Troubleshooting of Parallel and Counter Flow Heat Exchanger

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Abstract - *Heat exchanger is a device in which heat is moved from one fluid to another. It is widely used in various industries for heating and cooling applications. This paper represents troubleshooting and calibration of parallel and counter flow heat exchanger. The apparatus consists of a coaxial tube heat exchanger. Hot water flows through inner tube in one direction only and cold water flows by the outer tubes. Direction of cold fluid flow can be changed from parallel or counter to hot water so that unit can be operated as parallel or else counter flow heat exchanger. In campus water system was used for the water flow which was regulated by two ball–type valves. The Troubleshooting techniques of Parallel and Counter flow heat exchanger involves the ruptures and leakages of inner and outer tubes due to stress concentration in the tubes, loosened and broken thermocouple connections, alignment of the experimental setup, divulging of cauldron systems, malfunction of electric heater and errors in measuring instruments. In this paper we found that counter flow was efficient than parallel flow.*

Key Words: Parallel flow, Counter flow, Heat exchanger, concentric tube, Troubleshooting, Calibration, LMTD, Heat transfer coefficient, efficiency.

I. INTRODUCTION

Heat exchangers are one of the mostly used equipment in the process industries. Heat exchangers are used to transfer heat between two process streams. One can realize their usage that any process which involve cooling, heating, condensation, boiling or evaporation will require a heat exchanger for these purposes. Process fluids, usually are heated or cooled before the process or undergo a phase change. Different heat exchangers are named according to their application. For example, heat exchangers being used to condense is known as condensers, similarly heat exchanger for boiling purposes are called boilers. Performance and efficiency of heat exchangers are measured through the amount of heat transfer using least area of heat transfer and pressure drop. A better presentation of its efficiency is done by calculating over all heat transfer coefficient. Pressure drop and area required for a certain amount of heat transfer, provides an insight about the capital cost and power requirements (Running cost) of a heat exchanger. Usually, there is lots of literature and theories to design a heat exchanger according to the requirements. We are calibrating the overall efficiency and LMTD of concentric tube heat exchanger for parallel and counter flow in this paper

II. LITERATURE REVIEW

Akshaykumar Magadum et. Al. [1] experimentally investigated tube in tube HE with parallel and counter flow arrangements. Heat transfer rate found more nearly by 30% in counter flow compared to parallel flow. The results plotted on graph for LMTD v/s discharge and LMTD v/s efficiency for both parallel and counter flow. Conclusion of their work is as LMTD increases discharge and efficiency increases.

Swapnil Ahire et. al. [2] constructed and analyzed counter flow helical coil HE. Helical coil shape is given to tubes. To determine overall heat transfer coefficient, Wilson plot technique was used. They found that centrifugal force due to curvature of tubes results in secondary flow development, this secondary flow enhances heat transfer rate. For low Reynolds number graph of Nu v/s Re and hi v/s Re is steeper than that of high Reynolds number. Conclusion of their work is helical coils are efficient in low Reynolds number.

III. METHODOLOGY

In this project of parallel and counter flow heat exchanger the hot fluid always flows through the inner tube whereas the direction of flow of fluid of the outer fluid can be changed according to the requirements which may be either parallel flow or counter flow. The direction of the fluid flow which in this case is water is maintained with the help of ball valves mounted in the fluid system. The outer tube is thermally insulated to minimize the heat losses during the conduction experiment.

This entire project revolves around the measurement of the temperatures of various sections of the setup such as all the inlet and outlet temperatures of inner and outer tubes which is measured with the help of Temperature indicators by the aid of thermocouples, the temperature indication system is operated with the help of electrical supply which is regulated with an On/Off switch mounted on the device.

An electric heater containing two nichrome wires is also used in the project for the heating of the operating fluid before passing it through the inner tube of the concentric tube. The Nichrome wire is used as it can withstand much higher temperatures than required by the operation for unfortunate cases of human and system errors. To minimize oxidation of the equipment's due to prolonged utilization of the system under all practical situations GI (Galvanized Iron) is used as the material of construction.
(a)Electric heater: In this experiment the Nichrome wire electric heater is used. The heater is made up of an alloy of nickel and chrome which is in figure.1. The temperature window is 0^0C to 199^0C.

(b)Thermocouples: The thermocouples are made up of materials like copper which have highest conductivity of heat. They are used for measurement of temperature throughout the experimental setup. The Figure.2 shows a thermocouple.

Figure.1. Electric heater

Figure.2. Thermocouple

(c)Connections:
The experimental setup requires water connections, electrical connections and thermocouple connections.
(1). Water connections
The water connections were given through the main supply of the college premises. The setup of water connections includes PVC pipes and joints, two ball valves with their connectors, rubber pipes, etc.,

Figure.3. PVC pipe.

