_{ho} = T_2 = 40^\circ c$, $T_{ci} = T_3 = 28^\circ c$

∴ $\epsilon_2 = \frac{43-40}{43-28} \Rightarrow \boxed{\epsilon_2 = 0.2}$

(c) observation No:→3

for Hot water,
volume of water in 10 sec, $V = 240\,mL = 240\times10^{-6}\,m^3$

∴ Mass flow Rate of Hot water $\dot{m}_h = \frac{1000\times240\times10^{-6}}{10}$

$\Rightarrow \dot{m}_h = 0.024\ kg/s$

Date 07/11/2022 Signature ASk

for cold water,

volume of water in 10 sec, $V = 300 mL = 300 \times 10^{-6} m^3$

$\therefore$ mass flow Rate of cold water, $\dot{m}_c = \frac{1000 \times 300 \times 10^{-6}}{10}$

$\Rightarrow \dot{m}_c = 0.03 kg/s$

$\because \dot{m}_h < \dot{m}_c$ and $C_{Ph} = C_{Pc}$

$\therefore \dot{m}_h C_{Ph} < \dot{m}_c C_{Pc}$

$\therefore \epsilon_3 = \frac{\dot{m}_h C_{ph}(T_{hi} - T_{ho})}{\dot{m}_h C_{ph}(T_{hi} - T_{ci})} = \frac{T_{hi} - T_{ho}}{T_{hi} - T_{ci}}$

from observation table,

$T_{hi} = T1 = 57°c$, $T_{ho} = T_2 = 48°c$, $T_{ci} = T_3 = 28°c$

$\therefore \epsilon_3 = \frac{57 - 48}{57 - 28} \Rightarrow \boxed{\epsilon_3 = 0.3103}$

Hence the Average value of effectiveness for the Parallel flow Heat exchanger is,

$\epsilon = \frac{\epsilon_1 + \epsilon_2 + \epsilon_3}{3} = \frac{0.2857 + 0.2 + 0.3103}{3}$

$\Rightarrow \boxed{\epsilon = 0.2653}$

$\Rightarrow$ for counter flow :-

(a) observation No :- 1

For Hot water,

volume of water in 10 sec, $V = 680 mL = 680 \times 10^{-6} m^3$

$\therefore$ mass flow Rate of Hot water, $\dot{m}_h = \frac{1000 \times 680 \times 10^{-6}}{10}$

$\Rightarrow \dot{m}_h = 0.068 kg/s$

Date 07 | 11 | 2022 Signature ASK

for cold water,

volume of water in 10 sec, $V = 650 mL = 650 \times 10^{-6}\ m^3$

$\therefore$ Mass flow Rate of cold water, $\dot{m}_c = \frac{1000 \times 650 \times 10^{-6}}{10}$

$\Rightarrow \dot{m}_c = 0.065\ kg/s$

$\therefore \dot{m}_c < \dot{m}_h$ and $C_{pc} = C_{ph}$

$\therefore \dot{m}_c C_{pc} < \dot{m}_h C_{ph}$

$\therefore \epsilon_1 = \frac{\dot{m}_c C_{pc}(T_{co} - T_{ci})}{\dot{m}_c C_{pc}(T_{hi} - T_{ci})} = \frac{T_{co} - T_{ci}}{T_{hi} - T_{ci}}$

from observation table,

$T_{hi} = T_1 = 38°c$, $T_{ci} = T_4 = 28°c$, $T_{co} = T_3 = 29°c$

$\therefore \epsilon_1 = \frac{29 - 28}{38 - 28} \Rightarrow \boxed{\epsilon_1 = 0.1}$

(b) observation No :-> 2

for Hot water,

volume of water in 10 sec, $V = 610 mL = 610 \times 10^{-6}\ m^3$

$\therefore$ Mass flow Rate of Hot water, $\dot{m}_h = \frac{1000 \times 610 \times 10^{-6}}{10}$

$\Rightarrow \dot{m}_h = 0.061\ kg/s$

for cold water,

volume of water in 10 sec, $V = 570 mL = 570 \times 10^{-6}\ m^3$

$\therefore$ Mass flow Rate of cold water, $\dot{m}_c = \frac{1000 \times 570 \times 10^{-6}}{10}$

$\dot{m}_c = 0.057\ kg/s$

$\therefore \dot{m}_c < \dot{m}_h$ and $C_{pc} = C_{ph}$

$\therefore \dot{m}_c C_{pc} < \dot{m}_h C_{ph}$ $\therefore \epsilon_2 = \frac{\dot{m}_c C_{pc}(T_{co} - T_{ci})}{\dot{m}_c C_{pc}(T_{hi} - T_{ci})} = \frac{T_{co} - T_{ci}}{T_{hi} - T_{ci}}$

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from observation table,

$T_{hi} = T_1 = 40°c$, $T_{ci} = T_4 = 28°c$, $T_{co} = T_3 = 30°c$

$\therefore \epsilon_2 = \frac{30-28}{40-28} \Rightarrow \boxed{\epsilon_2 = 0.1667}$

(c) Observation No:→3

for Hot water,

Volume of water in 10 sec, $V = 290 ml = 290 \times 10^{-6} m^3$

$\therefore$ mass flow Rate of Hot water $\dot{m}_h = \frac{1000 \times 290 \times 10^{-6}}{10}$

$\Rightarrow \dot{m}_h = 0.029$ Kg/s

for cold water,

volume of water in 10 sec, $V = 340 ml = 340 \times 10^{-6} m^3$

$\therefore$ Mass flow Rate of cold water, $\dot{m}_c = \frac{1000 \times 340 \times 10^{-6}}{10}$

$\Rightarrow \dot{m}_c = 0.034$ Kg/s

$\because \dot{m}_h < \dot{m}_c$ and $c_{ph} = c_{pc}$

$\therefore \dot{m}_h c_{ph} < \dot{m}_c c_{pc}$

$\therefore \epsilon_3 = \frac{\dot{m}_h c_{ph} (T_{hi} - T_{ho})}{\dot{m}_h c_{ph} (T_{hi} - T_{co})} = \frac{T_{hi} - T_{ho}}{T_{hi} - T_{ci}}$

from observation table,

$T_{hi} = T_1 = 51°c$, $T_{ho} = T_2 = 45°c$, $T_{ci} = T_4 = 28°c$

$\therefore \epsilon_3 = \frac{51-45}{51-28} \Rightarrow \boxed{\epsilon_3 = 0.2609}$

Hence, the Average value of effectiveness for the counter flow Heat exchanger,

$\epsilon = \frac{\epsilon_1 + \epsilon_2 + \epsilon_3}{3} = \frac{0.1 + 0.1667 + 0.2609}{3}$

$\Rightarrow \boxed{\epsilon = 0.1759}$

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DEPARTMENT OF Mechanical Engineering PAGE NO 13

Results:-

(a) For Parallel flow Heat Exchanger:-

Obs.No	∈	Average value of ∈	LMTD	Avg. LMTD
1	0.2857	0.2653	10.72°C	14.35°C
2	0.2		11.74°C	
3	0.3103		20.60°C	

(b) For Counter flow Heat exchanger:-

Obs. No	∈	Avg. value of ∈	LMTD	Avg. LMTD
1	0.1	0.1759	9°C	12.33°C
2	0.1667		10°C	
3	0.2603		17.98°C	

⇒ Precautions:-

(i) The Reading in the volumetric flask must be taken Accurately

(ii) The fluid must be allowed to Reach steady state Condition after Heating.

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