EFFECT OF CORRUGATION ANGLE ON PRESSURE DROP OF VISCOUS FLUIDS IN SINUSOIDAL CORRUGATED PLATE HEAT EXCHANGER

B.Sreedhara Rao[1], Varun S[2], MVS Murali Krishna[3], R C Sastry[4]
[1]Asst professor, Department of Chemical Engineering, CBIT Hyderabad, AP, India
[2]PG Student, Department of Chemical Engineering, NIT Warangal, AP, India
[3]Professor, Department of Mechanical Engineering, CBIT Hyderabad, AP, India
[4]Professor, Department of Chemical Engineering, NIT Warangal, AP, India

ABSTRACT
In the present investigation, experimental studies have been carried out in 3 sinusoidal corrugated plate heat exchangers using water and 10% glycerol solution as test fluids. The plate heat exchanger is fabricated with two stainless steel sheets having a thickness of 1 mm. These sheets are welded together to form a corrugated test channel having a clearance of 5 mm and of length 30cm. 3 such plate heat exchangers have been fabricated with corrugation angles of 30, 40 and 50 degrees. The experiments have been conducted on a range of 0.5lpm to6 lpm through the channel and the pressure drop data has been collected and analyzed. The effect of the corrugation angle on both the pressure drop and friction factor of the test fluids have been found.

KEYWORDS: *Sinusoidal Plate Heat Exchanger, Corrugation Angle, Pressure Drop, and Friction Factor.*

I. INTRODUCTION

Heat exchangers find use in almost all types of industries, whether it is petroleum industry or a chemical process industry. A large number of heat exchangers have been developed so far to serve very specific requirements of different industries. The heat transfer efficiency of a heat exchanger is measured on the basis of specific surface area to volume ratio (β), the higher the value of this ratio the better it is for heat transfer operations. On this basis heat exchangers have been classified as compact heat exchanger which has a β value greater than $700m^2/m^3$and non compact heat exchangers having β value less than $700m^2/m^3$. In compact heat exchangers, a lot of research has been focused on plate heat exchangers. Plate heat exchangers has a large number of advantages over other exchangers like high heat transfer efficiency, highly portable nature, ease of handling and ease with which it can be scaled up. But plate heat exchangers offer a higher pressure drop as compared to conventional heat exchangers. It is found that minimal literature is available for pressure drop studies in this type of heat exchangers. [1]

The objective of this paper is to highlight the hydrodynamic studies of viscous fluids through sinusoidal corrugated plate heat exchangers. The data has been further analyzed to find the effect of corrugation angle on both pressure drop and friction factor.

II. LITERATURE REVIEW

G. Iulian et al [2] conducted exhaustive experimental studies on a chevron type plate heat exchanger, which involved the determination of nusselt number (Nu), friction factor (f) for various flow conditions. They concluded that the flow was essentially non uniform and moved along the edges.

Liombas et al [3] studied the gas-liquid two phase flow in a wide range of Reynolds number and they concluded from the experiments that flow exhibits basics of turbulent flow for a very low value of Reynolds number like 400. Heggs et al [4] suggested that a pure laminar flow does not exist in a Reynolds number range of 150-11500 and supported it by studying the heat transfer coefficients experimentally. Extensive mass transfer coefficients measurements were done by Goldstein et al [5] for a Reynolds number range of 150-2000. Lin et al [6] also investigated heat transfer between air-water system in a one side corrugated and one side flat system. Nema et al [7] have carried out similar work involving the heat transfer and pressure drop studies on a sinusoidal plate heat exchanger having a three channel arrangement. It involved study for air-water -system in the Reynolds number range 750-3200 for water and 16900-68000 for air. The effect of flow arrangements on the pressure drop has been extensively studied by Miura et al [8] by comparing the empirical correlations with CFD simulation results.