Figure.4. PVC. T – Joint

Figure.5. PVC Elbow Joint

Figure.6. Two-way Connector

Figure.7. Rubber Pipe

Figure.8. Ball Valve

(2) Thermocouple Connections:
The thermocouple connections are made to detect the temperatures of various parts of the heat exchanger.

- T_1 – Cold water outlet thermocouple.
- T_2 – Hot water inlet thermocouple.
- T_3 – Hot water outlet thermocouple.
- T_4 – Cold water inlet thermocouple.
- T_5 – Geyser Thermocouple

(3) Electrical Connections: The necessary electrical connections have to be made such as temperature indicator device and Nichrome heater.

(d)Temperature Indicator: The temperature indicator is used to convert the thermal temperature of required areas into displayable form. The thermocouples act as a connection between all the parts of the experimental setup and the temperature indicator. The thermocouple's wires are attached to the indicator such that all the connections can be easily identified while the performance of the experimental operations on the experimental setup. Thus the working of this temperature indicator is very crucial for this experimental setup failing which may result in errors and also no temperature of certain thermocouples.

(e)Concentric Tube: The tube is the main part of this experiment in which the heat exchanging process is carried out. The concentric tube works for both parallel flow and counter flow of the working fluid. The working fluid in this experiment is water.

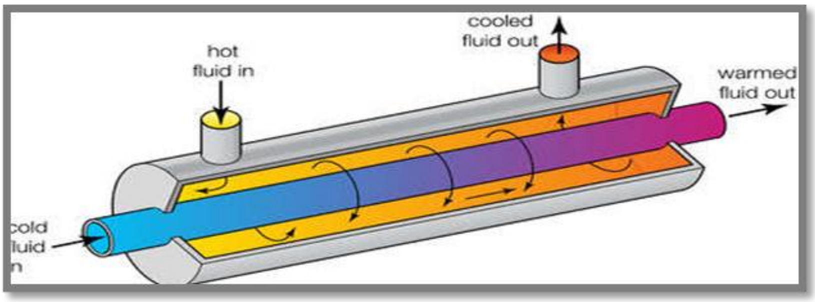

Figure.9. Temperature Indicator Figure.10. Concentric Tube Sectional View

Below are the flow arrangements of the parallel flow and counter flow heat exchanger in the Figure [11] and Figure [12] respectively.

