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Shell and Tube Heat Exchanger

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Abstract

A heat exchanger is a device that facilitates the exchange of heat between two fluids that are at different temperatures while keeping them away from mixing with each other. Heat exchangers are typically classified according to flow arrangement. The simplest heat exchanger is one for which the hot and cold fluids move in co-current flow (flows in same direction) and counter current flow (flows in the opposite direction),the objectives of this experiment are to demonstrate the differences between these two types of flow and to determine the overall heat transfer coefficient (U) for shell and tube heat exchanger using the logarithmic mean temperature difference (LMTD) also to investigate the effect of changes in hot and cold fluid flow rate (Q) on the temperature efficiencies and overall heat transfer coefficient, the experiment reveal that counter current is more efficient than co-current.

main results?.

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Results

Table 1 : Specifications of shell and tube heat exchanger

d_i (m)	0.00515	Cold water flow rate (co) (L/min)	2.06
d_o (m)	0.00635	Cold water flow rate (co) (m^3/s)	3.43E-05
$d_m = (d_o + d_i)/2$	0.00575	Cold water flow rate (counter) (L/min)	1.59
heat transmission length L (m)	1.008	Cold water flow rate (counter) (m^3/s)	0.0000265
Area (m^2)	0.0182		

Table 2 : Raw data for co-current flow

Hot water flow (L/min)	Hot water flow (m^3/s)	T hot in (T_2) (°C)	T hot out (T_1) (°C)	T cold in (T_3) (°C)	T cold out (T_4) (°C)	ΔT hot (°C)	ΔT cold (°C)	ΔT max (°C)
1	1.67E-05	61	52.1	17.7	21.2	8.9	3.5	43.3
2	3.33E-05	60	54.3	18.8	23.4	5.7	4.6	41.2
3	0.00005	59.7	55.1	19.1	24.7	4.6	5.6	40.6
4	6.67E-05	59.5	55.6	19.3	25.6	3.9	6.3	40.2
5	8.33E-05	59.8	56.3	19.4	26.3	3.5	6.9	40.4

Table 3 : Parameters for co-current flow

Tc Avg (K)	ρ_{cold} (kg/m^3)	Cp cold (J/kg. k)	mass cold (kg/s)	Th Avg (K)	ρ_{hot} (kg/m^3)	Cp hot (J/kg.k)	mass hot (kg/s)
292.6	998.32	4182.44	0.03428	329.7	984.43	4183.88	0.01641
294.25	997.99	4181.45	0.03426	330.3	984.14	4184.12	0.03280
295.05	997.81	4180.98	0.03426	330.55	984.04	4184.22	0.04920
295.6	997.68	4180.98	0.03425	330.7	983.98	4184.28	0.06560
296	997.59	4180.6	0.03425	331.2	983.79	4184.48	0.08198

Table 4 : Cont'd of parameters for co-current flow

Q_{abs} (W)	Q_{emi} (W)	Q_{loss} (W)	ΔT_1	ΔT_2	ΔT_{LMTD} (k)	U ($W/m^2.K$)	$\eta_{overall}$ (%)	η_{cold} (%)	η_{hot} (%)	η_{EX} (%)
501.75	610.95	109.20	43.3	30.9	36.7520	913.38	82.13	8.08	20.55	14.32
659.06	782.37	123.31	41.2	30.9	35.8034	1200.66	84.24	11.17	13.83	12.50
802.10	947.01	144.91	40.6	30.4	35.2544	1475.95	84.70	13.79	11.33	12.56
902.25	1070.48	168.24	40.2	30	34.8516	1687.67	84.28	15.67	9.70	12.69
988.00	1200.69	212.69	40.4	30	34.9424	1888.02	82.29	17.08	8.66	12.87