III. EXPERIMENTATION-

3.1 Experimental Setup

The experiments have been conducted on a plate heat exchanger unit shown in **Fig 1**. The setup consists of a test box, test fluid tank, test fluid collection tank and hot water tank. Each test box consists of two sinusoidal corrugated plates welded together to form a horizontal channel. The sinusoidal plate heat exchanger shown in **Fig -2** has the dimensions shown in **Table-1.** A manometer has been fitted across the test length to measure the pressure drop in the lower test fluid channel. The flow through these two channels is controlled using rotameters. The flow pattern is countercurrent. Three test boxes of having three different corrugation angles of 30, 40 and 50 are considered here.

Fig -1: Plate heat exchanger setup.

Fig -2: Sinusoidal test section

Table -1: Dimensions of the plate heat exchanger test box

Parameter	Dimensions
Length	0.30m
Width	0.1m
Test fluid channel spacing	0.05m
Corrugation angles	30,40 and 50 degrees

3.2 Materials

The test fluid considered here is water and 10% glycerol solution. The density and viscosity of all the materials are experimentally determined (**Table-2**).The u tube manometer uses carbon tetrachloride as the manometric fluid.

Table -2: Properties of test fluids

Fluid	Water	10% glycerol solution
Density	993.96 kg/m^3	1022 kg/m^3
viscosity	0.7284 cp	0.9844 cp

3.3 Experimental Procedure

The test fluid tank is initially filled with one test fluid at a time and the flow is started through the channel. The flow rate is started at a lower flow rate. The test fluid flow rate is varied from 0.5 to 6 lpm with a step size of 0.25 lpm. Once the pressure reading shown by the manometer becomes stable for a given flow rate, the pressure drop readings are noted down and process is repeated for all flow rates. After completion of this procedure the test fluid tank is emptied and filled with the second test fluid. The same experimental procedure is followed for all the 3 corrugated test channels.

IV. Results and Discussions

From the experimental results, it can be observed that the flow is affected by two parameters namely, the corrugation angle and the test fluid viscosity. Viscosity of the solution also affects the hydrodynamics as it also plays an important role in determining the rate of flow of test fluid through the corrugated channel. The corrugation angle forms a critical parameter in the study of plate heat exchangers. It is defined in various manners by different researchers. The corrugation angle for the plate heat exchanger is considered with respect to the horizontal as shown in **Fig-3.**

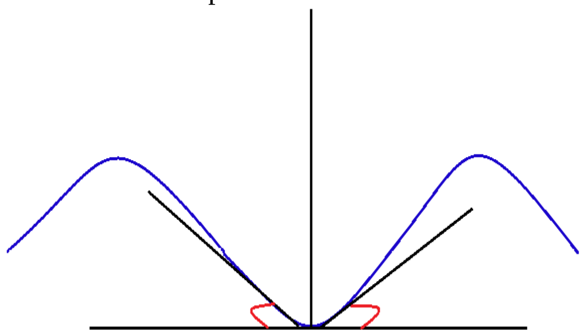

Fig -3: Corrugation angle taken for the sinusoidal plates

The Reynolds number for the flow can evaluated using the formula, by making use of equivalent diameter.

$$\mathrm{Re} = \rho v D_H / \mu \qquad - (1)$$

Pressure drop values for each flow rate are calculated using the pressure readings obtained from the manometer

$$\Delta P = H \Delta \rho g \qquad - (2)$$

Friction factor can be calculated making use of the flow velocity and the pressure drop for each flow rate.

$$f = \Delta P / (\mathrm{L} / \mathrm{D_H})(\mathrm{G} * \mathrm{G} / 2 \rho \mathrm{g_c}) \qquad - (3)$$

In detailed analysis, the variation of both ΔP vs Re and f vs Re for different corrugation angles are studied.

4.1 Pressure Drop

Initially pressure drop variation for 30, 40 and 50 degrees is studied individually. Fig -4 shows the pressure drop change with Reynolds number for 30 degree channel for both solutions.

