Experimental Study of the Effect of the Reynolds Number on Overall Heat Transfer Coefficient in Spiral Heat Exchanger for Acetic Acid – Water System

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Abstract

In this paper an experiments has been conducted to investigate overall heat transfer coefficient for co-current and counter current flow in spiral heat exchanger. Cold fluid is acetic acid water miscible solution. A series of runs were performed between hot and cold fluid. Hot fluid flows through spiral tube while cold fluid flows through shell side. Mass fraction of cold fluid was varied from 5 to 30%.For each run hot fluid flow rate was kept constant and the mass flow rate of cold fluid was varied from 5 lpm to 8 lpm. Experiments were performed to study the effect of Reynolds number on overall heat transfer coefficient.

Keywords - *Spiral heat exchanger, Reynolds Number, Overall Heat Transfer Coefficient.*

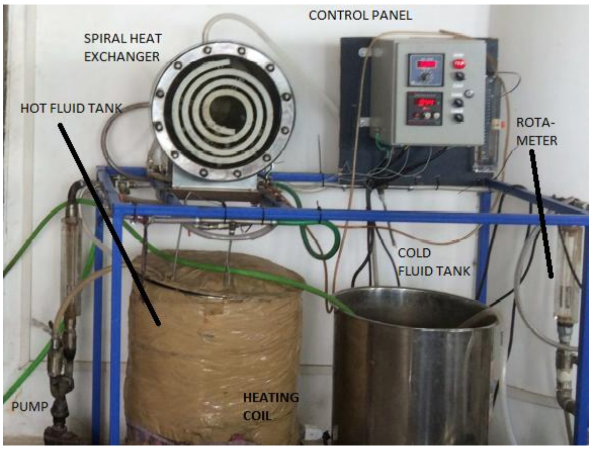
I. INTRODUCTION

Today chemical industry is facing severe problems of fouling in heat exchanger. Due to spiral path in spiral heat exchanger fouling is less as compared to other heat exchanger. Spiral heat exchanger is compact having large heat transfer area so giving high heat transfer rates. Spiral heat exchangers are easy to maintain. Spiral heat exchanger can handle high viscosity fluid. In spiral heat exchanger heat transfer surface is formed by rolled plates to form a spiral path. Thus spiral heat exchanger gives high heat transfer area in lower volume. That is why now a day's more efficient heat transfer equipment are in more demand as the cost of energy cost increasing.

