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Experimental Analysis of Double Pipe Heat Exchanger

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***Abstract* - A heat exchanger is a mechanical device used to exchange heat between different fluids. The fluids may be separated by some kind of solid wall to stop mixing or they may be in direct contact. Heat Exchangers are widely used in space heating, refrigeration, air conditioning, power stations, chemical plants, petrochemical plants, petroleum refineries, natural-gas processing, and sewage treatment.The design of double pipe heat exchanger for the laboratory used is aim to carry out the design of heat exchanger. The heat exchanger is aimed to manufacture and to prepare an experimental setup by means of this setup one can perform a practical work to understand concept of heat exchanger. Mild steel pipes are used for preparation of setup in both pipes. The effectiveness of this setup would be targeted between 10 to 20% as the losses and human errors are concerned.**

***Index Terms* – Heat exchanger, counter flow, effectiveness, heat transfer co-efficient.**

I. INTRODUCTION

An equipment which transfers energy from hot fluid to cold fluids with maximum rate and minimum investment & running cost. A heat exchanger is a device that is used to transfer thermal energy (enthalpy) between two or more fluids, between a solid surface and a fluid, or between solid particulates and a fluid, at different temperatures and in thermal contact. In heat exchangers, there are usually no external heat and work interactions. Typical applications involve heating or cooling of a fluid stream of concern and evaporation or condensation of single- or multicomponent fluid streams. In other applications, the objective may be to recover or reject heat, or sterilize, pasteurize, fractionate, distil, concentrate, crystallize, or control a process fluid. In a few heat exchangers, the fluids exchanging heat are in direct contact. In most heat exchangers, heat transfer between fluids takes place through a separating wall or into and out of a wall in a transient manner.

II. TYPES OF HEAT EXCHANGERS:

1. Nature of heat exchange process
   a. Direct Contact Heat Exchanger
   b. Indirect Contact Heat Exchanger
      - Regenerators
      - Recuperators or Surface exchanger
2. Relative direction of Fluid motion
   a. Parallel flow or Unidirectional flow
   b. Counter flow
   c. Cross flow
3. Design and Constructional features
   a. Concentric Tubes
   b. Shell and Tube
   c. Multi-Shell and Tube
   d. Compact Heat exchanger
4. Physical State of fluids
   a. Condensers
   b. Evaporators

III. NATURE OF HEAT EXCHANGE PROCESS:

1. Direct Contact Heat Exchanger
   In direct contact or open heat exchanger the exchange of heat takes place by direct mixing of hot and cold fluids and transfer of heat and mass takes place simultaneously.
2. Indirect Contact Heat Exchanger
   In this type of heat exchanger, the heat transfer between two fluids could be carried out by transmission through wall which separates the two fluids.

IV. Relative direction of fluid motion

1. Parallel Flow or Unidirectional Flow
   In a parallel flow heat exchanger, as the name suggests, the two fluid streams (hot and cold) travel in the same direction. The two streams enter at one end and leave at the other end.
2. Counter Flow
   In Counter flow heat exchanger, the two fluids flow in opposite directions. The hot and cold fluids enter at the opposite ends.
3. Cross-Flow Heat Exchanger
   In cross-flow heat exchangers, the two fluids (hot and cold) cross one another in space, usually at right angles.

V. Design and Constructional Features

1. Concentric tubes
   In this type, two concentric tubes are used, each carrying one of the fluids. The direction of flow may be parallel or counter. The effectiveness of the heat exchanger is increased by using swirling flow.
2. Shell and tube
   In this type of heat exchanger one of the fluids flows through a bundle of tubes enclosed by a shell. The other fluid is forced through the shell and it flows over the outside surface of the tubes. Such an arrangement is employed where reliability and heat transfer effectiveness are important.
3. Multiple Shell and tube
   Multiple shell and tube passes are used for enhancing the overall heat transfer. Multiple shell pass is possible where the fluid flowing through the shell is re-routed. The shell side fluid is forced to flow back and forth across the tubes by baffles. Multiple tube pass exchangers are those which re-route the fluid through tubes in the opposite direction.
4. Compact heat exchanger
   There are special purpose heat exchanger and have a very large transfer surface area per unit volume of the exchanger. They are generally employed when convective heat transfers co-efficient associated with one of the fluids is much smaller than that associated with the other fluid.

VI. Construction and Working of Double Pipe Heat exchanger

The heat exchanger consists of two thin wall mild steel tubes mounted concentrically on a panel. The flow of water through the center tube can be reversed for either counter current flow. The hot water flows through the center tube, and cold water flows in the annular region. Valves are used to set up desired flow conditions (rate and direction). Set the hot water valve in the correct position to achieve either counter current flow.