Table 5 : Raw data for counter-current flow

Hot water flow (L/min)	Hot water flow (m^3/s)	T hot in (T_1) (°C)	T hot out (T_2) (°C)	T cold in (T_3) (°C)	T cold out (T_4) (°C)	ΔT hot (°C)	ΔT cold (°C)	ΔT max (°C)
1	1.67E-05	59.9	52.6	19.3	23.2	7.3	3.9	40.6
2	3.33E-05	59.9	54.6	19.3	24.3	5.3	5	40.6
3	0.00005	59.8	55.4	19.3	25.5	4.4	6.2	40.5
4	6.67E-05	59.8	56.1	19.3	26.3	3.7	7	40.5
5	8.33E-05	59.7	56.5	19.3	27	3.2	7.7	40.4

Table 6 : Parameters for counter-current flow

Tc Avg (K)	ρ_{cold} (kg/m^3)	Cp cold (J/kg. k)	mass cold (kg/s)	Th Avg (K)	ρ_{hot} (kg/m^3)	Cp hot (J/kg.k)	mass hot (kg/s)
294.4	997.98	4181.36	0.02645	329.4	984.6	4183.76	0.01641
294.95	997.83	4181.03	0.02644	330.4	984.1	4184.16	0.03280
295.55	997.69	4180.78	0.02644	330.75	983.96	4184.3	0.04920
295.95	997.6	4180.62	0.02644	331.1	983.83	4184.44	0.06559
296.3	997.5	4180.48	0.02643	331.25	983.77	4184.5	0.08198

Table 7 : Cont'd of parameters for counter-current flow

Q_{abs} (W)	Q_{emi} (W)	Q_{loss} (W)	ΔT_1	ΔT_2	ΔT_{LMTD} (k)	U ($W/m^2.K$)	$\eta_{overall}$ (%)	η_{cold} (%)	η_{hot} (%)	η_{EX} (%)
431.27	501.19	69.91	36.7	33.3	34.9725	787.41	86.05	9.61	17.98	13.79
552.78	727.45	174.66	35.6	35.3	35.4498	1127.50	75.99	12.32	13.05	12.68
685.32	905.78	220.47	34.3	36.1	35.1923	1414.18	75.66	15.31	10.86	13.09
773.64	1015.47	241.83	33.5	36.8	35.1242	1588.51	76.19	17.28	9.14	13.21
850.89	1097.76	246.86	32.7	37.2	34.9017	1728.18	77.51	19.06	7.92	13.49

