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Heat Transfer Enhancement of Ethylene Glycol using Corrugated Plate Heat Exchanger

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Abstract: *This paper presents an experimental study on heat transfer rate for ethylene glycol using a flat plate heat exchanger and various corrugation angles of corrugated plate heat exchanger. Experimental set up provided with thermocouples to measure the temperatures along the length of each plate at seven locations. Additionally, four thermocouples were used to measure the inlet as well as outlet temperature of test fluid and hot fluid. Water was used as a hot fluid at constant temperature of 75°C and Ethylene glycol was used as a test fluid in a counter-current flow mode. The fluids flow rates were varied from 0.5 lpm to 4.5 lpm and the corresponding temperatures are measured. From the experimental readings, the heat transfer coefficient and Nusselt numbers were calculated for flat plate and corrugated plate exchangers. The heat transfer coefficient values and Nusselt numbers were compared with the corrugation angles (30^0, 40^0) of corrugated plate and flat plate heat exchangers. The heat transfer coefficient and Nusselt number enhances for corrugated plate with increasing in Reynolds number. The improvement in values is due to the high heat transfer rate caused by turbulence at the corrugation angle. Furthermore, as the increase of mass flow rate, gradual decrement observed for the heating effectiveness in corrugated plate as well as flat plate heat exchanger. This drop of effectiveness is due to decrease of time contact between the two fluids.*

Keywords : *Corrugated plate Heat Exchanger, Heat transfer coefficient, Reynolds number, effectiveness.*

I. INTRODUCTION

Heat exchanger is a device used to exchange of thermal energy from hot fluid to cold fluid, separated by a heat conducting metal partition. Heat exchangers are extensively used in thermal power stations, chemical, bio, pharmaceutical, oil and petroleum industries, waste heat recovery systems, air-conditioning and refrigeration systems. Such industry requires cost effective, high performance heat exchanger. Corrugated plate heat exchanger (CPHE) is one of such device which facilitates high heat transfer efficiency due to its internal design, which creates high turbulence at low velocities [1-2].

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CPHE have various advantages compared to other type of heat exchangers such as, high transfer per unit volume, operated at low velocity, compact design and ease of maintenance. It is highly suitable for low thermal conductivity liquids like water, ethylene glycol and alcohols.Several experimental [3-11] and simulation studies [12-16] demonstrated that there is enhancement in the thermal performance using corrugated plate heat exchanger. The design of corrugated plate also extends the mechanical strength to the plates [3]. As the corrugation angle increases in corrugated plate, the heat transfer coefficient also increases [4-7]. Furthermore, higher the angle of corrugations, higher is the area of contact, which eventually improves the rate of heat transfer with increase of pressure drop [2, 8]. Modified design of CPHE with horizontal and vertical corrugation improved heat transfer rate for unclean fluids [9]. It is compared with the regular chevron type design and 50% reduction in the pressure drop is observed. Using CPHE with different angles of 30°, 40° and 50° shown enhancement in heat transfer rate. And also noticed that, increase in heat transfer coefficient is high for 50° of corrugation angle at given Reynolds number [10]. Heat transfer rate and pressure drop are compared by using different type of plate heat exchangers like flat plate exchanger, asterisk exchanger and corrugated exchanger and based on set of experiments, a correlation is developed between exergy and friction factor [11]. Dimensionless correlations were derived using Buckingham Pi theorem to measure the performance of CPHE [12]. They substituted the practical data in the developed correlation to determine the flow characteristics which affects heat transfer rate.

The temperature distribution and velocity profiles were generated using finite element model and thermal performance of corrugated wall channels and values are compared with a smooth duct [13]. Temperature distribution, overall heat transfer coefficient and pressure drop of gasket plate heat exchanger are determined by simulating a mathematical model [14]. Furthermore, Joerge et al., applied a screening technique for optimization of plate exchanger which consists of number of plates with pass arrangements and finally the model was simplified [15]. Recently, set of experiments are conducted to determine the Optimized conditions using a corrugated type gasketed plate heat exchanger for dairy products [16].

