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Experimental Study of Heat Transfer in Conical Tube Heat Exchanger

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Abstract

In present experimental analysis, the outer cylindrical tube of the ordinary concentric tube type heat exchanger was replaced by conical tube. New conical tubes of different diameter ratios have been developed by using epoxy resin and glass fiber. Diameter ratios of conical tubes were 0.882, 0.741, and 0.612. Experiments were carried out for conical tube heat exchanger of length 1 meter. The flow rate of water for inner tube considered 1LPM and for outer conical tube 1 LPM to 7 LPM. The heat transfer results of conical tubes were analysed and compared with the results of cylindrical tubes. Results reveal that the rate of heat transfer is inversely proportional to diameter ratio. A correlation was developed for a HTR of water flowing through outer conical tubes. Results revealed a rise of heat transfer rate up to 22%.

Keywords: conical tube, heat transfer, regression analysis, heat exchanger

I. INTRODUCTION

Heat transfer equipment is required for the exchange and recapture of thermal energy in many commercial and household appliances. Few industrial applications i.e. heating and cooling of dairy products, heat recovery system, processing of juice as well raw fruit in food industries, power plant's vapor condensation process, heat transfer processes involved in chemical and pharmaceutical companies, Liquid heating in the concentrated solar collector and cooling of electronic devices and electrical equipment among others. Therefore, to ensure the economy of cost & energy, efficient functioning of heat transfer equipment is of prime interest.

Thermal resistance is inversely proportional to effective surface area & turbulence of fluid. Majority of heat transfer improvement methods focuses on reducing thermal resistance by using fins/rough surfaces for improving effective surface area & inserts, winglets, etc. for ensuring turbulence within the fluid.[1].

The heat transfer enhanced significantly when coil-wire was inserted in the inner tube. Naphon[2] observed that the coil-wire performed better, especially for the laminar region. Eiamsa-ard et al. [3] experimentally analyzed the heat transfer properties in heat exchanger having concentric tube arrangement equipped with twisted tape which are regularly spaced. Their results revealed that rise of the heat transfer co-efficient is directly proportional to twist ratio. Selvam et al.[4]conducted experiment having turbulator like Wire coiled-matrix used as an insert in the tube - tube heat exchanger. Their study revealed that a reduction in the pitch has a positive influence on the rate of heat transfer (HTR). Eiamsa-ard et al.[5] experimentally examined the HTR by commissioning louvered strips inside the double tube heat exchanger. Experimental results revealed that the application of inclined forward louvered strip rises the HTR by 2.84 to 4.13 times. Pourahmad and Pesteei [6]conducted experiments on the concentric tube heat exchanger in which wavy strips have been inserted at various angles to rise the HTR. It has been perceived that the performance of the heat exchanger improves with strip angle. Murugesan et al. [7]analyzed twisted tape with a trapezoidal cut on the periphery and observed the characteristics of heat transfer. From the results conclusion has made that, the HTR increase from 1.2 to 2 times for different configuration of twisted tape.

Shirvan et al.[8]analyzed the effectiveness of double-tube heat exchanger by mathematical model. They used nanofluid to enhance heat transfer and Response Surface Methodology to sensitivity analysis. Sheikholeslami et al. [9] conducted experiments to confirmed the outcome in terms of the HTR with use of discontinuous helical turbulators in tube-tube heat exchanger. Typical and perforated helical turbulators placed on the annulus side of the tube to enhance the HTR. Li et al.[10] studied the effectiveness of double tube heat exchanger in which helical fins were attached on the shell side along with vortex generators. Their results revealed that the compound technique has better performance than the shell side only attached with helical fins. Webnin et al. [11] introduced the small pipe insert placed consecutively in a concentric tube heat exchanger. The result of the experiments revealed that the HTR enhanced by 2.09-2.67 times with pipe inserts. Dizaji et al.[12] used a corrugated outer tube instead of a straight cylindrical tube. The experiments were conducted with Reynold number ranging from 3500 to 18000 and results reveals that maximum effectiveness obtains with outer tube as concave corrugated and inner tube having convex corrugated shape. Heat transfer rates in a double tube heat exchanger equipped with wire coil inserts in annulus space have been analyzed by Zohir et al.[13]. They investigated the influence

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of pulsating flow of fluid with different amplitude on the HTR and finding shows that the pitch of the coil is positively affects the HTR. Sheikholeslami & Ganji[14] formulated mathematical model of the HTR in double tube heat exchanger having use of perforated turbulator and finding supported with experiment. Their finding shows noteworthy improvement in the HTR by placing perforated turbulators as a ring on the inner pipe. Maakoul et al.[15]investigated the HTR in the heat exchanger having continuous helical baffles in the annulus side by mathematically and 3-D CFD analysis using FLUENT software. They observed that, a significant rise in the HTR of fluid with helical baffles and heat transfer coefficient increases with decrease in baffle spacing. Durmus et al.[16] used snail entrance to generate turbulence in outer annulus of the concentric tube heat exchanger. They used snails of different swirling angle and observed 120 % rise with 45° swirling angle.