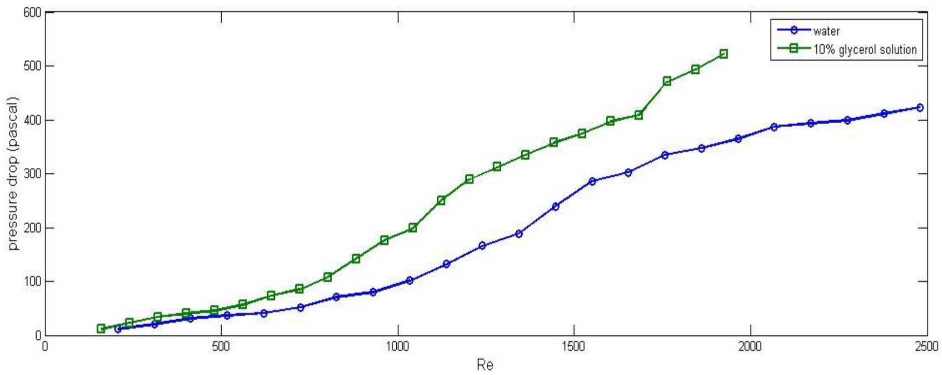

Fig -4: variation in pressure drop with Reynolds number for 30 degree corrugations

It can be seen that as the Reynolds number is increased, the pressure drop offered by both the solutions also increase. But in the entire range of Reynolds number, the pressure drop offered by 10% glycerol solution is always greater than that offered by water. The pressure drop values for water increase from 10 Pascal to 400 Pascal in the total range and for 10% glycerol solution; it increases from 12 Pascal to 500 Pascal. The difference in pressure drop is well distinguished in the higher Reynolds number ranges.

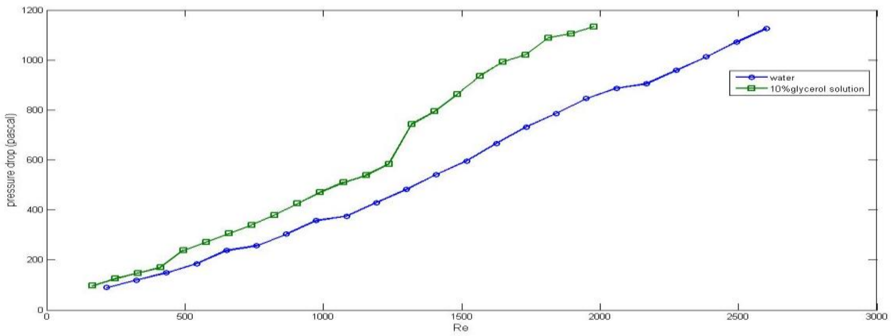

Fig -5: variation in pressure drop with Reynolds number for 40 degree corrugations

Fig-5 shows the pressure drop variation in a 40 degree corrugated channel. It also shows a trend similar to 30 degree plate. It can be seen that as the Reynolds number is increased, the pressure drop offered by both the solutions also increase. But in the entire range of Reynolds number, the pressure drop offered by 10% glycerol solution is always greater than that offered by water. The pressure drop values for water increase from 80 Pascal to 1100 Pascal in the total range and for 10% glycerol solution; it increases from 100 Pascal to 1200 Pascal. The difference in pressure drop is well distinguished in the higher Reynolds number ranges.

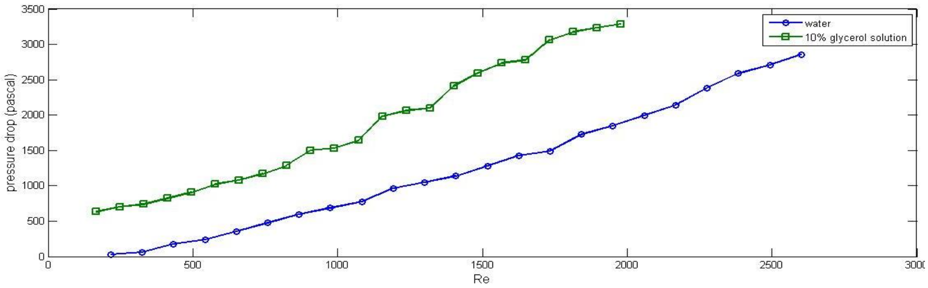

Fig -6: variation in pressure drop with Reynolds number for 30 degree corrugations