Most of the past research on CPHE is limited to water or air as the test fluid [4,17,18]. In the present investigation, an attempt is made to maximize the rate of heat transfer for ethylene glycol using flat plate and CPHE. In this study, ethylene glycol is used as test fluid and water as hot fluid.

Ethylene glycol is taken as a prior coolant because of its dual nature - as an anti-freezing agent and as a coolant. Moreover, it's widely spread applications oriented with heat transfer in fluids - industrial coolant for gas compressors, heating, ventilating, air-conditioning systems justifies its selection over other coolants.

II. EXPERIMENTAL SET UP AND PROCEDURE

The experimental set up consists of a corrugated plate, storage tanks connected with pumps for hot and cold fluid, two rotameters to measure the mass flow rates of both hot and cold fluids and a manometer to measure the pressure drop. The experiments were carried out with a flat plate and corrugated plates (figure 1). The corrugated plate is designed with 10mm channel spacing with angles(θ) of 30° and 40° taken with respect to the horizontal plane as shown in figure 2. The detailed dimensions of CPHE is given in table-I. Water is used as hot fluid at constant temperature of 75°C and ethylene glycol is used as a test fluid. Hot fluid is passed through top channel and the ethylene glycol is passed through the bottom channel of corrugated plate. The test fluid and hot fluid pass through the CPHE in counter current flow. The flow rates of ethylene glycol were varied from 0.5 to 4.5 lpm and the surface temperatures of the corrugated plate are measured using seven thermocouples, where the thermocouples are welded at different locations on CPHE. Furthermore, another four thermocouples are used to measure the inlet as well as outlet temperatures of hot and test fluids. All the thermocouples are connected to a digital temperature indicator (with an accuracy of $\pm 0.1^0$C). The readings were noted after reaching steady state temperature. By using temperatures, the local heat transfer coefficient (h) is calculated by the energy balance of hot and cold fluids and log mean temperature difference (LMTD). Reynolds number is calculated by using flow rate of fluids and Nusselts number (N_{Nu}) is calculated using h values by using following equation

Reynolds number, $N_{Re} = \frac{D_H V \rho}{\mu}$

Nusselts number, $N_{Nu} = \frac{h\, D_H}{k}$

$$D_H = \frac{4A}{P} = \frac{2Wx}{W+x}$$

Where D_H is hydraulic diameter of the channel and k is the thermal conductivity of fluid in KW/m^{2}K. All the values plotted are obtained by averaging the data from three different experiments.

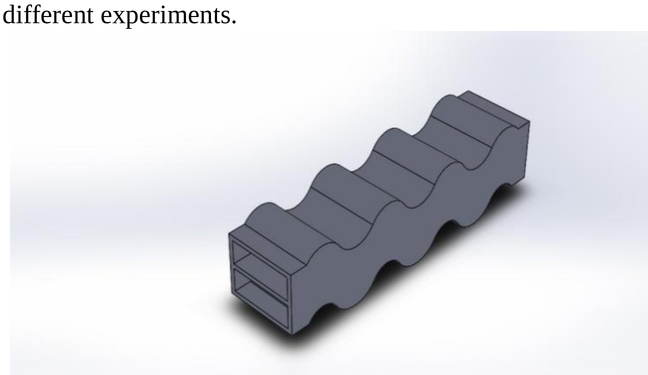

Fig.1. Schematic of corrugated plate.

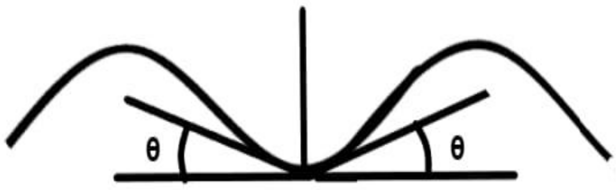

Fig.2. Schematic of corrugated plate with corrugated angle (θ).