Figures

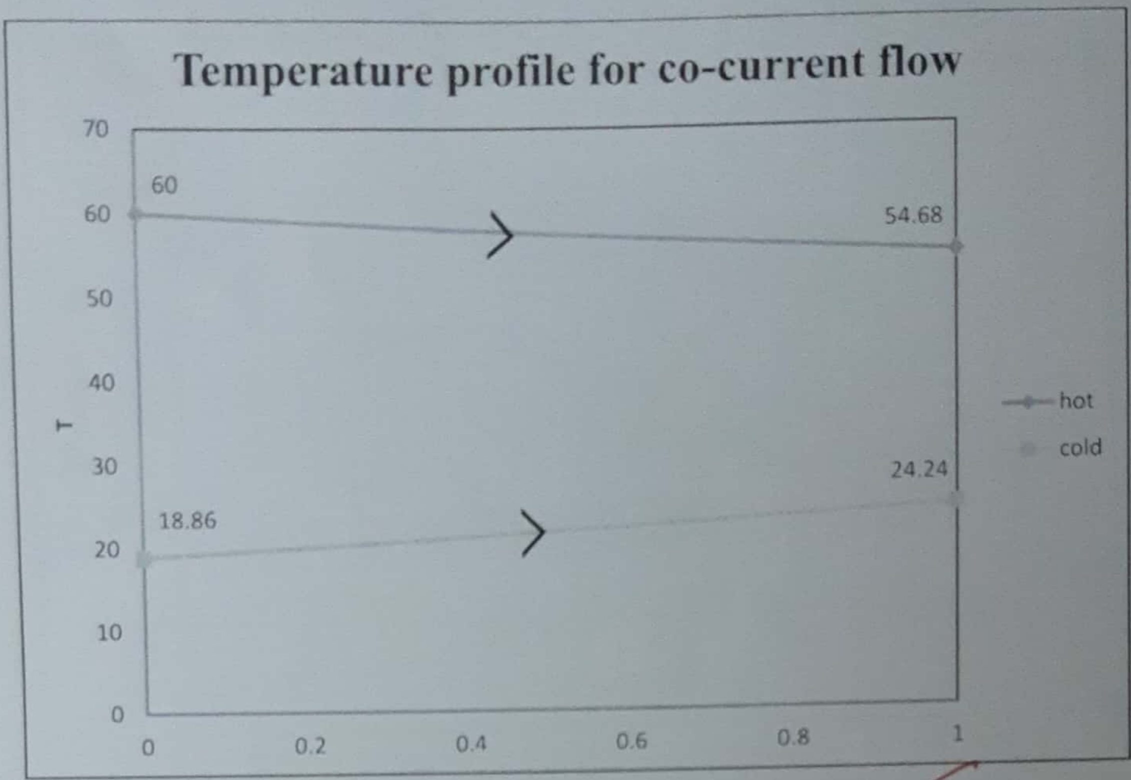

Figure 1 : Temperature profile for co-current flow

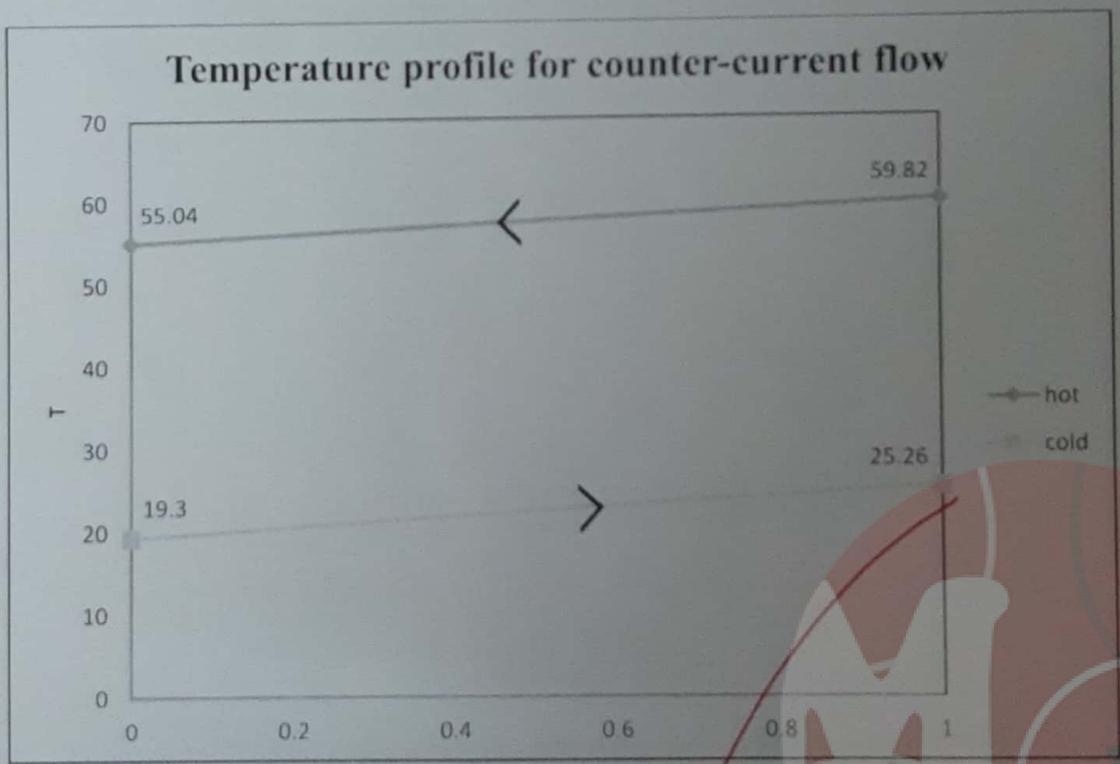

Figure 2 : Temperature profile for counter-current flow

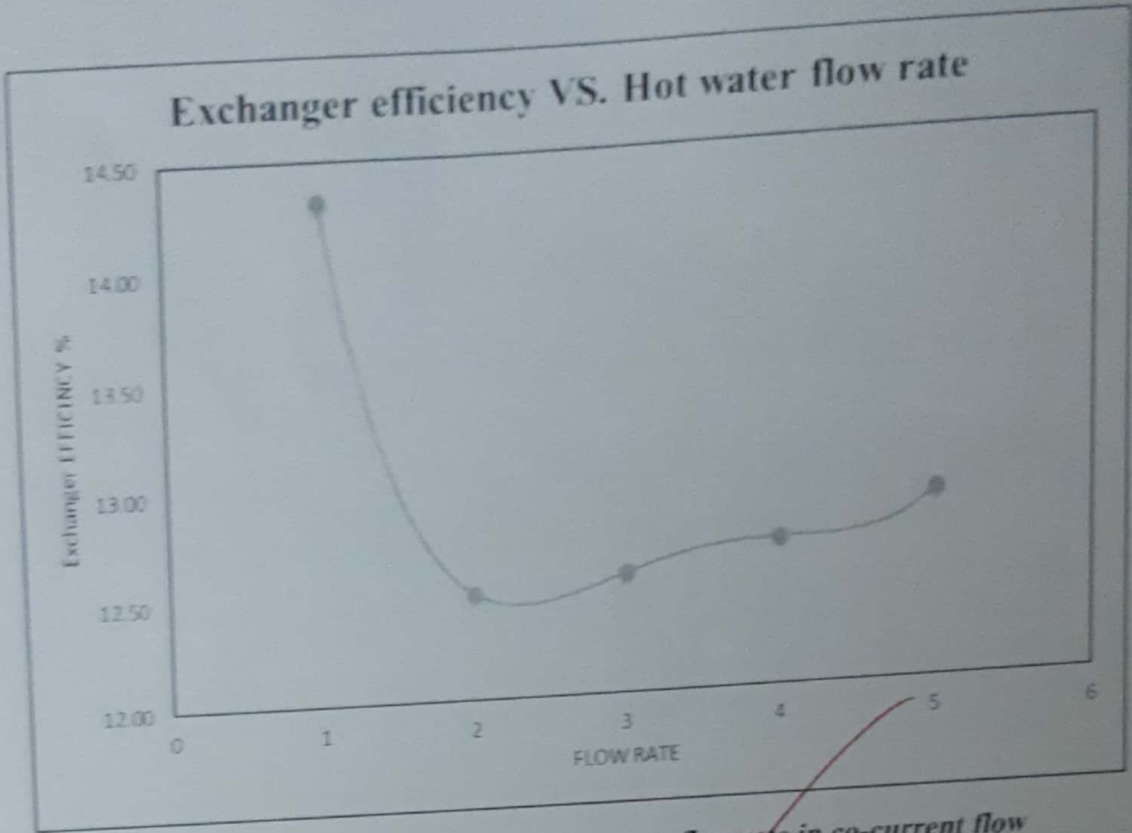

Figure 3 : Exchanger efficiency VS. Hot water flow rate in co-current flow

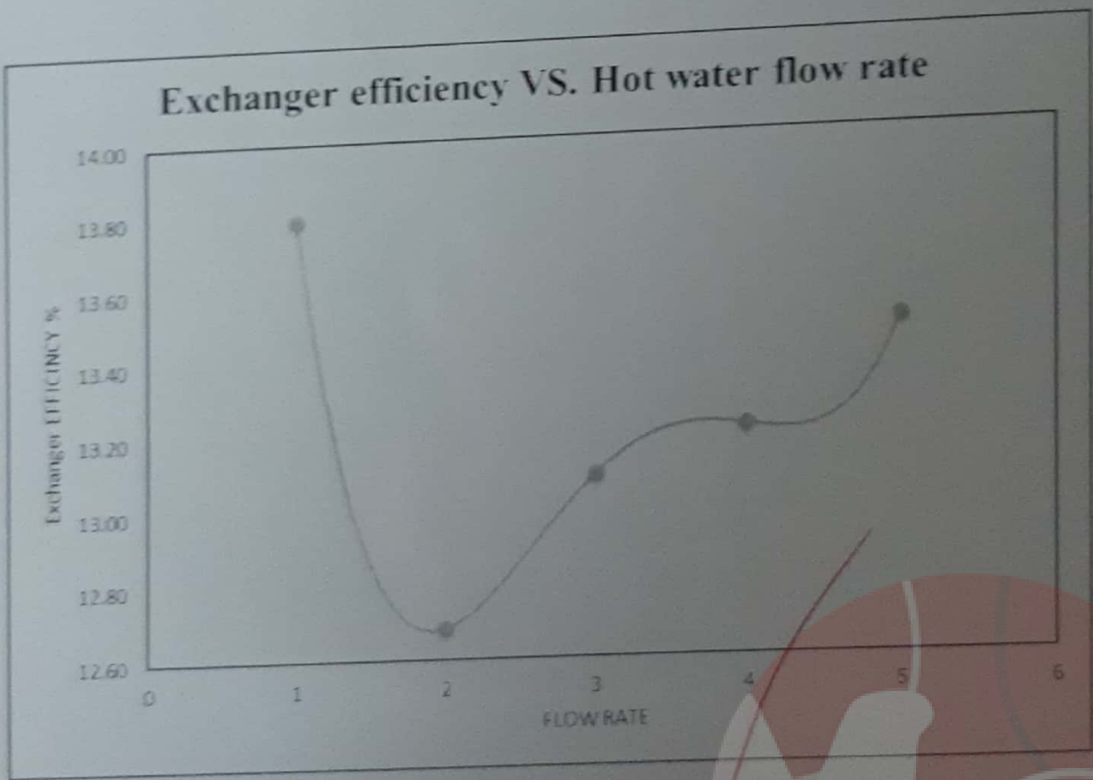

Figure 4 : Exchanger efficiency VS. Hot water flow rate in counter-current flow

Discussion

Figure 3&4 shows the results obtained for the efficiency of the heat exchanger in the tube, using the flow parameters of the hot fluid. If flow rate of hot water increased the efficiency would increase because increased of flow would improve heat exchanged which was turned to increase Re and turbulence therefore the efficiency would be higher. An error occurred in the results, the curves show that the rate of change in the efficiency values with the flow is irregular, sometimes it increased and sometimes it decreased because the time between each flow was not enough and therefore the heat exchange did not take place well.