Fig-6shows the pressure drop variation in a 50 degree corrugated channel. It also shows a trend similar to 30 and 40 degree plates. It can be seen that as the Reynolds number is increased, the pressure drop offered by both the solutions also increase. But in the entire range of Reynolds number, the pressure drop offered by 10% glycerol solution is always greater than that offered by water. The pressure drop values for water increase from 50 Pascal to 2500 Pascal in the total range and for 10% glycerol solution; it increases from 600 Pascal to 3300 Pascal. The difference in pressure drop is well distinguished in the higher Reynolds number ranges.

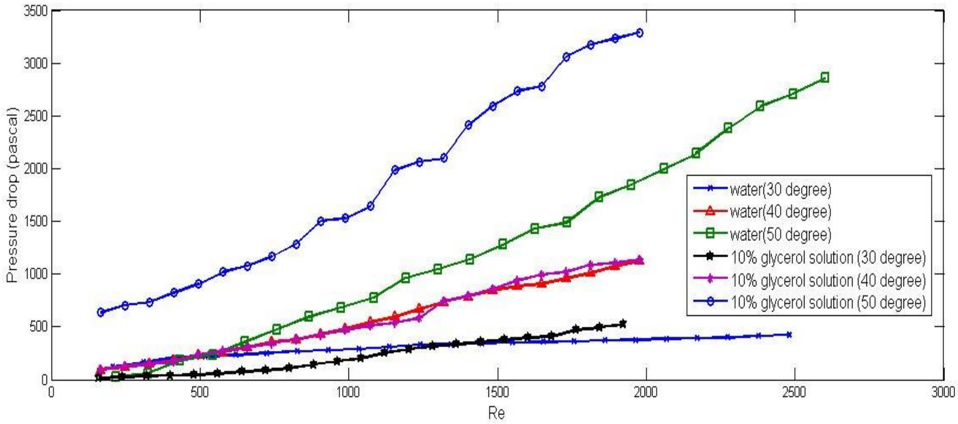

Fig -7: variation in pressure drop with Reynolds number for 30, 40 and 50 degree corrugations

The collective analysis for all three corrugation angles has been done in **Fig-7.** The maximum pressure drop is offered by 10%glycerol solution flowing through 50 degree corrugated plate and minimum pressure drop is offered by water flowing through 30 degree corrugated plate. It is observed that the pressure drops offered by both solutions in 30 and 40 degree corrugations are almost comparable. But this does not stand true in the case of 50 degree corrugation as both the trend lines are separated.

4.2 Friction Factor

Initially friction factor variation for 30, 40 and 50 degrees is studied individually. Theoretically as pressure drop for a flow increases, it results in decrease in the friction factor values. **Fig -8** shows the friction factor change with Reynolds number for 30 degree channel for both solutions. It can be seen that as the Reynolds number is increased, the friction factor for both the solutions decrease. But in the entire range of Reynolds number, the friction factor of 10% glycerol solution is always less than that of water. The decrease observed is almost linear on a logarithmic scale.