Set up configuration is stated below:

1. Water Heater = 3000W, 230V
2. Pipes = Mild steel, 1 inch inner pipe diameter, 2.5 inch outer pipe diameter, Length of 3 meters of effective
3. Thermocouples = 4 nos, PT100 type
4. Support base = mild steel channel

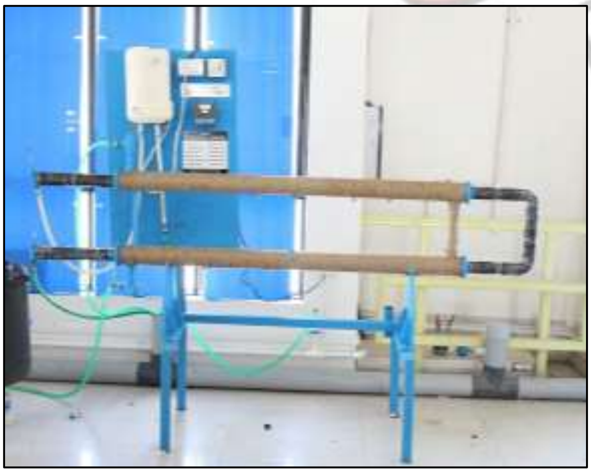

Fig. 1: set up of double pipe heat exchanger

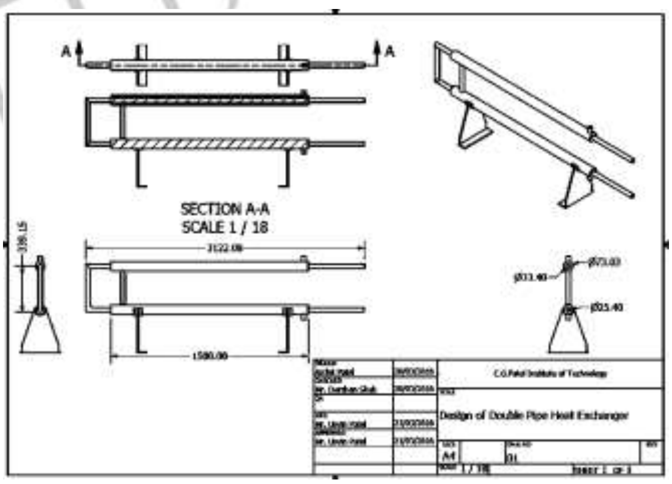

Fig. 2: Dimensional layout of double pipe heat exchanger

VII. DESIGN AND DEVELOPMENT OF SETUP [5]

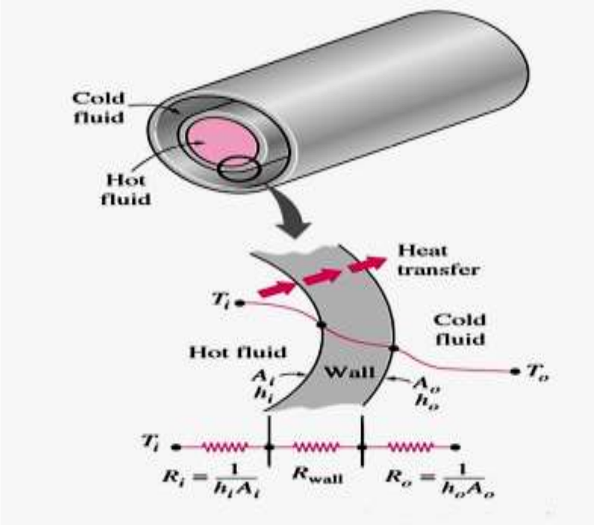

Fig. 3: Thermal resistance network associated with heat transfer in a double pipe heat exchanger[4]

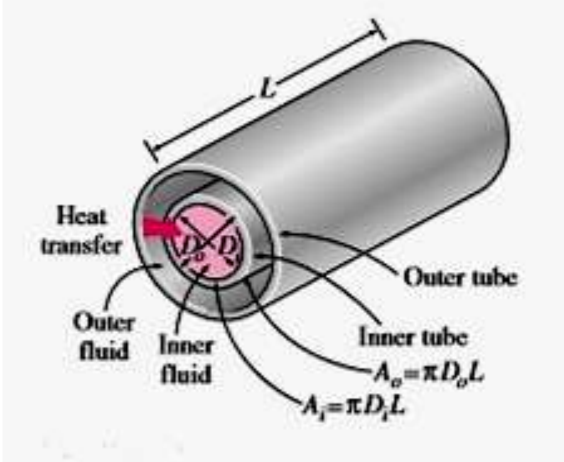

Fig. 4: Heat transfer surface areas associated with a double pipe heat exchanger[4]

