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Experimental Heat Transfer Studies of Water in Corrugated Plate Heat Exchangers: Effect of Corrugation Angle

B. Sreedhara Rao[1], Varun S[2], Surywanshi G D[2], Prof. R C Sastry[2]
[1]Department of Chemical Engineering, CBIT Hyderabad, AP, INDIA
[2]Department of Chemical Engineering, NIT Warangal, AP, INDIA
rc_sastry@yahoo.co.in

Abstract: ***In the present investigations heat transfer studies are made in three different types of corrugated plate heat exchangers having a length of 30 cm and width of 10 cm. The corrugated channel has a spacing of 5 mm. Three different corrugation angles are used in this study which are 30^0, 40^0 and 50^0. Water is taken as test fluid as well as the heating medium. The wall temperatures are measured along the length of exchanger at seven different locations by means of thermocouples. The inlet and outlet temperatures of test fluid and hot fluid are measured by means of four more thermocouples. The experiments are carried out at a flowrate ranging from 0.5 lpm to 6 lpm with the test fluid. From the experimental observations film heat transfer coefficient as well as Nusselt number are calculated. These values are compared with different Reynolds numbers as well as corrugation angles. The effect of corrugation angle on heat transfer rates is discussed.***

Keywords: **Corrugated plate heat exchanger, corrugation angle, thermocouples, Nusselt number, and Reynolds number.**

I. Introduction

Plate heat exchangers were devised for hygienic applications such as the dairy or brewing industries primarily because of their ease of cleaning and maintenance [1]. Over the last two decades, the use of PHE has spread to chemical process industries like paper, pharmaceutical or petrochemical and in particular for process heating or cooling applications. The reason for the wide spread application of PHE compared to shell and tube heat exchanger in industry today is not only ease of maintenance but also because of higher turbulence at low fluid velocities that can be achieved, high overall heat transfer coefficient due to intensive turbulence induced by corrugated plate surface, low fouling tendency because of high shearing forces and turbulence. With plate heat exchangers heat can be recovered with comparatively lower temperature difference between the fluids [2]. In compact heat exchangers, a lot of research is focused on plate heat exchanger. Plate heat exchanger are highly attractive for use because of its high heat transfer efficiency, ease of handling, highly portable nature and is with which it can be scaled up. The design of corrugated channel is more complex, but it improves two or three times heat transfer compared to conventional channel [3,4]. The sinusoidal wavy plate arrangements and channel geometries were improved the heat transfer performance by increasing the surface area [5,6].

The main variable in this type of heat exchanger is the different corrugation angles which have an influence on the heat transfer performance. In the present studies it is proposed to investigate the heat transfer characteristics of water as a test fluid in wavy type corrugated plate heat exchanger with different corrugation angles having fixed spacing. The three different corrugation angles used are 30^0, 40^0, and 50^0 measured from the horizontal plane. Experimental data along with these corrugation angles is used to plot heat transfer coefficients and Nusselt number versus the Reynolds number to study the effect of corrugation angle on heat transfer rates. These plots were used to compare results for different corrugation angles and also to study the effect of heat transfer rates on corrugation angles. The range of Reynolds number used is 210 to 2500.

Heggs et al. [7] developed electrochemical mass transfer techniques to calculate values of local heat transfer coefficients within corrugated PHE channels. He performed experiments over 30^0, 45^0, 60^0, and 90^0 corrugation angles. They analyzed that the mass transfer coefficient results revels that particularly at low corrugation angle (30^0 corrugation angle), pure laminar flow does not occur for the Reynolds number range of 150 to 11500. Pandey and Nema [8] conducted experiments to determine the heat transfer characteristics for fully developed flow of air and water flowing in alternate corrugated ducts. A test section was formed by three identical corrugated channels having corrugation angle of 30^0 with cold air flowing in the middle one and hot water equally divided in the adjacent channels. He obtained various correlations of Nusselt number for water and air.

II. Material and Methodology

The experimental setup is shown in Fig. 1 and it consists of corrugated plate heat exchanger, storage tanks for test fluid and hot fluid, rotameters, digital temperature indicator, pumps and manometer. The dimensions of the Plate Heat Exchanger are shown in table 1.

Table 1. Dimensions of PHE.

Sr. No.	Specification	Dimension
1	Length of each plate	30 cm

2	Width of each plate	10 cm
3	Plate spacing	0.5 cm
4	Corrugation angle	30 °, 40 ° & 50 °

Fig.1 Experimental setup of plate heat exchange.