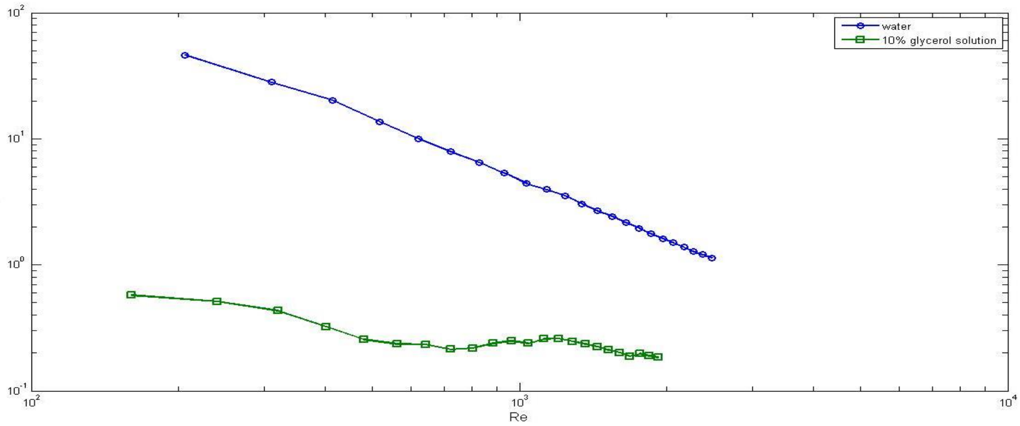

Fig -8: variation in friction factor with Reynolds number for 30 degree corrugations

Fig -9 shows the friction factor change with Reynolds number for 40 degree channel for both solutions. It can be seen that as the Reynolds number is increased, the friction factor for both the solutions decrease. But in the entire range of Reynolds number, the friction factor of 10% glycerol solution is always less than that of water. The decrease observed is almost linear on a logarithmic scale.

Fig -10 shows the friction factor change with Reynolds number for 50 degree channel for both solutions. It can be seen that as the Reynolds number is increased, the friction factor for both the solutions decrease. But in the entire range of Reynolds number, the friction factor of 10% glycerol solution is always less than that of water. The decrease observed is almost linear on a logarithmic scale.

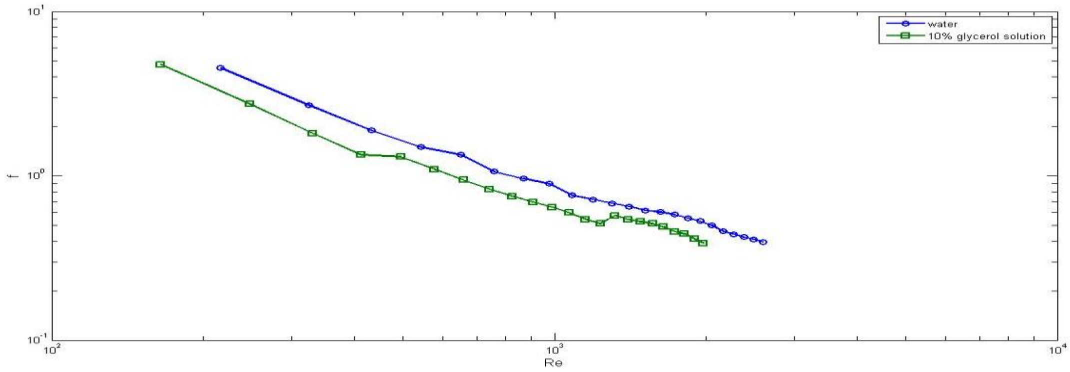

Fig -9: variation in friction factor with Reynolds number for 40 degree corrugations

