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Concentric Tube Heat Exchanger

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Abstract

The Concentric Tube Heat Exchanger is two coaxial tubes one inside the other carrying fluids of different temperatures, due to the temperature difference, heat will flow from the hotter stream to the cooler one. A heat exchanger is a tool designed to transfer heat effectively from one medium to another. The purpose of this experiment is to show how a concentric tube heat exchanger works when there is co-current flow and counter-current flow. Also, to show the impact of flow rate variation on a concentric tube heat exchanger's performance while it operates under co-current or counter-current flow conditions, for both hot and cold flow. The main results is counter current is better than co-current flow and turbulent flow is better than laminar flow so that increasing in flow rate leads to increasing in overall heat transfer coefficient (U). Also, there are some of heat losses to the surrounding.

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Results

Table 1 : Specifications of the tubes

Tube outer diameter $D_{t,o}$ (mm)	15	Insulation Thickness (mm wall)	20
Tube thickness (mm)	0.7	Heat Transmission Length (m)	1.5
Shell outer diameter $D_{s,o}$ (mm)	22	Heat Transmission Area (m^2)	0.067
Shell thickness (mm)	0.9	Cold water flow rate (cm^3/s)	1000

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)
1000	0.0000167	78	61	26	44	17	18	52
1500	0.000025	78	64	26	48	14	22	52
2000	0.0000333	78	66	26	52	12	26	52
2500	0.0000417	78	66	26	52	12	26	52

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)
308.15	993.78	4178	0.016563	342.65	977.91	4189.59	0.01633
310.15	992.99	4178.03	0.016549	344.15	977.05	4190.49	0.02443
312.15	992.20	4178.43	0.016537	345.15	976.47	4191.12	0.03252
312.15	992.20	4178.43	0.016536	345.15	976.47	4191.12	0.04072

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} (%)
1245.60	1163.15	-82.45	52	17	31.305	554.56	107.09	34.62	32.69	33.65
1521.21	1433.01	-88.19	52	16	30.543	700.26	106.15	42.31	26.92	34.62
1796.53	1635.36	-161.2	52	14	28.959	842.85	109.86	50.0	23.08	36.54
1796.53	2047.89	251.4	52	14	28.959	1055.46	87.73	50.0	23.08	36.54

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)
1000	1.67E-05	78	56	25	40	22	15	53
1500	0.000025	78	59	26	44	19	18	52
2000	3.33E-05	78	62	26	45	16	19	52
2500	4.17E-05	78	65	26	47	13	21	52

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)
305.65	994.76	4178	0.01658	340.15	979.34	4188.09	0.016
308.15	993.78	4178	0.01656	341.65	978.48	4188.99	0.024
308.65	993.58	4178	0.01656	343.15	977.62	4189.89	0.033
309.65	993.19	4178	0.01655	344.65	976.76	4190.79	0.041

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} (%)
1039.03	1503.91	464.88	38	31	34.38	652.87	69.09	28.3	41.51	34.91
1245.60	1946.95	701.35	34	33	33.5	867.5	63.98	34.62	36.54	35.58
1314.54	2184.6	870.06	33	36	34.48	945.7	60.17	36.54	30.77	33.65
1452.34	2217.26	764.91	31	39	34.85	949.67	65.5	40.39	25.00	32.69