Increased in the flow rate of cold fluid results in increased in the overall heat transfer coefficient as can be seen, this is because increased in the flow rate increased the Reynolds number, which in turn increased the overall heat transfer coefficient.

Counter-current Heat Exchangers are better than Co-current because if LMTD increased, the required surface A would decrease that would result in reduced cost another reason the temperature difference was the driving force of heat transfer. There was always a large and homogeneous temperature difference in a counter-current heat exchanger, but this temperature difference is very low in the case of co-current exchangers at the end of the exchanger where fluid exits.

Conclusion

By conducting the experiments on shell and tube heat exchangers with two types of flow co-current and counter-current flow, we can conclude that:

- The Heat absorbed or emitted by the water increases with increasing the mass flow rate of water in the two types.
- The amount of heat loss from the hot water is unequal to the heat gain by the cold water, due to the heat loss to the surrounding.
- The overall heat transfer coefficient (U) increases as flow rate increases, so heat transfer in turbulent flow is better than in laminar flow.
- Counter current is more efficient than Co-current heat exchanger because of large heat rate will be obtained.

References

1) Chemical engineering laboratory "1" (0915361); University of Jordan; faculty of engineering and Technology; Department of Chemical engineering.

2) Incropera, (2011), Fundamentals of Heat and Mass Transfer, John Wiley & Sons, Inc., seventh edition, (pp. 1003).

3) Robert W. Serth and Thomas Lestina (Auth.), (2014), Process Heat Transfer. Principles, Applications and Rules of Thumb-Academic Press, 2nd edition.