Any radiation effects are usually included in the convection heat transfer coefficients. The thermal resistance network associated with this heat transfer process involves two convections and one conduction resistances, as shown in Figure. Here the subscripts I and o represent the inner and outer surfaces of the inner tube. For a double-pipe heat exchanger, we have $Ai = \pi D_i L$ and $A_o = \pi D_o L$, and the thermal resistance of the tube wall in this case is

$$R_{wall} = \frac{ln\frac{D_o}{D_i}}{2\pi kL}$$

Where k is the thermal conductivity of the wall material and L is the length of the tube. Then the total thermal resistance becomes

$$R - R_{total} - R_i + R_{wall} + R_o = \frac{1}{h_i * A_i} + \frac{ln\frac{D_o}{D_i}}{2\pi kL} + \frac{1}{h_o * A_o}$$

A_i is the area of the inner surface of the wall that separates the two fluids, and A_o is the area of the outer surface of the wall. In other words, A_i and A_o are surface areas of the separating wall wetted by the inner and the outer fluids, respectively. When one fluid flows inside a circular tube and the other outside of it, we have $A_i = \pi D_i L$ and $A_o = \pi D_o L$. In the analysis of heat exchangers, it is convenient to combine all the thermal resistances in the path of heat flow from the hot fluid to the cold one into a single resistance R, and to express the rate of heat transfer between the two fluids as

$$Q = \frac{\Delta T}{R} = UA\Delta T = U_i A_i \Delta T = U_o A_o \Delta T$$

Where, U is the overall heat transfer coefficient, whose unit is W/m^2.°C, which is identical to the unit of the ordinary convection coefficient h. Cancelling ΔT, Equation reduces to

$$\frac{1}{UA_s} = \frac{1}{U_i A_i} = \frac{1}{U_o A_o} = R = \frac{1}{h_i A_i} + R_{wall} + \frac{1}{h_o A_o}$$

Perhaps you are wondering why we have two overall heat transfer coefficients U_i and U_i for a heat exchanger. The reason is that every heat exchanger has two heat transfer surface areas A_i and A_o, which, in general, are not equal to each other.

Note that $U_i A_i = U_o A_o$, but $U_i \neq U_o$ unless $A_i = A_o$. Therefore, the overall heat transfer coefficient U of a heat exchanger is meaningless unless the area on which it is based is specified. This is especially the case when one side of the tube wall is finned and the other side is not, since the surface area of the finned side is several times that of the unfinned side.

When the wall thickness of the tube is small and the thermal conductivity of the tube material is high, as is usually the case, the thermal resistance of the tube is negligible (($R_{wall} \approx 0$) and the inner and outer surfaces of the tube are almost identical ($A_i \approx A_o \approx A_s$). Then equation for the overall heat transfer coefficient simplifies to

$$\frac{1}{U} \approx \frac{1}{h_i} + \frac{1}{h_o}$$

Where $U \approx U_i \approx U_o$. The individual convection heat transfer coefficients inside and outside the tube, hi and ho, are determined using the convection relations.

Logarithmic Mean Temperature Difference:

The temperature difference between the hot and cold fluids varies along the heat exchanger, and it is convenient to have a mean temperature difference ΔT_m for use in the relation $Q = UA_s \Delta T_m$.

In order to develop a relation for the equivalent average temperature difference between the two fluids, consider the parallel-flow double-pipe heat exchanger shown in Figure. Note that the temperature difference ΔT between the hot and cold fluids is large at the inlet of the heat exchanger but decreases exponentially toward the outlet. As you would expect, the temperature of the hot fluid decreases and the temperature of the cold fluid increases along the heat exchanger, but the temperature of the cold fluid can never exceed that of the hot fluid no matter how long the heat exchanger is. Assuming the outer surface of the heat exchanger to be well insulated so that any heat transfer occurs between the two fluids, and disregarding any changes in kinetic and potential energy, an energy balance on each fluid in a differential section of the heat exchanger can be expressed as

$$\delta Q = -m_h C_{ph} dT_h$$

and

$$\delta Q = m_c C_{pc} dT_c$$

That is, the rate of heat loss from the hot fluid at any section of a heat exchanger is equal to the rate of heat gain by the cold fluid in that section. The temperature change of the hot fluid is a negative quantity, and so a negative sign is added to equation to make the heat transfer rate, a positive quantity. Solving the equations above for dT_h and dT_c gives

$$dT_h = -\frac{\delta Q}{m_h C_{ph}}$$

$$dT_c = -\frac{\delta Q}{m_c C_{pc}}$$

Taking their difference, we get

$$dT_h - dT_c = d(T_h - T_c) = -\delta Q(\frac{1}{m_h C_{ph}} + \frac{1}{m_c C_{pc}})$$