II. LITERATURE SURVEY

The review was done by Prof. Priyanka M. Jhavar, Prof. Ravi D. Gujarati on review paper on analysis of heat transfer in spiral plate heat exchanger using experimental and cfd [1]. They studied that as energy cost is increasing the demand of more efficient heat transfer equipment is increasing. They explained computational methods that can be replaced experimental methods. They concluded that many scientists worked on spiral heat exchanger for design, geometry shape, some by varying parameters like temperature, mass flow rate, pressure to obtain more heat transfer rate. They also concluded that some researchers worked on CFD analysis and compared results with experimental results. The research was carried out by S. Sathiyan et al. on an experimental study of spiral plate heat exchanger for nitrobenzene-water two phase system[2].They studied two phase immiscible liquids heat transfer by using a spiral heat exchanger. They used water as hot fluid and two phase system of nitrobenzene water as cold fluid. They correlated two phase heat transfer coefficient with reynolds number, prandtl number by using equation. Finally experimental results compared with the theoretical results. They developed a new correlation for calculating nusselt number. The research was carried out by Esam Jassim on spiral coil heat exchanger- experimental study [3]. He studied behaviour of spiral tubes when the coil is embedded in a rectangular conducting slab. He found out that heat transfer increases by increasing the number of turns per unit length. He used water as tube side fluid and stagnant water in the container. The coils were made from copper. He measured water temperature at several depths of the container. He concluded that coil orientation, number of loops, coil geometry influence the heat transfer rate. He also concluded that an embedded spiral coil has a better performance vertically than horizontally embedded spiral coils. The research was carried out by Delia Garleanu et al. On the new repair technology the spiral heat exchangers [4]. They studied and developed a new technology for repair of spiral heat exchanger which is more advantageous than old method. They investigated and found out that due to small distance between coils, scrapping the outside to the inside of the coils to obtain access to the area with defects. They concluded that by using new technology the repair cost is decreased and time spends by 80 %. The research was done by M. R. Haque on minimizing fouling in spiral heat exchangers at BCTMP mill [5]. He investigated the effects of calcium oxalate in spiral heat exchanger. He performed experiments and observed that effluent super saturates and form scale on cold surface of heat exchanger which causes rapid fouling. He suggested replacement of sodium hydroxide with magnesium hydroxide during alkaline bleaching to reduce fouling. He finally concluded that calcium oxalate is the main scaling component. He recommended that deposition rate will be reduced by decreasing the contents of calcium oxalate. The research was carried out by M. Bidabadi et al. on spiral heat exchanger optimization using genetic algorithm [6]. They investigated optimization methods using genetic algorithms for spiral heat exchanger. They optimized using single objective functions to investigate parameter behaviour in two different applications. They finally concluded that spiral heat exchanger optimized cost value and increase heat transfer coefficient. They also concluded that heat transfer increased by 13% and the cost is optimized by 50% compared to basic design. The research was done by Santosh D. Katkade et al. on experimental investigation of spiral fin tube heat exchanger with different fin thickness[7]. They studied the importance of compact heat exchanger in industry. They studied that fins are used to increase heat transfer coefficient and efficiency of heat exchanger. They explained importance of spiral fins in industry. They found out that for different fin thickness of 0.5, 0.6, .07 mm at various Reynolds number. They concluded that as air velocity is increased the heat transfer rate increases. The research was carried out by Roshan V. Marode et al. on thermal analysis validation for different design tubes in a heat exchanger. They investigated on single tube with different fluids in shell and tube heat exchanger. They designed and fabricated a model to perform experimental runs. They concluded that study shows the design and thermal analysis of different tubes and compared experimental results with ANSYS software. The research was done by R. W. Tapre et al. on heat transfer characteristic of spiral heat exchanger: effect of Reynolds number on heat transfer coefficient for acetic acid - water system [9]. They investigated heat transfer coefficient for acetic acid water system. They performed experiments by varying mass flow rates of cold fluid from 0.0833 to 0.133 kg/sec and hot fluid flow rate was kept constant. They concluded that heat transfer coefficient increases linearly with reynolds number. The research was done by R. W. Tapre et al. on experimental analysis of spiral heat exchanger: evaluation of Reynolds number and Nusselt number for acetic acid – water system [10]. They investigated effects of Reynolds number on Nusselt number for different concentration acetic acid – water miscible system in spiral heat exchanger. They varied mass flow rate of cold fluid and hot fluid flow rate was kept constant and values of Nusselt number were calculated. They concluded that Nusselt number increase with increase in Reynolds number.

III. EXPERIMENTAL SETUP



IV.METODOLOGY

The experimental setup of spiral heat exchanger consists two storage tanks for hot and cold fluid. Two pumps for hot and cold fluid of 0.5 hp each are connected to the tanks. Valves are used to adjust the flow rate as per the requirement. Drain is provided at the bottom of shell which can be opened or closed with a valve when required. Two rotameters are connected to the hot and cold water tanks to measure the flow rates. Digital temperature indicator is used to measure the accurate inlet and outlet temperature of hot and cold fluids [10].

V. PROCEDURE

The two tanks are initially filled with the respective fluids up to approximately 75% of their capacity. The heating system is switched on. Heating commences and is continued till the required (predefined) temperatures are attained. The fluids are pumped with the help of pumps attached to the pipes at a specific flow rate and adjusted using the valves fitted to the pipes. Then flow rates are measured. The valve of the drain at the bottom is initially kept shut so that the fluid entering the channel is not allowed to escape. Both the channels are allowed to fill up completely. Since the fluid in the coil, i.e. the hot fluid is not linked to the drain directly; there will be some amount of residual fluid in the coil from the earlier runs. Hence, care should be taken to ensure that the temperature readings from the fluid in the coil are taken only after the residual fluid has been emptied. Heat exchange takes place and the temperature readings of the inlet and outlet of the hot fluid and those of the cold fluid are noted. Log Mean Temperature Difference (LMTD) is calculated using these readings. Reynolds number is calculated accordingly. The flow rates are varied and the procedure is repeated. The values of Reynolds number, overall heat transfer co-efficient are obtained.