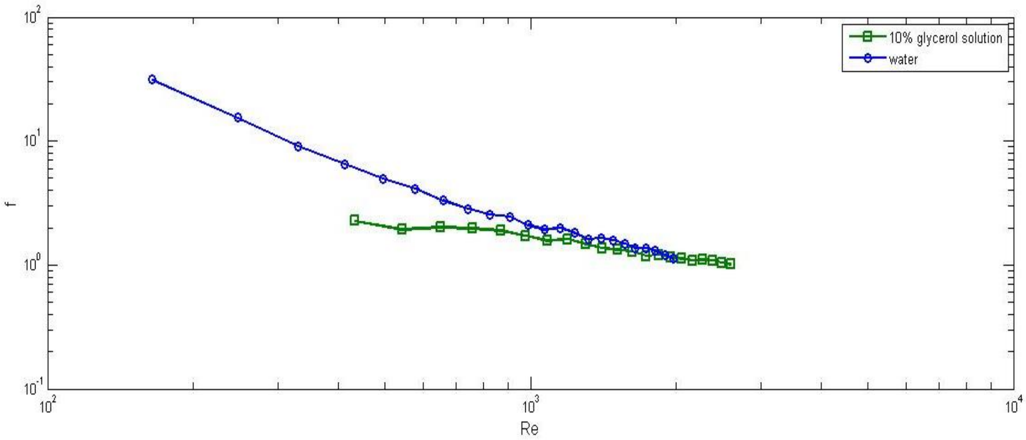

Fig -10: variation in friction factor with Reynolds number for 50 degree corrugations

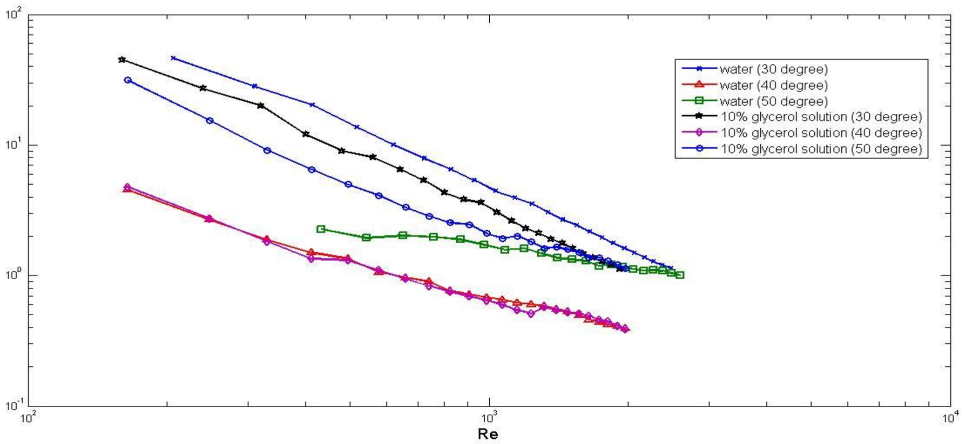

Fig -11: variation in friction factor with Reynolds number for all three corrugations

The collective analysis for all three corrugation angles has been done in **Fig-11.** The maximum friction factor is of water flowing through 30 degree corrugated plate. It is observed that the friction factor values for both solutions in 30, 40 and 50 degree corrugations are almost comparable.

V. CONCLUSIONS

It is evident from the experimental analysis that both the corrugation angle and the viscosity of the test solution affect the hydrodynamics of the flow in sinusoidal corrugated channels. As the corrugation angle increases, pressure drop offered by the channel increases and the friction factor deceases. The increase in pressure drop can be attributed to increase in turbulence occurring in the channel. As the corrugation angle increases, the channel becomes sharper and induces turbulence even at a low flow rate. As the viscosity of the test fluid increases the tendency of the liquid to flow decreases or the liquid's resistance to flow increases, it results in a higher pressure drop and lower friction factor as compared to water.

VI. SCOPE FOR FUTURE WORK

The present work can be extended to include more test fluids with increase in concentration of glycerol solutions. The work can also be extended to include higher corrugation angles. The effect of the clearance between the plates on the hydrodynamics can also be investigated.

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BIOGRAPHIES

B. Sreedhara Raois working as Sr Asst Professor in Chemical Engineering department at CBIT Hyderabad India.

Varun S is a student of Master of Technology in department of Chemical Engineering at NIT Warangal India.

MVS Murali Krishna is working as Professor in Mechanical Engineering department at CBIT Hyderabad India.

R. C. Sastry is working as Professor in Chemical Engineering department at NIT Warangal India. He worked as the Head of the Department for a period of 5 years from 2001 to 2006.