Table- I: Details of CPHE

Sl. No.	*Specification of each plate*	*Dimensions*
1	Plate Length	0.3m
2	Plate Width	0.1m
3	Plate spacing	0.005m
4	Corrugation angle (θ)	30^0 and 40^0

III. RESULTS AND DISCUSSIONS

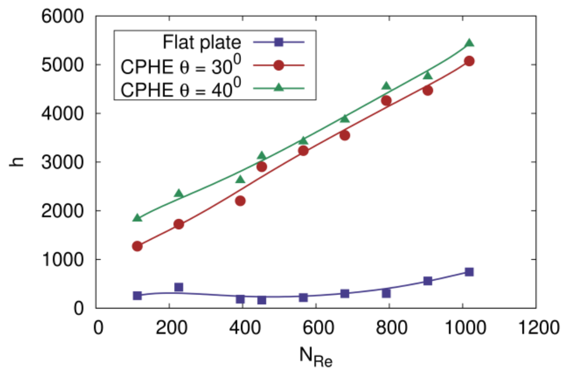

Fig.3. Heat transfer coefficients (h) for various Reynolds number (N_{Re}) for Flat Plate ( ), corrugated plate with corrugation angle θ = 30^0 ( ) and θ=40^0 ( ). The h value is maximum for corrugation angle of θ=40^0 for given Reynolds number.

All the calculated data from the experiments for ethylene glycol are tabulated in Table-II and the result are plotted on the graphs are in shown in figure 3 and 4. Experiments are conducted in the laminar flow region at bulk temperature 75°C of water. Figure 3 displays the heat transfer coefficient (h) as a function of the Reynolds number (N_{Re}) for a flat plate and corrugated plates with different corrugation angles. From the figure it is observed that, as the Reynolds number increases, there is not much influence on heat transfer coefficient for flat plate. For corrugation plates, significant increase in h is observed for a particular corrugation angle. And it also shows that h is maximum for a given N_{Re} for θ=40^0 compared to both θ=30^0 and flat plate. A smaller angle causes a lower turbulence flow and lower heat transfer coefficients.

Table- II: Experimental results for ethylene glycol for flat plate, CPHE with θ = 30⁰ and θ=40⁰.

Flow rate (LPM)	N_{Re}	Flat plate		CPHE with θ = 30^0		CPHE with θ=40^0	
		h	N_{NU}	h	N_{NU}	h	N_{NU}
0.5	113.0	257.3	10.2	1273.7	50.8	1833.5	73.2
1.0	226.1	430.8	17.2	1725.5	68.9	2339.9	93.4
1.5	393.7	184.6	7.3	2204.5	88.0	2622.7	104.7
2.0	452.3	166.8	6.6	2903.6	112.9	3115.6	125.4
2.5	565.4	216.6	8.6	3234.7	125.2	3416.5	135.4
3.0	678.5	298.8	11.9	3548.5	140.7	3866.6	152.4
3.5	791.6	301.1	12.0	4263.3	170.2	4545.4	181.3
4.0	904.7	558.5	22.31	4471.7	178.6	4754.2	189.9
4.5	744.6	744.6	29.7	5074.7	202.7	5428.5	216.8

Similar result was observed for variation of Nusselt's number with Reynolds number for flat plate and corrugated plates (Figure.4). The N_{NU} is maximum for θ=40^0 as compared to other plates. This increment is due to high corrugation angles produces high turbulence in the fluid.

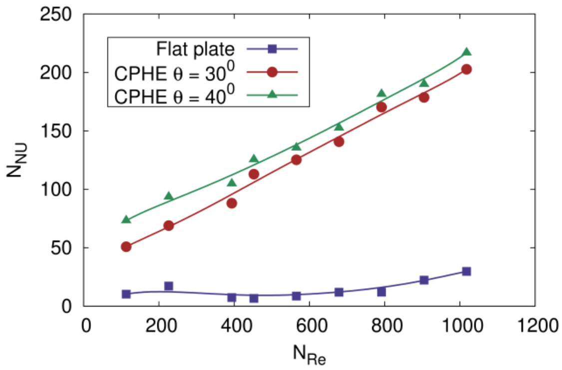

Fig.4. Nusselt number (N_{NU}) for various Reynolds number (N_{Re}) for a flat plate ( ), corrugated plate with corrugation angle θ = 30^0 ( ) and θ=40^0 ( ).