In the concentric tube heat exchanger, inner and outer tubes both are cylindrical. However, in this experimental analysis, the outer cylindrical tube was replaced by conical tube and focus was made on the analysis of the HTR in the outer conical tube of a concentric tube heat exchanger.

II. EXPERIMENTAL SETUP:

The representation diagram of the experimental flow process is shown in Figure 1. Set-up having two concentric tubes, in which cold fluid (water) flows through the annulus side and hot water flows through the inner tube. The inner tube was cylindrical, made from copper. Copper is used as an inner tube material due to its high thermal conductance, which is even useful for higher the HTR between hot and cold fluid. The inner diameter of the copper tube is 35 mm and the outer diameter is 38 mm. Experiments were conducted for a length of 1 m span. Hot water moves through inner tube having 0.5 m of settlement zone at inlet of the pipe to reduce the effect of turbulence. Epoxy - Glass fiber was used as outer tube having conical shape. For better thermal resistance at the outer surface and to devise an irregular shape at the outer shell epoxy resin and glass fiber was used. To construct conical shell, a conical wooden part has been constructed which can be used as a core of conical shell. After constructing a core, a coating of glass fibre and epoxy resin has been made over a conical core. After setting period, core was removed to get conical shell. In conical shell, cold fluid moves from larger diameter to smaller diameter. The ratio of smaller outlet diameter to larger inlet diameter of conical shell represents as a diameter ratio. Three outer conical shells have been constructed considering diameter ratios as 0.882, 0.741 and 0.612. Figure 2 shows the circular tube and conical shell heat exchanger. Resistance temperature detectors (RTDs) were used to measure temperature. These RTDs are made with PT100 sensor for better accuracy. Temperature indicator is having indicating capacity 0.1 ° C. RTDs, are attached with wire of length 1.5 m. Two RTDs were mounted on the copper tube for measurement of the inside water temperature, one at the inlet of the tube and second at the outlet of the tube. In addition, two RTDs were fitted in the annulus of the test section to keep track of the temperature of outer water. The flow rate was measured by placing tanks at the outlet end of the tube in the experiment. Two centrifugal pumps attached with electric motor of capacity 0.5 hp were used for transfer of hot and cold water separately. A heater of rating 1 kw capacity was used for heating of water.

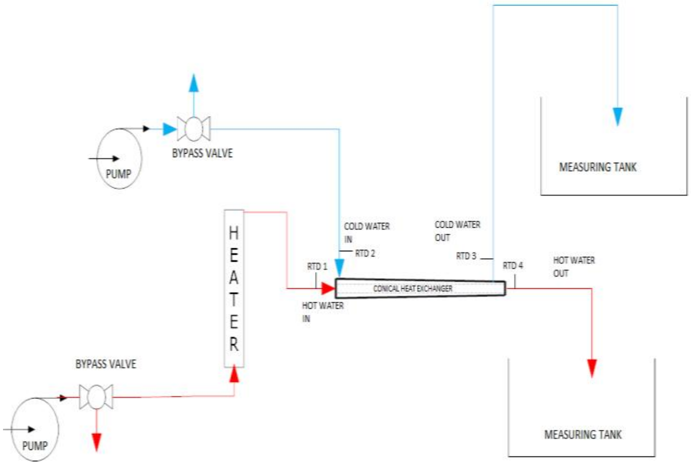

Fig. 1 Schematic line drawing of the experimental setup

The conical shape was introduced on the outer shell to increase the turbulence of water in annulus space. The hot water was made to flow constant at 1 LPM through an inner copper tube and cold water was set to flow varying from 1 LPM to 7 LPM through the annulus. Once the steady-state condition achieved, temperatures at the inlet and outlet of hot water and cold water were measured for all configuration of the cylindrical and conical outer tubes.