Fig 2 Top view of thermocouples fixing on middle plate.

Three plates of corrugation configuration, forming two channels, one for the test fluid (bottom) and another for the hot fluid (top). The corrugation angle is taken with reference to the horizontal plane and shown in the Fig. 3.

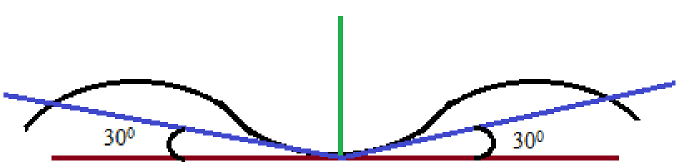

Fig. 3 Corrugated angle of corrugated plate

Experimental Procedure

The experiments were carried out in the plate heat exchanger having 5mm spacing. The corrugation angles used are 30^o, 40^o and 50^o. The experiments were carried out with the water of viscosity 0.7284 cp at 35^0C as test fluid.

For all the experiments hot water at 70^0C at constant flow rate was used for heating the test fluids. For each experimental reading, the inlet and outlet temperatures of the fluid as well as the wall temperatures on the heat exchanger plate at seven different locations were noted by means of thermocouples welded at these locations and read through the digital temperature indicator. These temperatures were used for the analysis of heat transfer. For making the heat transfer studies the hot fluid flow rate was maintained constant. The test fluids were pumped into the bottom channel through the calibrated rotameter from 0.5 to 6 lpm. The middle plate is fitted with 7 thermocouples, along the length and breadth of the plate, to measure the wall temperatures. Four more thermocouples are inserted into the bulk fluid to measure the inlet and outlet temperatures of hot and cold fluids. These thermocouples are connected to a digital temperature indicator having an accuracy of 0.1^0C. For each flow rate the inlet and outlet temperatures as well as the wall temperatures were noted from the temperature indicator, when it shows a constant value. For all the heat transfer studies the inside film heat transfer coefficient (h_i) is calculated by making an energy balance with log mean temperature difference (LMTD). The viscosity and specific gravity of the fluids are determined experimentally by Redwood Viscometer no. 1 and hydrometer respectively.

III. Results and discussion

The effect of Reynolds number on Nusselt number is more significant than that of any of the other parameters [9]. The arithmetic mean temperature of wall measured at seven different locations is $T_{w,avg}$, using this temperature the log mean temperature difference (LMTD) is calculated using equation (1). The rate of heat transfer is calculated using equation (2) applied for cold fluid (test fluid). The average heat transfer coefficient is calculated using equation (3).

$$LMTD = \frac{(T_{avg} - T_{c,in}) - (T_{avg} - T_{c,out})}{\ln \frac{T_{avg} - T_{c,in}}{T_{avg} - T_{c,out}}} \qquad (1)$$

$$Q = MFR \times C_P \times \Delta T_{cold} \qquad (2)$$

$$Q = hA(LMTD) \qquad (3)$$

Where $T_{c,in}$ and $T_{c,out}$ are inlet and outlet temperatures of cold fluid (test fluid). Where MFR is mass flowrate of water in kg/s. C_p is specific heat capacity of water in kJ/kgK. All the temperatures are measured in ^{0}C.

Once heat transfer coefficient is known, the Nusselt number were calculated using equation (4).

$$Nu = \frac{hD_H}{k} \qquad (4)$$

Here D_h is hydraulic diameter of channel and this was calculated by use of equation (5).

$$D_h = \frac{4A}{p} = \frac{2Wx}{W+x} \qquad (5)$$

K is thermal conductivity of water in KW/m^2K.

All the experimental data collected for a system along with the different corrugation angles are plotted on graphs are shown in Figs. 4 to 9. Figs. 10 and 11 represent a combined graph of h Vs Re and Nu Vs Re respectively for all the three corrugation angles for the system water. From these figures it is observed that h increases with Reynolds number for a particular corrugation angle. It is also observed from this figure that h is higher for a given Re for 50^0 corrugation angle compared to 30^0 and 40^0 corrugation angles. This is due to the high turbulence of the fluid generated for higher corrugation angles.