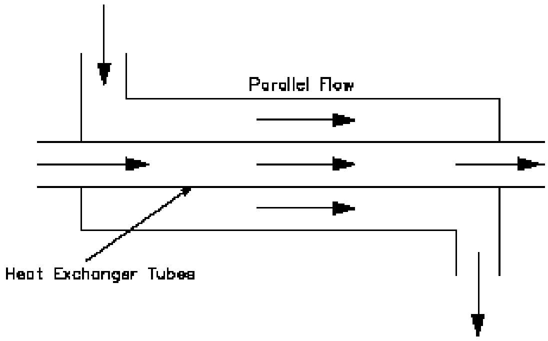

Figure.11.Parallel flow

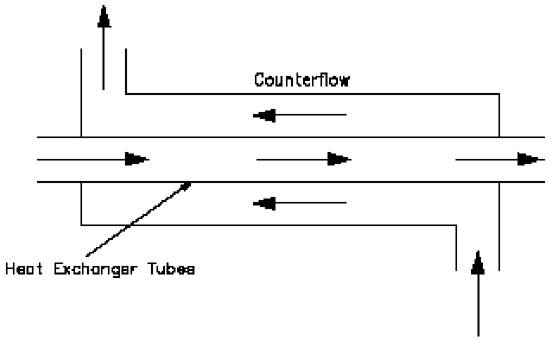

Figure – 12: Counter flow

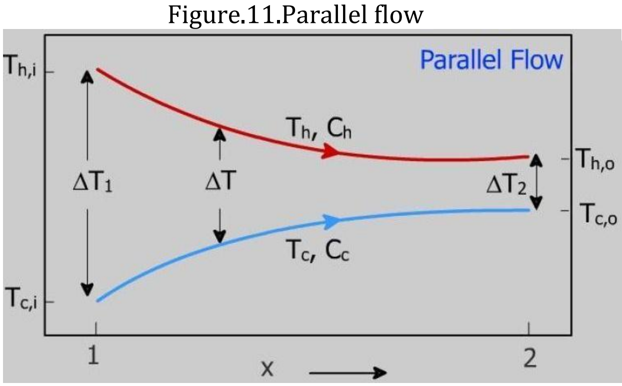

Figure.13.TS – Diagram for parallel flow

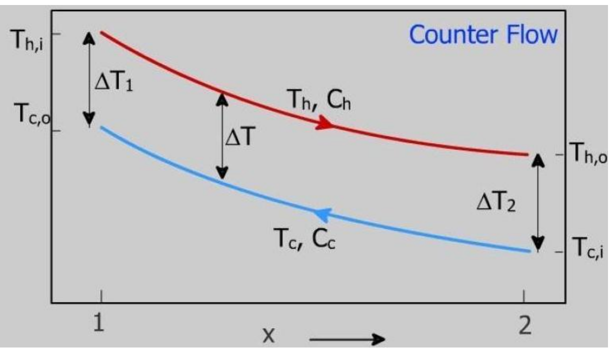

Figure.14.TS – Diagram for counter flow

The figure [13] and figure [14] portrays the graphs plotted for the parallel flow and counter flow heat exchangers where we can observe the differences of temperatures and entropies of both the flows at their respective inlets and outlets during the fluid flow.

IV. PROCEDURE

(a)Experimental Analysis:

1. Start the water supply and adjust the water supply on hot and cold sides so the arrangement is parallel flow.
2. Switch 'ON' the Geyser, temperature starts rising. After few minutes note down the readings.
3. Repeat the experiment by changing the flow by interchanging connections i.e, counter flow.
4. After few minutes note down the readings
5. After repeating the experiment 3 times for both parallel and counter flow calculate the results

(b)Calculations and Results

FORMULAS:

1. For parallel flow heat exchanger

i) Heat Transfer rate, is calculated as

q_h = Heat transfer rate from hot water

= $m_h C_{ph} (T_{hi} - T_{ho})$ Kcal/hr.

q_c = Heat Transfer rate to the cold water

= $M_h C_{pc} (T_{co} - T_{ci})$ Kcal/hr.

Q = (($q_h + q_c$) / 2) Kcal/hr.

Assume $C_{ph} = C_{pc}$ =1Kcal/kg.°C

ii) L M T D = LMTD (Logarithmic Mean Temperature Difference) which can be calculated as per the formulae.

$$\Delta Tm = \left(\frac{\Delta T_i - \Delta T_o}{\ln(\Delta T_i/\Delta T_o)}\right) = \left(\frac{(T_{hi} - T_{ci}) - (T_{ho} - T_{co})}{2.3\log[(T_{hi} - T_{ci})/(T_{ho} - T_{co})]}\right)$$

____Eqn.1

Where, $\Delta T_i = T_{hi} - T_{ci}$ (for parallel flow)

= $T_{hi} - T_{co}$(for counter flow)

NOTE that in special case of counter flow exchanger exists when the capacity rates C_c and C_h are equal, then $T_{hi} - T_{co} = T_{ho} - T_{ci}$ thereby making $DT_i = \Delta T_o$. In this case LMTD is of the form 0/0 and so unidentified. But it is obvious that since ΔT is constant throughout the exchanger, hence

$\Delta T_m = \Delta T_i = \Delta T_o$

(according to ref. Fundamental of Engineering Heat and Mass Transfer by R.C. Sachdeva Pg.499)

iii) Overall heat transfer coefficient can be calculated by using

$Q = UA\,\Delta T_m$ ___Eqn.2

∴ $U = q/A\,\Delta T_m$ K cal/hr. m²- °C

Calculated U_h based on $A_i = \pi d_i L$

U_{ro} based on $A_o = \pi d_o L$

$U = (U_{ri} + U_{ro} / 2)$ ____Eqn.3

iv) Compare the values of ΔT_m and q in the parallel flow and counter flow runs. Note that if experiment is conducted very carefully then the superiority of counter flow arrangements in the terms of higher values of T_m and excess value q for same flow rates conduction can be revealed.

(a).1. Calculations:

Parallel flow:

Where,

T_{hi} = Temperature of hot water input, 62°C

T_{ho} = Temperature of hot water output, 48°C (for parallel flow), 44°C (for counter flow)

T_{ci} = Temperature of cold-water input, 28°C

T_{co} = Temperature of cold water output, 40°C (for parallel flow), 37°C(for counter flow)

Inner tube material= I.D. 15mm

Outer tube material= I.D 28mm

Length of heat exchanger= L= 1.2m

Area of inner tube $A_i = \pi d_i L$ = 3.14 x 0.015 x 1 = 0.0471

Area of outer tube $A_o = \pi d_o L$ = 3.14 x 0.025 x 1 = 0.0785

M_h hot water flow rate = 1000 / 24 = 41.67

M_c cold water flow rate = 1000 / 20 = 50

Assume $C_{ph} = C_{pc}$ = 1 Kcal/kg.°C

1. Heat transfer rate:

Q_h = Heat transfer rate from hot water.