VI. CALCULATION METHODOLOGY

The heat released or absorbed is calculated using the expression [9],

$$Q = \dot{m}\ Cp\ \Delta T \qquad (1)$$

Where, ṁ is hot or cold fluid flow rate,
Cp is specific heat capacity of hot or cold fluid,
ΔT is Temperature difference of hot and cold fluid.
To calculate theoretically the Nusselt number for cold fluid shell side a new correlation was established which fit the experimental data. [9],

$$Nu = 1.7\ (Re)^{0.4}\ (Pr)^{0.4} \qquad (2)$$

Similarly to calculate theoretically the Nusselt number for hot fluid tube side [9],

$$Nu = 1.7\ (De)^{0.4}\ (Pr)^{0.4} \qquad (3)$$

Where,
Nu= Nusselt Number,
De= Dean Number of hot fluid,
Pr =Prandtl Number of cold fluid

To calculate heat transfer coefficient (h) of cold and hot side fluid [9],

$$Nu = \frac{h\,de}{k} \qquad (4)$$

$$h = \frac{Nu\ k}{de} \qquad (5)$$

k = Thermal conductivity of hot or cold fluid,
d_e= Equivalent diameter shell side or tube side
To calculate theoretically Overall heat transfer coefficient (U) [9],

$$\frac{1}{U} = \frac{1}{h_i} + \frac{1}{h_o} + \frac{t_s}{k_s} \qquad (6)$$

Experimentally Overall heat transfer coefficient is calculated as
Logarithmic mean temperature difference (LMTD) can be found from the following equation. [9]

$$\Delta T_{lm} = \frac{(T_1 - T_3) - (T_2 - T_4)}{\ln\left[\frac{T_1 - T_3}{T_2 - T_4}\right]} \qquad (7)$$

Where,

T_1=Hot water inlet temperature;
T_2= Hot water outlet temperature;
T_3=Cold water inlet temperature;
T_4=Cold water outlet temperature

Experimentally overall heat transfer coefficient (U) is estimated from the following equation [9],

$$U = \frac{Q}{A\ \Delta T_{lm}} \qquad (8)$$

VII. RESULT AND DISCUSSION

Experiment has been performed to study the effect of Reynolds number on overall heat transfer coefficient. Experiments have been conducted by varying the mass fraction of cold fluid from 5%, 12%, 18%, 25% and 30% of acetic acid in water. For each mass fraction of cold fluid experiment were performed in four set. In each set mass flow rate of hot fluid was kept constant (0.0833 Kg/sec to 0.133 Kg/sec) and mass flow rate of cold fluid was varied from 0.0833 Kg/sec to 0.133 Kg/sec. Calculations were done and from the experimental results graphs were plotted for experimental overall heat transfer coefficient with respect to Reynolds number of the cold fluid are illustrated from Figures 1 to 10 for different mass fraction of cold fluid for co-current and counter flow arrangement in spiral heat exchanger.

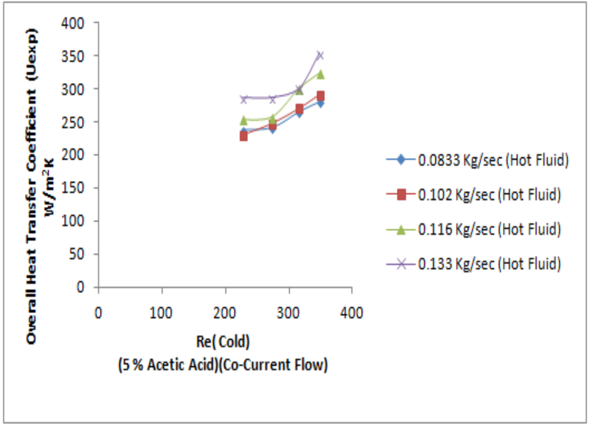


Fig. 1: Variation of Experimental Overall Heat Transfer Coefficient with Reynolds Number for different cold water flow rates for 5 % Acetic Acid-Water system (co-current flow)