Fig. 2 Conical shell heat exchanger

III. DATA REDUCTION:

- Heat transfer from the hot fluid

  $Q = mC_p(\Delta T_h) = mC_p(T_{h,in} - T_{h,out})$

- Heat transfer to the cold fluid

  $Q = mC_p(\Delta T_c) = mC_p(T_{c,out} - T_{c,in})$

Logarithmic mean temperature difference

$\theta_1 = T_{h1} - T_{c2}$, $\theta_2 = T_{h2} - T_{c1}$

$$\Delta T_{lm} = LMTD = \frac{\theta_1 - \theta_2}{\ln\frac{\theta_1}{\theta_2}}$$

The overall heat transfer coefficient of the system

$$U = \frac{Q}{A.\Delta T_{lm}}$$

The percentage error of heat loss from hot water and heat gain by cold water was found out to be 1% to 7.8%, ensuring a minimum possible loss of heat to the atmosphere.

IV. EXPLORATORY RESULTS and DISCUSSION:

In the present study, heat transfer characteristics are investigated experimentally. Table 1 represents the Logarithmic Mean Temperature Difference of all the experiments performed in this investigation.

Table 1: Logarithmic Mean Temperature Difference

Flow rate	LMTD			
LPM	°C			
	1	0.882	0.741	0.612
1.00	28.75	27.80	23.35	21.33
1.50	28.93	28.93	24.17	22.87
2.00	29.49	28.04	27.08	23.16
2.50	28.96	27.40	26.59	22.26
3.00	29.94	27.48	24.70	22.78
3.50	29.17	29.13	26.47	23.08
4.00	28.55	27.20	25.00	23.48
4.50	29.54	28.84	24.47	23.79
5.00	29.26	26.95	25.66	23.56
6.00	28.32	27.30	25.86	24.23
7.00	28.49	28.31	26.13	23.79

Figure 3 shows the HTR at different configuration of diameter ratio with change in flow rate of fluid. Fig. 4 shows the overall heat transfer coefficient for same configurations and flow rates.

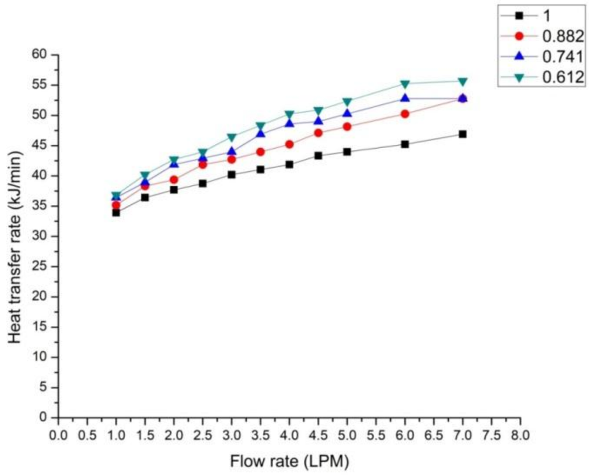

Figure 3: Rate of Heat transfer Vs flow rate

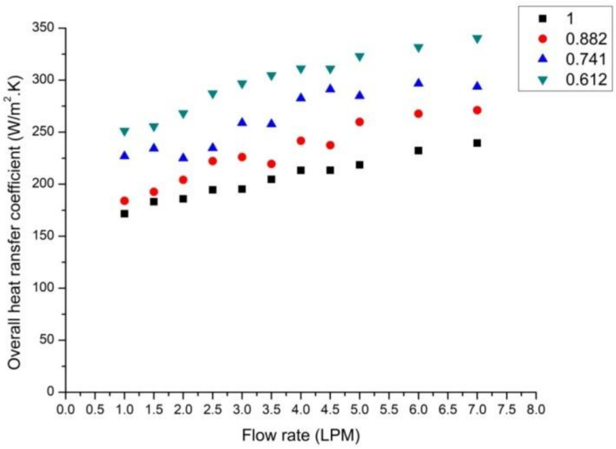

Figure 4: Overall heat transfer coefficient Vs. flow rate

The effects of the flow rate of fluid (water) and diameter ratio of the outer conical tube on heat transfer characteristics were examined. Figure 3 shows the HTR for flow rate ranging from 1 LPM to 7 LPM on outer annulus space. In this experiment, the analysis was done for flow through outer tubes having diameter ratio 1, 0.882, 0.741 and 0.612. The heat transfer rate for cylindrical shell (diameter ratio 1) heat exchanger varies from 33.91kJ/min at 1 LPM to 46.89 kJ/min at 7 LPM. Whereas the heat transfer rate in conical shell heat exchanger is: 35.17 kJ/min to 52.75 kJ/min for conical HE with diameter ratio 0.882, 36.42 kJ/min to 52.76 kJ/min for HE with diameter ratio 0.741 and 36.84 kJ/min to 55.68 kJ/min for HE with diameter ratio 0.612. Figure 4 shows the overall heat transfer coefficient. The overall heat transfer coefficient for heat exchanger having diameter ratio 1 varies with flow rate (1 LPM to 7 LPM) from 171.5 W/m2K to 239.34 W/m2K. It is for heat exchanger having diameter ratio 0.882, 0.741 and 0.612 was 183.9 W/m2K to 271 W/m2K, 226.8 W/m2K to 293 W/m2K and 251 W/m2K to 340.3 W/m2K respectively.