Figures

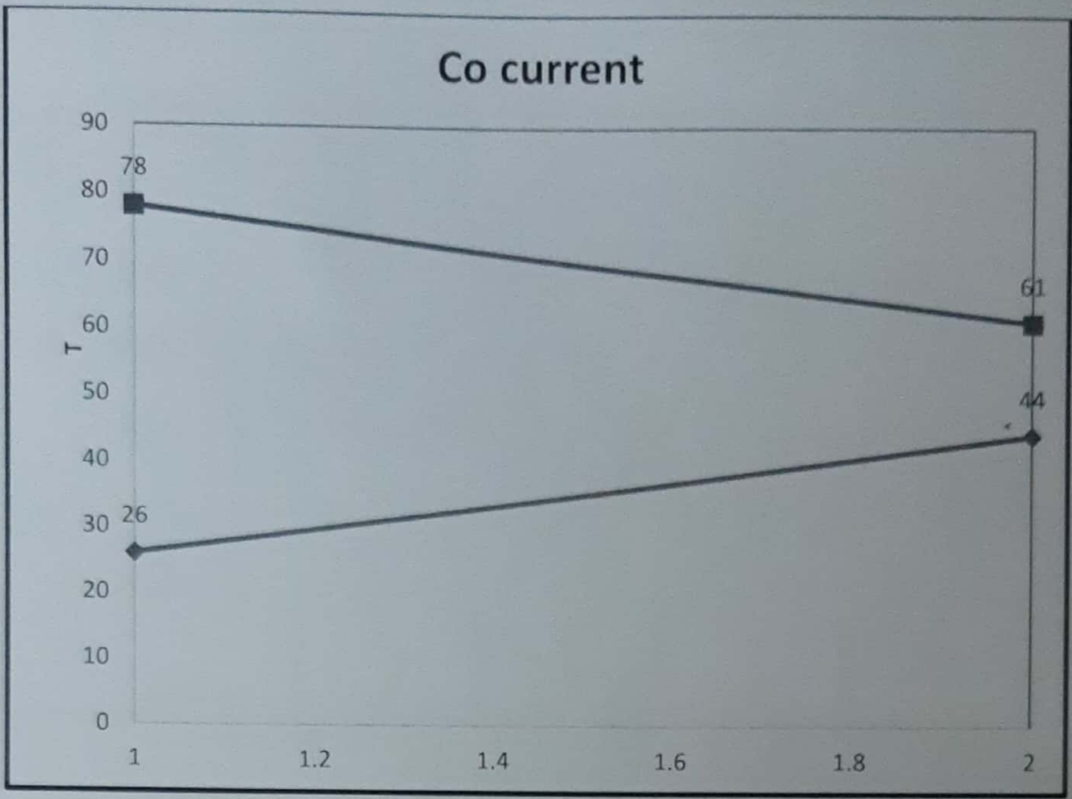

Figure 1 : Temperature profile for co-current flow

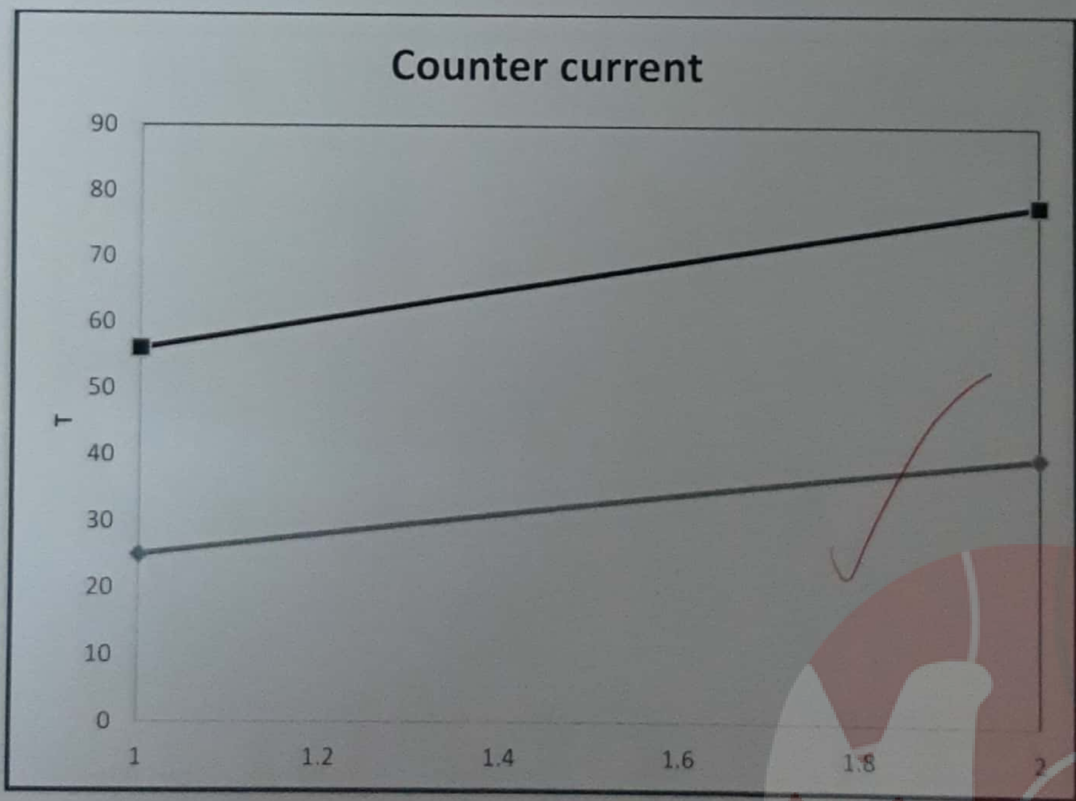

Figure 2 : Temperature profile for counter-current flow

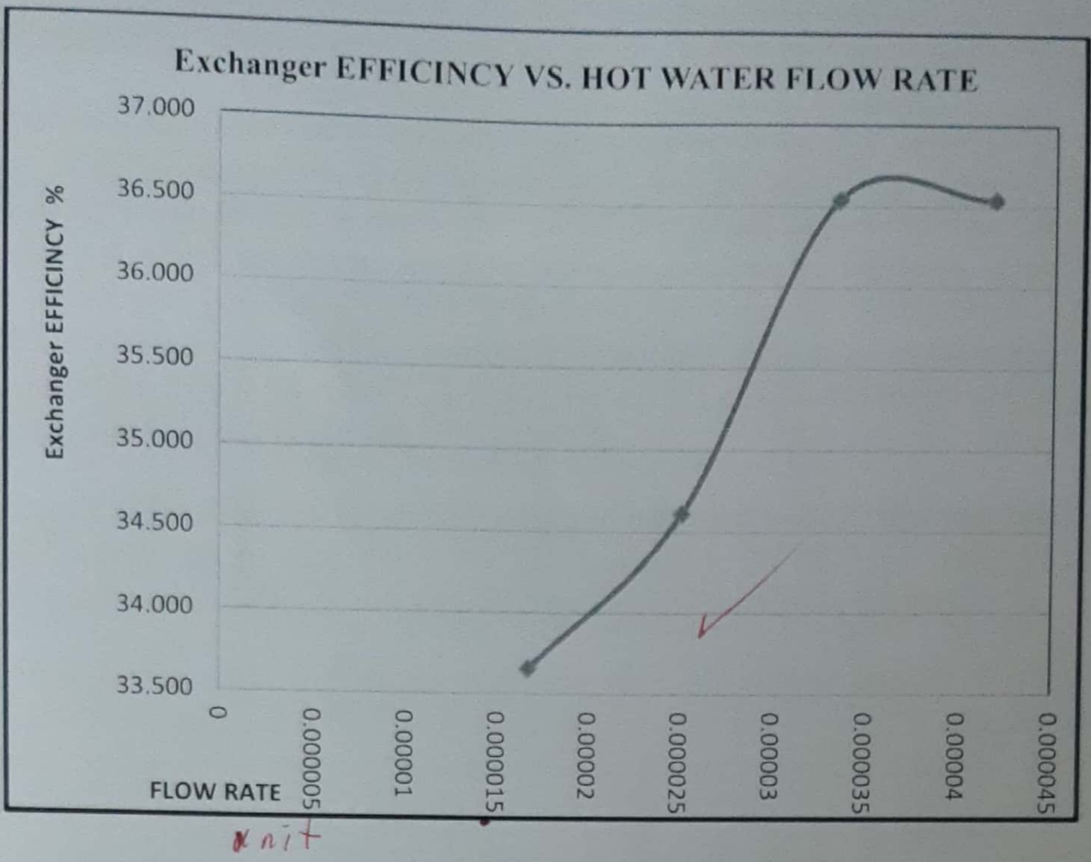

Figure 3 : Exchanger efficiency VS. Hot water flow rate in co-current flow

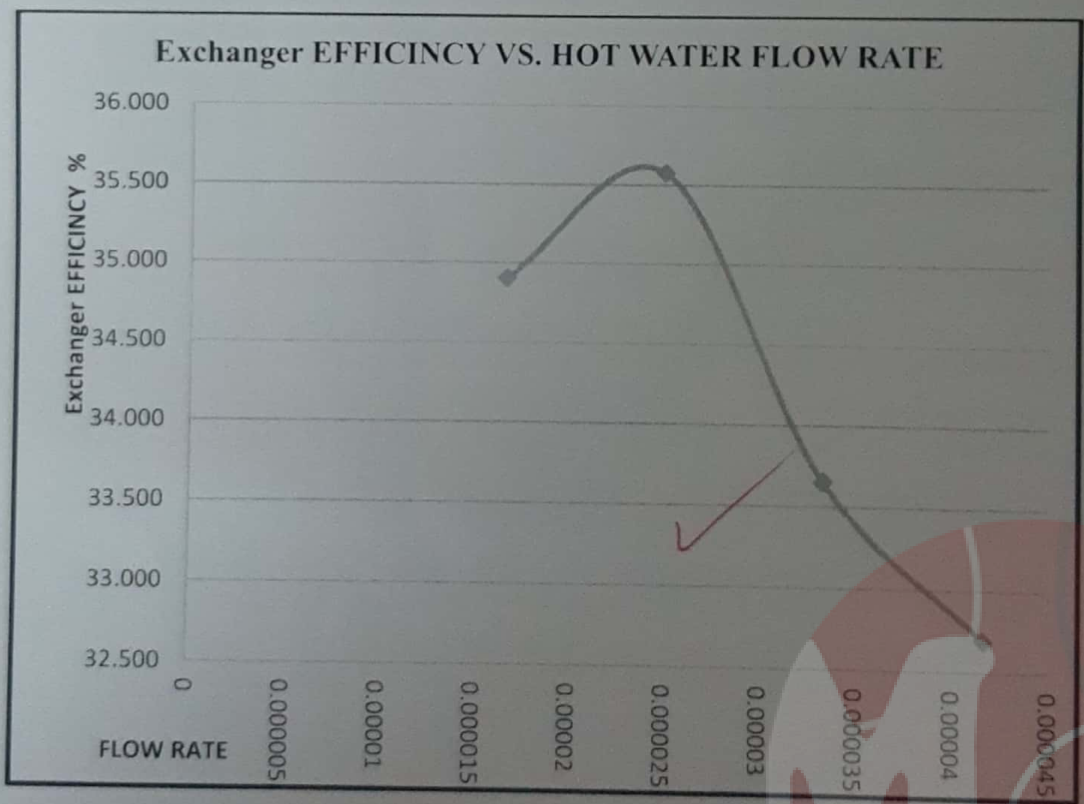

Figure 4 : Exchanger efficiency VS. Hot water flow rate in counter-current flow

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 hot 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 area 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 countercurrent heat exchanger, but this temperature difference is very low in the case of cocurrent 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) = (78-61) = 17°C

   ΔT cold = (T_4 -T_3) = (44 – 26) = 18 °C

   ΔT max = (T_2 - T_3) = (78- 26) = 52 °C

2) **Hot water flow**

   $= 1000\ cm^3\backslash min = \frac{1}{(100^3 \times 60)} = 0.0000167\ m^3/s$

3) $T_{avg,\ cold} = (\frac{T_1 + T_2}{2}) + 273.15 = 308.15\ K$

   → (ρ = 993.78 kg/m³ & Cp= 4178 J/Kg.K)

