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Heat Transfer Characteristic of Spiral Heat Exchanger: Effect of Reynolds Number on Heat Transfer Coefficient for Acetic Acid - Water System

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ABSTRACT

In this paper an experimental study has been conducted to investigate heat transfer coefficients and effectiveness for acetic acid- water miscible system in the spiral heat exchanger (SHE).Cold fluid is Acetic acid – water solution while hot fluid is water. Experiments have been conducted by varying the mass flow rate of cold fluid (5 % to 30% Acetic acid in water) from 0.0833 Kg/sec to 0.133 Kg/sec and keeping the hot fluid flow rate constant then the values of Reynolds number and heat transfer coefficient are calculated.

Keywords : Spiral Heat Exchanger; Reynolds number; Heat transfer coefficient.

I. INTRODUCTION

Energy saving is very important in our global world, heat exchanger is useful for energy saving.Spiral heat exchangers play a main role in cooling high density and viscous fluids. Spiral heat exchanger has excellent heat exchange because of far compact and high heat transfer efficiency. Spiral heat exchangers consist of two long plates rolled together forming a spiral. The space between the plates is kept by welding to form the channels for the flow of the fluids. Spiral heat exchanger is self cleaning equipment with low fouling, easily accessible for inspection or mechanical cleaning and with less space requirements.