So, the overall heat transfer coefficient rises up to 12 % in conical shape heat exchanger having diameter ratio of 0.882 compared to cylindrical heat exchanger. Same as overall heat transfer coefficient rises up to 16 % and 22 % in conical shape heat exchanger having diameter ratio 0.741 and 0.612 respectively. From the experimental results, it has been observed that the HTR and the overall heat transfer coefficient improves with the rise in flow rate. It has also been observed that the HTR and the overall heat transfer coefficient increase with the decrease in diameter ratio. Improvement in heat transfer characteristics in conical outer geometry is due to turbulence generated when water passes through the taper section. It happens due to the continuous increase in Re Number along the length. Increases of Re Number along the length ultimately improve the HTR and performance of heat exchanger.

In this research, regression analysis was carried out considering R-square value, which shows the closeness with experimental results. The linear regression model was developed using Minitab software for the HTE in the conical shell heat exchanger. R-square value of regression model is 94.02%. Equation of the HTR in the form of flow rate and diameter ratio was developed. The data of the HTR were fitted by following empirical correlation.

$$Q = 48.20 + 2.705(m) - 16.64\,(d_o/d_i)$$

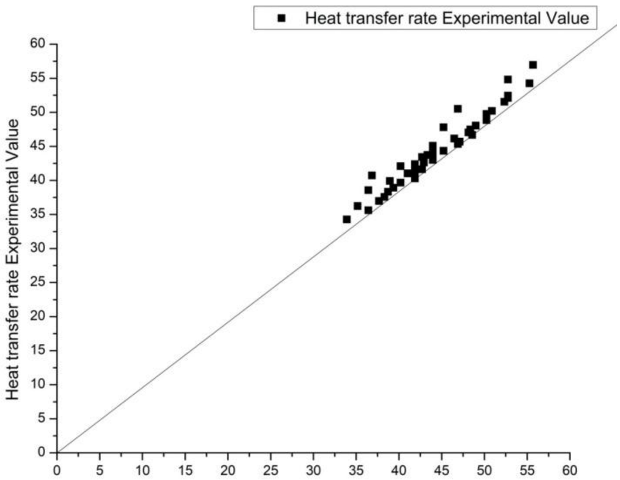

Figure 5: Predicted Vs. experimental results

Fig 5 represents the comparison between fitted values of the HTR and experimental data. From the figure, it has been concluded that the predicted results are in good agreement with experimental results. The similarity between fitted and experimental values is very well, within a range of ± 7%.

V. CONCLUSION:

In the present study, experiments were carried out to analyze the heat transfer rate in the cylindrical and conical outer shell. The flow rate was considered as one of the variable parameter and experiments were conducted for 1 LPM to 7LPM flow rate for both of the outer shell geometry. From the results concluded that for concentric tube heat exchanger with low flow rate operating conditions, an increase in the HTR is achieved with the use of the conical outer shell.

Detailed conclusions were drawn:

- It has been concluded from the results that HTR and overall heat transfer coefficient increases with a decrease in diameter ratio.
- The linear correlation was developed relating flow rate and diameter ratio was matching with the experimental data within ± 7 %.

The experiment can extend for a high flow rate with conical outer shape and further extend with different geometrical shapes.

The conical shape at outer shell raises the overall heat transfer rate of the heat exchanger in compared to the cylindrical shape.

NOMENCLATURE:

Q = Heat transfer rate of fluid, [kW]

m = Flow rate of water, [ltr/min]

Cp= Specific heat of water, [kJ/kg. K]

Th,in = Hot water temperature at entry, [oC]

Th,out = Hot water temperature at exit, [oC]

Tc,in = Cold water temperature at entry, [oC]

Tc,out = Cold water temperature at exit, [oC]

ΔT_{lm} = Logarithmic mean temperature difference, [oC]

do = Outlet diameter of outer conical tube, [mm]

di= Inlet diameter of outer conical tube, [mm]

U = Overall heat transfer coefficient, [W/m2. K]

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