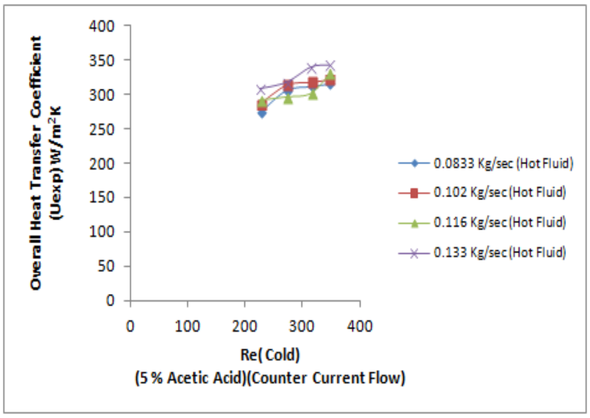


Fig. 2: Variation of Overall Heat Transfer Coefficient with Reynolds Number for different cold water flow rates for 5 % Acetic Acid-Water system (counter current flow)

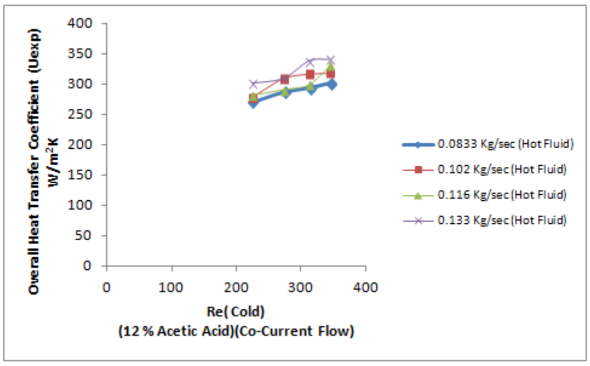


Fig. 3: Variation of Experimental Overall Heat Transfer Coefficient with Reynolds Number for different cold water flow rates for 12% Acetic Acid-Water system (co-current flow)

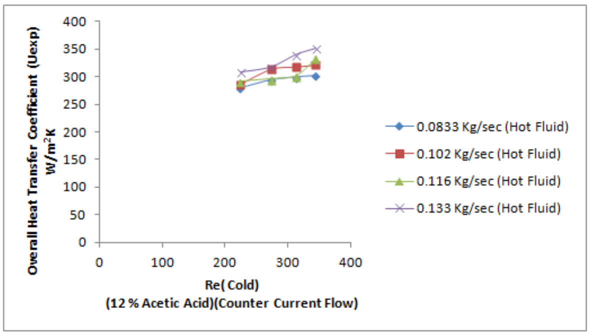


Fig. 4: Variation of Overall Heat Transfer Coefficient with Reynolds Number for different cold water flow rates for 12 % Acetic Acid-Water system (counter current flow)

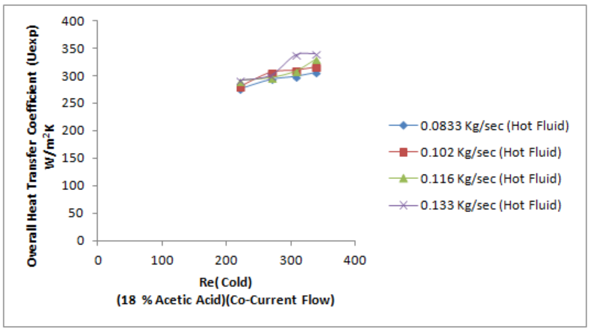


Fig. 5: Variation of Experimental Overall Heat Transfer Coefficient with Reynolds Number for different cold water flow rates for 18 % Acetic Acid-Water system (co-current flow)

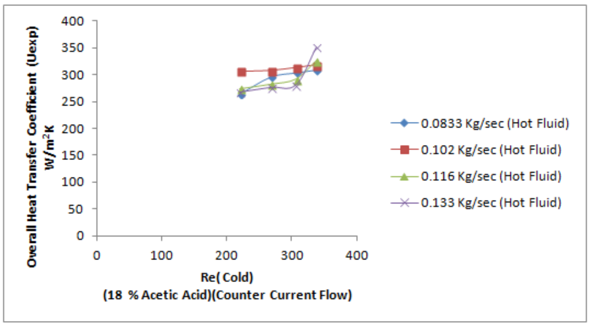


Fig. 6: Variation of Experimental Overall Heat Transfer Coefficient with Reynolds Number for different cold water flow rates for 18 % Acetic Acid-Water system (counter current flow)