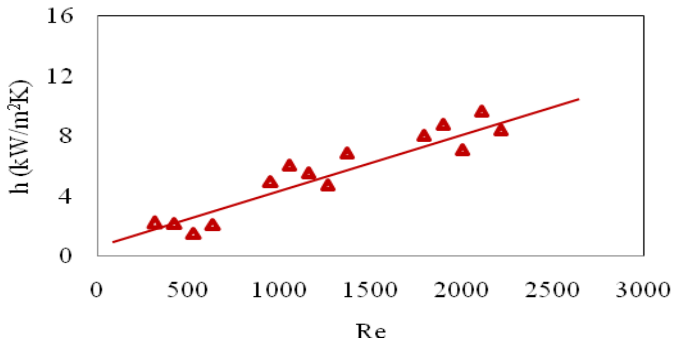

Fig. 4 Heat transfer coefficient Vs Reynolds number Water, 30^0 Corrugation angle.

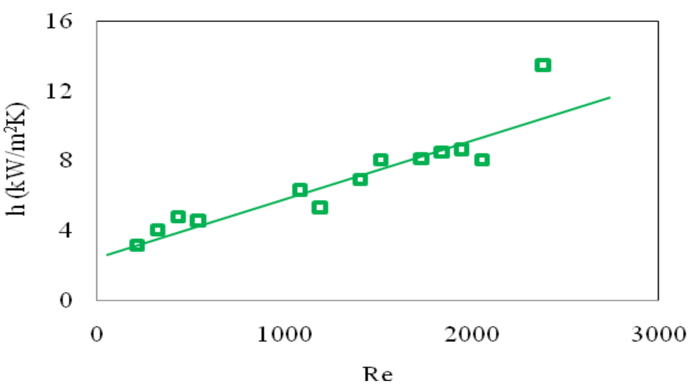

Fig. 5 Heat transfer coefficient Vs Reynolds number Water, 40^0 Corrugation angle.

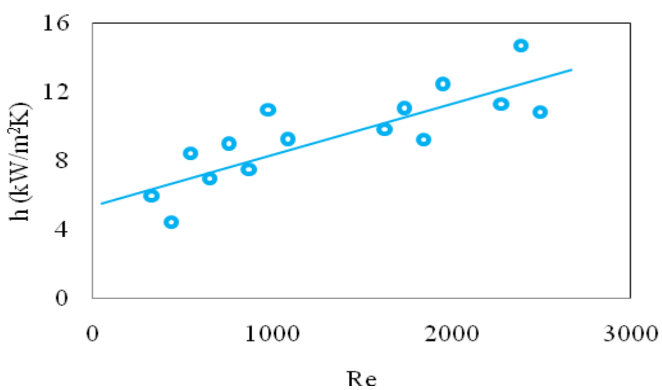

Fig. 6 Heat transfer coefficient Vs Reynolds number Water, 50^0 Corrugation angle.

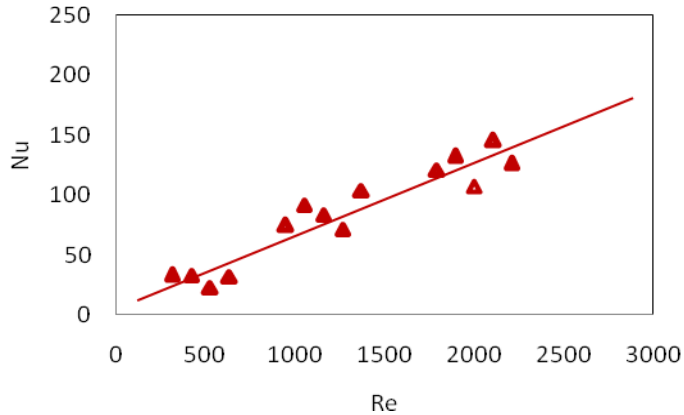

Fig. 7 Nusselt number Vs Reynolds number Water, 30^0 Corrugation angle.

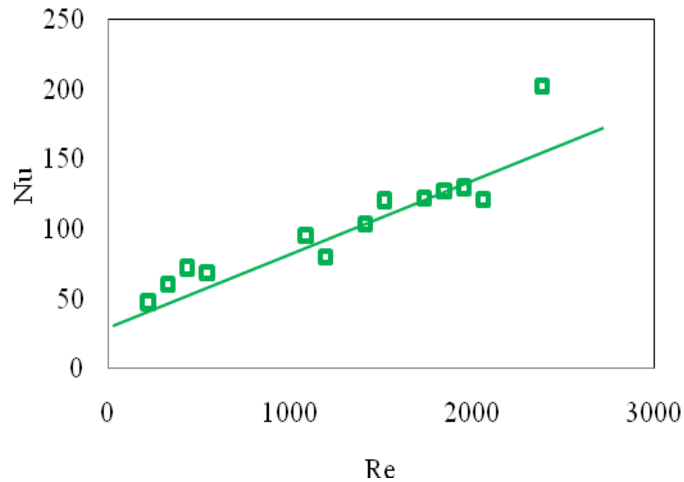

Fig. 8 Nusselt number Vs Reynolds number Water, 40^0 Corrugation angle.