The rate of heat transfer in the differential section of the heat exchanger can also be expressed as

$$\delta Q = U(T_h - T_c)dA_s$$

Substituting this equation into Equation and rearranging gives

$$\frac{d(T_h - T_c)}{T_h - T_c} = -UdA_s(\frac{1}{m_h C_{ph}} + \frac{1}{m_c C_{pc}})$$

Integrating from the inlet of the heat exchanger to its outlet, we obtain

$$\text{Ln}\,\frac{T_{ho} - T_{co}}{T_{hi} - T_{ci}} = -UA_s(\frac{1}{m_h C_{ph}} + \frac{1}{m_c C_{pc}})$$

Finally, solving Equations for $m_c C_{pc}$ and $m_h C_{ph}$ and substituting into Equation gives, after some rearrangement,

$$Q = UA_s \Delta T_{lm}$$

Where,

$$\Delta T_{lm} = \frac{\Delta T_1 - \Delta T_2}{\ln(\frac{\Delta T_1}{\Delta T_2})}$$

VIII. RESULTS

From the experimental setup of heat exchanger, following results (stated in the table) are achieved. Around 12.6% effectiveness from Number of Transfer Unit (NTU) method. And with the Mild Steel as the base material have achieved Ideal effectiveness of 32.143%. The result of different readings noted down is as below:

Table. 1: Results

	Temperature				Time		Mass Flow Rate							
Sr. no.	T_{h1}	T_{h2}	T_{c1}	T_{c2}	t_h	t_c	m_h	m_c	NTU	% ε	h_i	h_o	U_f	ΔT_m
	˚C	˚C	˚C	˚C	sec	sec	Kg/Sec	Kg/Sec			W/m^2*K	W/m^2*K	W/m^2*K	˚C
1	50	44.6	33.2	35.1	21	6	0.05	0.17	0.14	12.60	746.44	166.57	113.96	13.07
2	59.8	50.8	35.5	46.2	29.89	33.73	0.03	0.03	0.08	7.83	593.29	50.87	43.70	14.43
3	60.5	50.8	36.4	44.3	41.05	29.72	0.02	0.03	0.11	9.89	490.16	55.35	45.95	15.28
4	53.9	48.7	35.5	40.5	16.33	22.33	0.06	0.04	0.07	6.72	950.72	64.23	55.67	13.30
5	54.7	49.1	35.5	41.4	16.33	22.33	0.06	0.04	0.07	6.86	957.30	65.91	56.96	13.45
6	64.6	52.4	35.7	44.3	33.57	26.15	0.03	0.04	0.10	8.94	589.42	60.38	50.50	18.44
7	59.8	48.2	33.5	39.4	38	20	0.03	0.05	0.12	11.03	509.67	69.01	55.31	17.39
8	61.1	50.9	33.5	40.3	38	20	0.03	0.05	0.12	11.13	521.94	69.57	55.86	19.05
9	60.8	52.6	37.4	48	26.72	40.66	0.04	0.02	0.09	8.73	688.05	45.73	40.34	13.97
10	61.6	49.3	33.7	37.1	35.83	20.94	0.03	0.05	0.11	10.11	542.01	65.62	53.54	19.72
11	48.8	44.6	33.8	37.8	18.87	13.45	0.05	0.07	0.08	7.48	801.46	91.85	73.86	10.90
12	54.6	48.4	34.2	39.6	27.11	16.99	0.04	0.06	0.10	9.11	642.38	78.52	63.32	14.60
13	46.4	44.9	36.4	41.5	12.6	46.18	0.08	0.02	0.10	9.08	1087.81	39.62	36.41	6.54
14	66.5	50.1	36.5	42.4	18.33	40.09	0.05	0.02	0.09	8.59	937.64	44.09	39.85	18.35
15	60.1	50.4	36.7	43.3	34.29	31.93	0.03	0.03	0.09	8.06	559.41	52.31	44.49	15.20

IX. CONCLUSION

It is concluded that the more heat transfer surface is kept in the heat exchanger the more effectiveness is achieved. Optimization of heat loss can be done by applying more thick and effective for reducing the heat loss to the atmosphere. The effectiveness of 12.6% is achieved in the experimental setup. If the losses are taken in a serious concerned then the effectiveness can be increased optimistically.

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