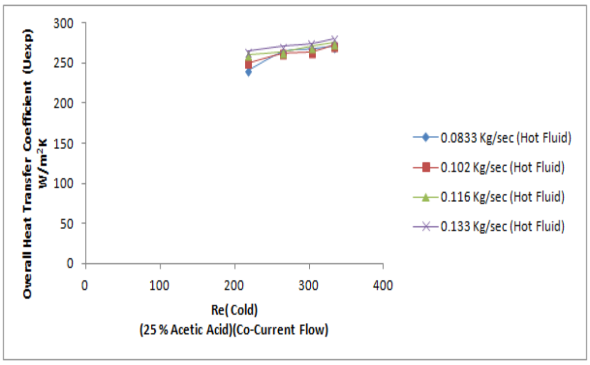


Fig. 7: Variation of Experimental Overall Heat Transfer Coefficient with Reynolds Number for different cold water flow rates for 25 % Acetic Acid-Water system (co-current flow)

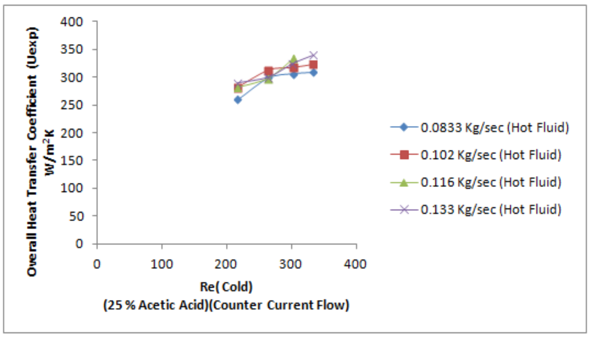


Fig. 8: Variation of Experimental Overall Heat Transfer Coefficient with Reynolds Number for different cold water flow rates for 25 % Acetic Acid-Water system (counter current flow)

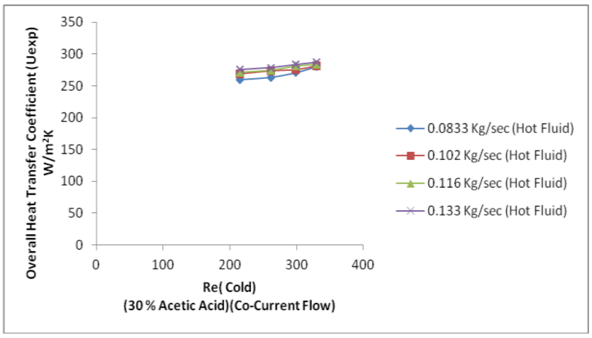


Fig. 9: Variation of Experimental Overall Heat Transfer Coefficient with Reynolds Number for different cold water flow rates for 30 % Acetic Acid-Water system (co-current flow)

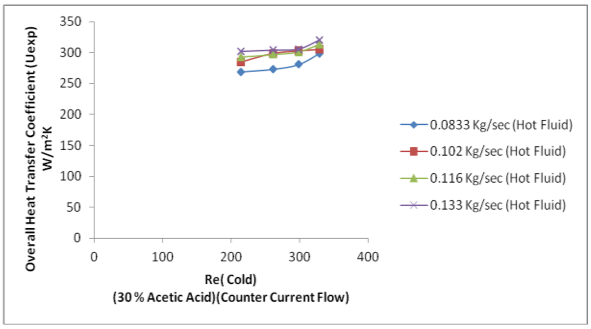


Fig. 10: Variation of Experimental Overall Heat Transfer Coefficient with Reynolds Number for different cold water flow rates for 30 % Acetic Acid-Water system (counter current flow)

VIII. CONCLUSION

Experiments were conducted in a spiral heat exchanger by keeping hot fluid flow rate constant and varying the cold side flow rates for different mass fraction of cold fluid in both co-current flow and counter current flow pattern. A comparison of experimental overall heat transfer coefficient with respect to Reynolds number was made between co-current flow and counter current flow in spiral heat exchanger. The effects of experimental overall heat transfer rate on Reynolds number (Re) for four different cold water flow rate is studied. It is observed that the experimental overall heat transfer rate increases with increasing Reynolds number (Re), which is acceptable for the spiral coil heat exchanger. It is also observed that experimental overall heat transfer coefficient is more in counter current flow than co-current flow for the same operating conditions. Thus we conclude that rate of heat transfer is more in counter current flow in spiral heat exchanger.

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