   $T_{avg,\ hot} = (\frac{T_1 + T_2}{2}) + 273.15 = 342.65\ K$

   → (ρ = 977.91 Kg/m³ & Cp= 4189.59 J/Kg.K)

4) **Mass of cold flow rate**

   = Cold water flow * ρ

   = 1.66667E-05 * 993.78 = 0.01656 Kg/s

5) **Mass of hot flow rate**

   = Hot water flow * ρ

   = 0.0000167 * 977.91 = 0.01633 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

   $Q_{abs} = m_{cold}\ cp\ \Delta T_{cold}$ = 0.016563 *4178* 18 =1245.60 W

   Heat power lost or gained

   $Q_{lose} = Q_{emi} - Q_{ans}$ = 1163.150– 1245.60= -82.454 W

7) ΔT_1 = (T_2 - T_3) = (78- 26) = 52 °C =52 K

   ΔT_2 = (T_1 – T_4) = (61 – 44) = 17 °C = 17 K

8) ΔT_{LMTD}

   $$\Delta T_{LMTD} = \frac{\Delta T_1 - \Delta T_2}{Ln(^{\Delta T_1}/_{\Delta T_2})} = \frac{52 - 17}{Ln(^{52}/_{17})} = 304.455\ K$$

9) **The overall heat transfer coefficient**

$$U = \frac{Q_{emi}}{A.\Delta T_{LMTD}} = \frac{1163.15}{0.067 \times 304.455} = 57.021\ W/m^2.K$$

10) **The overall heat transfer efficiency**

$$\eta_{overall} = \frac{Q_{abs}}{Q_{emi}} \times 100\% = \frac{1245.60}{1163.15} \times 100\% = 107\ \%$$