II. LITERATURE SURVEY

The research was done by Dr. M. A. Hossian, M. I. Islam et. al on compressive study on heat transfer coefficient and effectiveness for water using spiral heat exchanger [1]. They conducted experiments to investigate the overall heat transfer coefficient and effectiveness for water using spiral heat exchanger. They designed a physical model of spiral heat exchanger. They varied mass flow rate of hot fluid from 0.049 kg/sec to 0.298 kg/sec and mass flow rate of cold fluid was varied from .029 kg/sec to 0.225 kg/sec.They observed that heat transfer rate depends directly on mass flow rate of hot and cold water in which maximum heat transfer rate is obtained at lower hot water flow rate. They also concluded that heat transfer coefficient increases with increase in Reynolds number and hot water flow rates and effectiveness decreases with increase in hot water flow rates .The research was carried out by Bhavsar et al. on design and experimental analysis of spiral tube heat exchanger [2].Their aim was to develop new design methodology for flow of hot and cold fluids, where hot fluid flows in axial path while the cold fluid flows in a spiral path. They designed and fabricated the spiral tube heat exchanger to measure the experimental tests. They worked to streamline design methodology of spiral tube heat exchanger. They have designed methodology for spiral tube heat exchanger and experiments performed on it to analyses pressure drop and temperature change in hot and cold fluid on shell side and tube side. The research was carried out by Yoo Geun-jong et. al on fluid flow and heat transfer characteristics of spiral coiled tube and effects of Reynolds number and curvature ratio [3].They performed a numerical analysis and studied flow and heat transfer characteristics in spiral coiled tube heat exchanger. They increased gradually increased radius of curvature of spiral coiled tube till total rotating angle of 12 Π is reached. They concluded that cross sectional velocity distribution of the main flow and secondary flow shows similarity for both spiral and helical coiled tubes. They also concluded that friction factor and Nu increases in sane proportion with Re and square root of dean number in both coiled tubes. They finally concluded that Re had stronger effect as compared to curvature ratio. The research was carried out by Naphon and Wongwises on study of the heat transfer characteristics of a compact spiral coil heat exchanger under wet-surface conditions [4]. The main focus of their work was to find the heat transfer characteristics and the performance of a spiral coil heat exchanger under cooling and humidifying conditions. They used air and water as working fluids. They developed a mathematical model based on mass and energy conservation and solved by using the Newton–Raphson iterative method to determine the heat transfer characteristics. They found out that enthalpy, effectiveness and the humidity effectiveness decreased with increasing air mass flow rate for a given inlet-water temperature, inlet-air humidity ratio and water mass flow rate. The increase in the outlet enthalpy and outlet humidity ratio of air was larger than those of the enthalpy of saturated air and humidity ratio of saturated air. Therefore, the enthalpy effectiveness and humidity effectiveness tend to decrease with increasing air mass flow rate. They also observed that the effect of inlet-air temperature on the tube surface temperature. At a specific inlet-air temperature, the tube surface temperature generally increases with increasing air mass flow rate; however, the increase of the tube surface temperature at higher inlet-air temperatures was higher than at lower ones for the same range of air mass flow rates. They found that at a specific air mass flow rate, the tube surface temperature decreases as water mass flow increases. Finally the results obtained from the developed model are validated by comparing with the measured data. The research was carried out by Shuobing Yang et. al on modelling on the fluid temperature distribution of a spiral heat exchanger [5].They derived a non linear model by investigating a small volume of spiral heat exchanger. They compared proposed model with the previous model. They established a nonlinear mathematical model. They finally concluded that model of spiral heat exchanger based on Bessel function and verified that simulation results obey the heat exchange principle. The research was carried out by M. Ghobadi et. al on heat transfer and pressure drop in a spiral square channel [6]. They fabricated spiral channel on a copper plate. They performed experiments once with fluids entering from the side of the spiral channel and existing from the middle of the spiral channel and vice-versa. They noticed heat transfer behaviour for different flow rates from laminar to turbulent flow. They observed heat transfer increased due to the spiral geometry. They finally concluded heat transfer and pressure drop performance of spiral heat exchanger channel for four different silicone oils. They found that 0.65 cSt silicone oil gives better heat transfer than other fluids. They came to know that spiral channel does not increase the augmentation for low flow rates and pressure drop increases with increase in flow rates. The research was carried out by Hui Zhu et. al on experimental study on the heat transfer enhancement by dean vortices in spiral tubes [7]. They experimentally studied heat transfer enhancement in spiral tubes by controlling dean vortices like Reynolds number, fluid viscosity and curvature ratio. They also considered torsion of the spiral tube. They performed experiments under constant wall temperature with one straight coil and 7 kinds of spiral copper tubes. They concluded that Nusselt number increases with increase in Reynolds number, viscosity and curvature ratio. They also found out that pressure drop increases with increase in Reynolds number. They noticed that heat transfer performance of spiral tube is better than a straight tube. They developed a correlation equation of heat transfer enhancement by dean vortices obtained through multiple regressions. The research was carried out by Rajavel and Saravanan on an experimental study of spiral plate heat exchanger for electrolytes[8].They investigated convective heat transfer coefficient for electrolytes using spiral heat exchanger.They varied the mass flowrate,temperature and pressure of the cold fluid,keeping the mass flowrate of hot fluid constant.They concluded that heat transfer coefficient increases with increase in reynolds number of electrolytes which increases the Nusselt number.The data obtained from the experimental study compared with the theoretical data. They have also developed a new correlation based on experimental data for practical application. The research was carried out by Xinjun Li on the numerical analysis of spiral heat exchanger[9]. He used lumped parameter method and established a mathematical model for spiral heat exchanger. He used finite difference method for obtaining a differential equation and calculated steady temperature field of spiral heat exchanger. He concluded that response time is not affected by the temperature or the flow rate of the heat source. He also came to know that the maximum error between two methods was 5% only which proves that lumped parameter method is right. He finally concluded that lumped parameter plays an important role in guiding design and analysis of the spiral heat exchanger.