$= m_h C_{ph} (T_{hi} - T_{ho})$ Kcal/hr.
$= 41.67 \times 1 \times (62 - 48) = 583.38$ Kcal/hr.
Q_c = Heat transfer rate to the cold water.
$= M_c C_{pc} (T_{co} - T_{ci})$ Kcal/hr.
$= 50 \times 1 \times (40 - 28) = 600$ Kcal/hr

$Q = (q_h+q_c) / 2$ Kcal/hr. = (583.38+600) / 2 = 591.70
Q = 591.70 Kcal/hr.

2. LMTD – Logarithmic Mean Temperature Difference which can be calculated as per the following Formula:

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

Where, $\Delta T_i = T_{hi} - T_{ci}$ (for parallel flow)
= 62 – 28=34
$\Delta T_o = T_{ho} - T_{co}$ (for parallel flow)

= 48 – 40=8
$\Delta T_m = \Delta T_i = \Delta T_o$

3. Overall heat transfer coefficient can be calculated by using
$Q = UA \Delta T_m$
∴ $U = q/A \Delta T_m$ Kcal/hr.m^2 – ^{o}C

Calculated U_{ri} based on A_i=0.0471
U_{ro} based on A_o=0.078
U_{ri} = (591.70 / 0.0471) x 34 = 427129
U_{ro} = (600 / 0.0785) x 8 = 61146
$U = (U_{ri}+U_{ro}) / 2$ =
U = (427129 + 61146) / 2 = 244138

U = 244138

Counter flow:

1. Heat transfer rate:

Q_h = heat transfer rate from hot water
$= m_h C_{ph} (T_{hi} - T_{ho})$ Kcal/hr.
$= 41.67 \times 1 \times (62 - 44) = 750$ Kcal/hr.
Q_c = heat transfer rate to cold water
$= M_c C_{pc} (T_{co} - T_{ci})$ Kcal/hr.
$= 50 \times 1 \times (37 - 28) = 450$ Kcal/hr
$Q = (q_h + q_c) / 2$ Kcal/hr. = (750 + 450) / 2 = 600
Q = 600 Kcal /hr

2. LMTD – Logarithmic Mean Temperature Difference which can be calculated as per the following Formula:

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

Where, $\Delta T_i = T_{hi} - T_{ci}$ (for counter flow)
= 62 – 37=25
$\Delta T_o = T_{ho} - T_{co}$ (for counter flow)
= 44 – 28=16

3. Overall heat transfer coefficient can be calculated by using
$Q = UA \Delta T_m$
∴ $U = q/A \Delta T_m$ Kcal/hr.m^2 – ^{o}C

Calculated U_{ri} based on A_i = 0.0471

U_{ro} based on A_o = 0.078

U_{ri} = (591.70/0.0471) x 34 = 427129

U_{ro} = 600 / 0.0785 x 8 = 61146

U = U_{ri}+U_{ro} / 2 =___________

U = 427129 + 61146 / 2 = 244138

U = 244138

By calculating the averages of the observed data in the tabular columns we have calculated the results for the experiment.

TABLE.1. Parallel Flow:

S.No	Hot water side			Cold water side		
	Flow rate M_h kg/hr	***T_{hi}°C***	***T_{ho}°C***	***Flow rate M_c kg/hr***	***T_{ci}°C***	***T_{co}°C***
1.	41.67	62	48	50	28	40
2.	40.55	61	49	48	27	39
3.	42.79	63	47	52	29	41
Average	41.67	62	48	50	28	40

TABLE.2. Counter Flow:

S.No	Hot water side			Cold water side		
	Flow rate M_h kg/hr	***T_{hi}°C***	***T_{ho}°C***	***Flow rate M_c kg/hr***	***T_{ci}°C***	***T_{co}°C***
1.	41.67	62	44	50	28	37
2.	40.55	61	40	48	27	38
3.	42.79	63	48	52	29	36
Average	41.67	62	44	50	28	37

Table.3. Result

Sl. No	Parallel Flow		Counter Flow	
	Q= Kcal/hr	***U= w/m² °C***	***Q= Kcal/hr***	***U=w/m² °C***
1.	591.70	244138	600	244138

V. Conclusion

The conclusion of the experimental analysis of the parallel flow and counter flow heat exchanger is that the LMTD of the counter flow heat exchanger is more when compared to parallel flow. The efficiency of counter flow heat exchanger is more when calibrated precisely. The overall heat transfer rate of the counter flow is greater when compared to the parallel flow. Hence, we concluded to the result that the counter flow heat exchanger performance is greater than the parallel flow heat exchanger among all the calibrated data.

VI. References

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