The thermal efficiency for the cold side

$$\eta_{cold} = \frac{\Delta T_{cold}}{\Delta T_{max}} \times 100\% = \frac{18}{52} \times 100\% = 34.6\ \%$$

The thermal efficiency for the hot side

$$\eta_{cold} = \frac{\Delta T_{hot}}{\Delta T_{max}} \times 100\% = \frac{17}{52} \times 100\% = 32.7\ \%$$

Then the efficiency of exchanger

$$\eta_{HX} = \frac{\eta_{cold} + \eta_{hot}}{2} \times 100\% = 33.7\ \%$$

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Concentric Tube Heat Exchanger Data Sheet

Heat transfer area: ________0.067 m²________

Heat transfer length: ______1.5m________

Cold water flow rate: __________1000 cm³/min______

Co-current flow:

Hot water flow rate (cm³/min)	$T_{hot,in}$ (°C)	$T_{hot,out}$ (°C)	$T_{cold,in}$ (°C)	$T_{cold,out}$ (°C)
1000	78	61	26	44
1500	78	64	26	48
2000	78	66	26	52
2500	78	66	26	52

Counter-current flow:

Hot water flow rate (cm³/min)	$T_{hot,in}$ (°C)	$T_{hot,out}$ (°C)	$T_{cold,in}$ (°C)	$T_{cold,out}$ (°C)
1000	78	56	25	40
1500	78	59	26	44
2000	78	62	26	45
2500	78	65	26	47