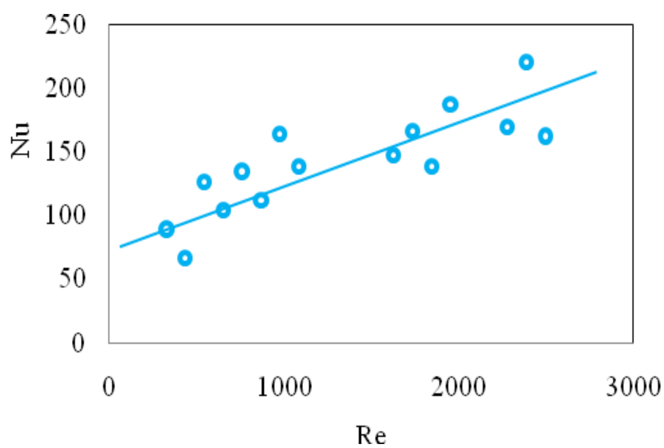

Fig. 9 Nusselt number Vs Reynolds number Water, 50^0 Corrugation angle.

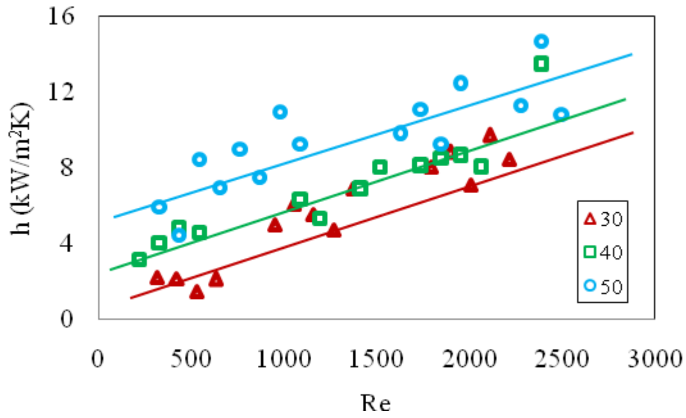

Fig. 10 Heat transfer coefficient Vs Reynolds number for Water, 30^0, 40^0 and 50^0 Corrugation angle.

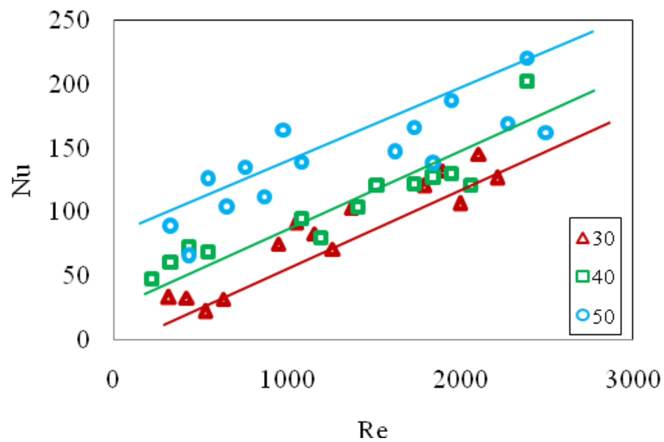

Fig. 11 Nusselt number Vs Reynolds number for Water, 30^0, 40^0 and 50^0 Corrugation angle.

IV. Conclusions

Experimentally determined heat transfer coefficient at different corrugation angles and results are compared. It is found that heat transfer coefficient and Nusselt number are higher at a given Reynolds number for 50^0 corrugation angle as compared to 30^0 and 40^0 corrugation angles. The higher heat transfer rates are due to high turbulence that is created at high corrugation angles. It is also found that the percentage increase in heat transfer coefficient for water for 30^0 to 40^0 corrugation angle is 14%, for 40^0 to 50^0 corrugation angle is 30% and for 30^0 to 50^0 corrugation angle is 40%. At higher corrugation angles, higher heat transfer rates are achieved.

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