In order to determine the performance of heat exchanger, heating effectiveness [19-20] is calculated by using following equations

Heat transfer for hot fluid, $Q_h = m_h C_{ph} (t_{h1}-t_{h2})$

Heat transfer for cold fluid, $Q_c = m_c C_{pc} (t_{c1}-t_{c2})$

Logarithmic mean temperature difference,

$$\Delta T_{LMTD} = \frac{(T_{avg}-T_{c,in})-(T_{avg}-T_{c,out})}{\ln\frac{T_{avg}-T_{c,in}}{T_{avg}-T_{c,out}}}$$

Where, $T_{c,in}$ and $T_{c,out}$ are temperature of inlet and outlet of test fluid. Where, c_p is the specific heat capacity in KJ/KgK.

Total heat transfer, $Q = \frac{Q_h+Q_c}{2}$

Overall heat transfer coefficient, $U = \frac{Q}{A.\,\Delta T_{LMTD}}$

Number of transfer unit, $NTU = \frac{U.A}{m_c.C_{pc}}$

Capacity ratio, $C_r = \frac{m.C_c}{m.C_h}$

Effectiveness, $E = \frac{1-e^{(1-C_r).NTU}}{1-C_r.e^{(1-C_r).NTU}}$

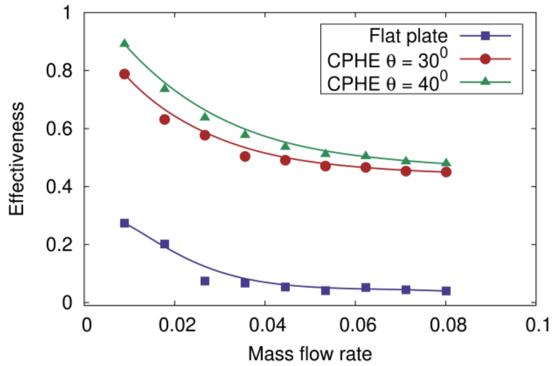

Fig.5. Heat exchanger effectiveness vs Mass flow rate (Kg/s) for Flat Plate ( ), corrugated plate with corrugation angle θ = 30^0 ( ) and θ=40^0 ( ).

Figure 5 displays the variation of heating effectiveness as a function of change in the mass flow rate of test fluid. The results indicate that, at low flow rates of fluids, the effectiveness is maximum for all the plates. Moreover, the effectiveness observed is highest for the corrugated plate heat exchanger with corrugation angle θ = 40^0 as compared with θ = 30^0 and flat plate. In contrast, as mass flow rate increases, there is a gradual decrease in the effectiveness for flat plate and corrugated plate heat exchanger (θ = 30^0 and θ = 40^0). At low mass flow rates, transfer of thermal energy is high due to sufficient time contact between cold and hot fluids, so, high heat transfer rate is attained, which results in maximum effectiveness. Whereas a further raise in the mass flow rate gradually decreases the time of contact for heat transfer between hot fluid and test fluid, thus resulting in low heating effectiveness.

IV. CONCLUSION

Experimental investigations are conducted on heat transfer using corrugated plate heat exchanger with corrugation angles of 30^0, 40^0 and a flat plate for ethylene glycol at low Reynolds number. The obtained heat transfer coefficients and heating effectiveness of CPHE at different corrugation angles are compared with the results obtained for a flat plate.

At a given Reynolds number, heat transfer coefficients for CPHE $\theta = 40^0$ is higher than other plates. As the corrugation angle increases, there is significant improvement in the Nusselt number which causes the swirling flow in the flow regime resulting in the enhancement of heat transfer. Moreover, for any mass flow rate, the obtained heat exchanger effectiveness is maximum for corrugated angle of 40^0.

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