III. METODOLOGY

The experimental setup for the Spiral Plate Heat Exchanger includes two large storage tanks, one for storing the hot fluid and the other for storing the cold fluid. There are two pumps (0.5 hp) connected to the tanks, one at the side of either tank. They provide the driving force required to push the fluids into the respective inlet nozzles of the heat exchanger and to maintain the flow within the unit. The fluid is pumped through the pipes, i.e., the tank outlets which have valves fitted on them to adjust the flow rate. One of the pipe is connected between the outlet of the cold fluid storage tank and the inlet nozzle of the shell (top) while the other pipe is attached to the shell outlet nozzle (front) and is let out into the tank at the other end. On the other hand, one of the pipe is connected between the outlet of the hot fluid storage tank and inlet nozzle of the coil (back) while the other pipe is attached to the coil outlet nozzle (top) and is let out into the tank at the other end. Pipe is attached to the outlet nozzle located towards the bottom of the shell at the back. This acts as the drain. The pipes are provided with adequate sized horse clips fixed at the point of attachment to the nozzles of the Spiral Plate Heat Exchanger, to hold the pipes firmly in place. The drain at the back is provided with a valve that can be opened and shut as and when required.

IV. PROCEDURE

The two tanks are initially filled with the respective fluids up to approximately 75% of their capacity. The heating system is switched on, activating the pumps. Heating commences and is continued till the required (predefined) temperatures are attained. The fluids are pumped through the pipes at a specific flow rate, which can be adjusted using the valves fitted to the pipes. Prior to that, the 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 and Prandtl number are also calculated accordingly, using the values of the flow rate. The flow rates are varied and the procedure is repeated. The values of Reynolds number, Prandtl number and the heat transfer co-efficient, heat transfer rate, heat transfer area, effectivess and number of transfer units are obtained.

V. CALCULATION METHODOLOGY

The heat released or absorbed is calculated using the expression,

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

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,

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

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

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

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,

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

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

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),

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

Experimentally Overall heat transfer coefficient is calculated as

Logarithmic mean temperature difference (LMTD) can be found from the following equation

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

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

Experimental Overall Heat transfer coefficient (U) is estimated from the following equation,

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

Capacity Ratio (R)

$$R = \frac{(\dot{m}\ cp)min}{(\dot{m}\ cp)max} \quad (9)$$

Fin Analogy number is calculated by following equation

$$F_a = \frac{NTU\ (1-R)}{2} \quad (10)$$

Efficiency is calculated by following equation

$$\eta = \frac{\tanh(Fa)}{Fa} \quad (11)$$

Effectiveness (ε) of the heat exchanger,

$$\varepsilon = \frac{(T_4 - T_3)}{(T_1 - T_3)} \quad (12)$$

VI. RESULT AND DISCUSSION

The performance characteristics of spiral heat echanger for different concentration acetic acid – water system is studied. The cold fluid concentration is varied from 5% to 30% respectively.The effects of heat transfer coefficient with respect to reynolds number is studied for both co-current and counter flow arrangements as shown in figure 1.

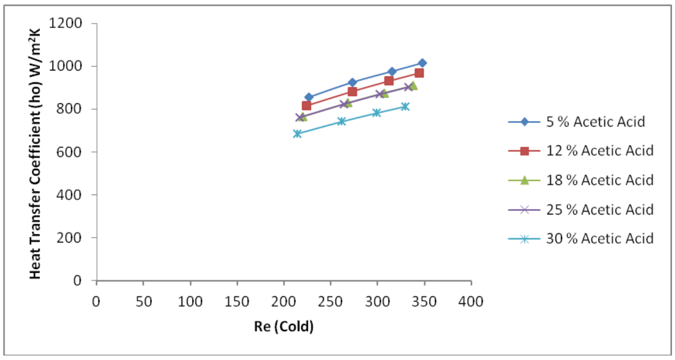

Fig. 1: Heat Transfer Coefficient (Cold) Vs Reynolds Number (Cold) for Acetc Acid-Water System

It is observed that heat transfer coefficient increases with increase in Reynolds number for all four cold water flow rate from 0.0833 Kg/sec to 0.133 Kg/sec for both co-current and counter current flow.

VII. CONCLUSION

Experiments were performed on spiral heat exchanger with different cold water flow rates and different concentration of cold fluids in parallel and counter current flow arrangements.The result shows that heat transfer coefficient increases linearly with Reynolds number for four different cold water flow rate which is satisfactory for spiral heat exchanger.

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