Appendix

- **Sample of calculation; taking the first raw of co-current tables:**

1) **ΔT hot** = $(T_2 - T_1)$ = (61-52.1) = 8.9 °C

   ΔT cold = $(T_4 - T_3)$ = (21.2 – 17.7) = 3.5 °C

   ΔT max = $(T_2 - T_3)$ = (61- 17.7) = 43.3 °C

2) **Hot water flow**

   $= 1\ L\backslash min = \frac{1}{(1000 \times 60)} = 1.67*10^{-5}\ m^3/s$

3) $T_{avg,\ cold} = (\frac{T_1 + T_2}{2}) + 273.15 = 292.6\ K$

   → (ρ = 988.32 kg/m³ & Cp= 4182.44 J/Kg.K)

   $T_{avg,\ hot} = (\frac{T_1 + T_2}{2}) + 273.15 = 329.7\ K$

   → (ρ = 988.43 Kg/m³ & Cp= 4183.88 J/Kg.K)

4) **Mass of cold flow rate**

   = Cold water flow * ρ

   $= 3.43 * 10^{-5} * 988.32 = 0.0343$ Kg/s

5) **Mass of hot flow rate**

   = Hot water flow * ρ

   $= 1.67 * 10^{-5} * 984.43 = 0.0164$ Kg/s

6) **Heat power emitted from hot fluid**

   $Q_{emi} = m_{hot}\ c_p\ \Delta T_{hot} = 0.01641 * 4183.88 * 8.9 = 610.95$ W

   Heat power absorbed by cold fluid

   $Q_{abs} = m_{cold}\ cp\ \Delta T_{cold} = 0.03428 * 4182.44 * 3.5 = 501.75$ W

   Heat power lost or gained

   $Q_{lose} = Q_{emi} - Q_{ans} = 610.95 - 510.75 = 109.20$

7) $\Delta T_1 = (T_2 - T_3)$ = (61- 17.7) = 43.3 °C = 43.3 K

   $\Delta T_2 = (T_1 - T_4)$ = (52.1 – 21.2) = 30.9 °C = 30.9 K

8) ΔT_{LMTD}

   $$\Delta T_{LMTD} = \frac{\Delta T_1 - \Delta T_2}{Ln(^{\Delta T_1}/_{\Delta T_2})} = \frac{43.3 - 30.9}{Ln(^{43.3}/_{30.9})} = 36.75\ K$$

9) **The overall heat transfer coefficient**

$$U = \frac{Q_{emi}}{A.\Delta T_{LMTD}} = \frac{610.95}{0.0182 \times 36.75} = 913.38\ W/m^2.K$$

10) **The overall heat transfer efficiency**

$$\eta_{overall} = \frac{Q_{abs}}{Q_{emi}} \times 100\% = \frac{501.75}{610.95} \times 100\% = 82.13\ \%$$

The thermal efficiency for the cold side

$$\eta_{cold} = \frac{\Delta T_{cold}}{\Delta T_{max}} \times 100\% = \frac{3.5}{43.3} \times 100\% = 8.08\ \%$$

The thermal efficiency for the hot side

$$\eta_{cold} = \frac{\Delta T_{hot}}{\Delta T_{max}} \times 100\% = \frac{8.9}{43.3} \times 100\% = 20.55\ \%$$

Then the efficiency of exchanger

$$\eta_{HX} = \frac{\eta_{cold} + \eta_{hot}}{2} \times 100\% = 14.32\ \%$$

Cold water flow rate: ____________

Co-current flow:

Hot water flow rate (Liter/min)	$T_{hot,in}$ (T_2) (°C)	$T_{hot,out}$ (T_1) (°C)	$T_{cold,in}$ (T_3) (°C)	$T_{cold,out}$ (T_4) (°C)
1	61	52.1	17.7	21.2
2	60	54.3	18.8	23.4
3	59.7	55.1	19.1	24.7
4	59.5	55.6	19.3	25.6
5	59.8	56.3	19.4	26.3

Counter-current flow:

Hot water flow rate (Liter/min)	$T_{hot,in}$ (T_1) (°C)	$T_{hot,out}$ (T_2) (°C)	$T_{cold,in}$ (T_3) (°C)	$T_{cold,out}$ (T_4) (°C)
1	59.9	52.6	19.3	23.2
2	59.9	54.6	19.3	24.3
3	59.8	55.4	19.3	25.5
4	59.8	56.1	19.3	26.3
5	59.7	56.5	19.3	27.0