

Development of Correlation for Fluid Flow in Wavy Corrugated Plate Heat Exchangers

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ABSTRACT: Compact heat exchangers are those which provide large area for heat transfer, occupying very less space. Corrugated plate heat exchanger is a classification under compact heat exchangers. Experimental investigations have been undertaken to explore the pressure drop and friction factor characteristics in a corrugated plate heat exchanger. For a fluid at higher concentration, it is observed that pressure drop increases with increase in Reynolds number and friction factor decreases with increase in Reynolds number. Concentration of the test fluid and corrugation angle contributes to the variation in friction factor. An experimental correlation has been proposed for the variation of friction factor with Reynolds number and corrugation angle in wavy corrugated plate heat exchanger and the R^2 value was observed to be 0.902.

KEYWORDS: Compact heat exchangers, Corrugated Plate Heat Exchanger, Corrugation Angle, Friction Factor, Reynolds number

I. INTRODUCTION

Heat exchangers are used in a multitude of process industries. Heat is transferred from the hot fluid to the cold fluid in a heat exchanger. A corrugated plate heat exchanger has an edge over a plate heat exchanger. The corrugated plate heat exchanger is designed with the main aim of increasing the surface area of heat transfer, along with increasing the turbulence in the fluid flow caused due to the corrugations^[5]. This would result in the increased efficiency of the heat exchanger and makes it appropriate to apply the corrugated plate heat exchanger in heating heat sensitive fluids and also pasteurisation operations.

Friction factor is a dimensionless quantity that signifies the ease with which a fluid flows through a conduit. It also predicts the frictional energy losses that take place as the fluid flows through the conduit. On the other hand, Reynolds number characterizes the nature of flow and classifies the flow as laminar, transition or turbulent flow. It is important to note that the Reynolds number depends on the type of conduit in which the fluid is flowing. Glycerine solutions of 30%, 40% and 50% (by volume) solutions are the test fluids considered in this analysis.

The primary aim of the experiments conducted was to heat the test fluid using hot water. The analysis is supported by data obtained for different flow rates of the test fluid and constant flow rate of water.

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II. RELATED WORK

There are many studies being carried out on corrugated plate heat exchangers due to its whole host of applications in different industries. An unsteady laminar flow of a Newtonian fluid in a channel with sinusoidal walls, driven by a constant pressure gradient, has been studied by Zachary Grant Mills^[1]. Besides, the effects of surface geometry on heat transfer, friction factor and energy loss on a flat plate heat exchanger were analysed by Dovic´ D., and presented a correlation for flat plate heat exchangers, which related Nusselts number, Reynolds number and friction factor^[6].

In this study, the flow of Newtonian fluid in corrugated plate heat exchangers was analysed and the variations of pressure drop with Reynolds Number were noted. Also, the effect of geometry of the corrugated plate, that is, the angle of corrugation, on pressure drop and friction factor has been studied. Consequently, a correlation between fiction factor, Reynolds number and angle of corrugation, for the wavy corrugated plate heat exchanger has been developed.

III. EXPERIMENTAL SETUP AND PROCEDURE

Experiments were carried out by considering 30°, 40° and 50° corrugation angles. A digital manometer is fixed along the length of the corrugated plate to measure the pressure drop in the test fluid channel. The flow through these two channels is controlled using rotameters. The fluids are operated in counter current fashion. The following Table 1 represents the dimensions of the equipment on which experiments have been conducted.

Table 1:

PARAMETER	DIMENSIONS
Length	0.30m
Width	0.1m
Test fluid channel spacing	0.015m
Corrugation angles	30°, 40°, 50°

The test fluid considered here is water, 60% glycerine solution, 50% glycerine solution and 40% glycerine solution. The properties of the solutions are as shown in Table 2.

Table 2

PROPERTIES AT 308K (35°C)	WATER	GLYCERINE 40%	GLYCERINE 50%	GLYCERINE 60%
DENSITY (kg/m ³)	994.0385238	1112.98	1137.768	1175.62
VISCOSITY (Ns/m ²)	0.000719315	0.001801556	0.002574	0.004058
THERMAL CONDUCTIVITY (W/m-K)	0.6548861137	0.377925586	0.35414366	0.335172858
SPECIFIC HEAT(kJ/Kg-K)	4.1785	3.1906826	3.01721	2.814344

The test fluid is loaded in the test fluid tank and the flow is started through the channel at a lower flow rate. The test fluid flow rate is varied from 0.25 lpm to 6 lpm with a step size of 0.25 lpm. The pressure drop readings are noted

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down for each flow rate and the process is repeated for all flow rates. The same experimental procedure is followed for all 3 test channels.

IV. EXPERIMENTAL RESULTS

From the experimental results, it was observed that the flow is affected by the angle of corrugation and the concentration of the fluid. The corrugation angle also forms a critical parameter in this study. The analysis involves the calculation of the Reynolds number for the flow in test fluid channel using the equation given below.

$$Re = \frac{D_{eq} v \rho}{\mu}$$

Where

D_{eq} = equivalent diameter of the corrugated plate, m

v = velocity of fluid flow, m/s

ρ = density of the fluid, kg/m³

μ = viscosity of test fluid, Ns/m²

The friction factor is calculated by rearranging the Darcy equation which is given by

$$f = \frac{\Delta P D_{eq}}{2 l v^2 \rho}$$

Where

f = Friction Factor

l = Length of the pipe, m

D_{eq} = equivalent diameter, m

v = velocity, m/s

ΔP = magnitude of pressure drop, N/m²

ρ = density of test fluid, kg/m³

In the detailed analysis, the variation of friction factor, f , versus Reynolds number, Re , for different corrugation angles is studied. Also, the variation of pressure drop in the corrugated channel with Reynolds number is analysed. From the calculations made the Reynolds number varies from 133 to 3200 for 60% glycerine solution, 90 to 2165 for 50% glycerine solution and 126 to 3030 for 40% glycerine solution.

The following are the plots of representing the variation of Pressure Drop with Reynolds number. The notations P30, P40 and P50 in the following plots (Fig.1. to Fig.4.) indicate the values of pressure drop in 30°, 40° and 50° corrugation angles respectively.

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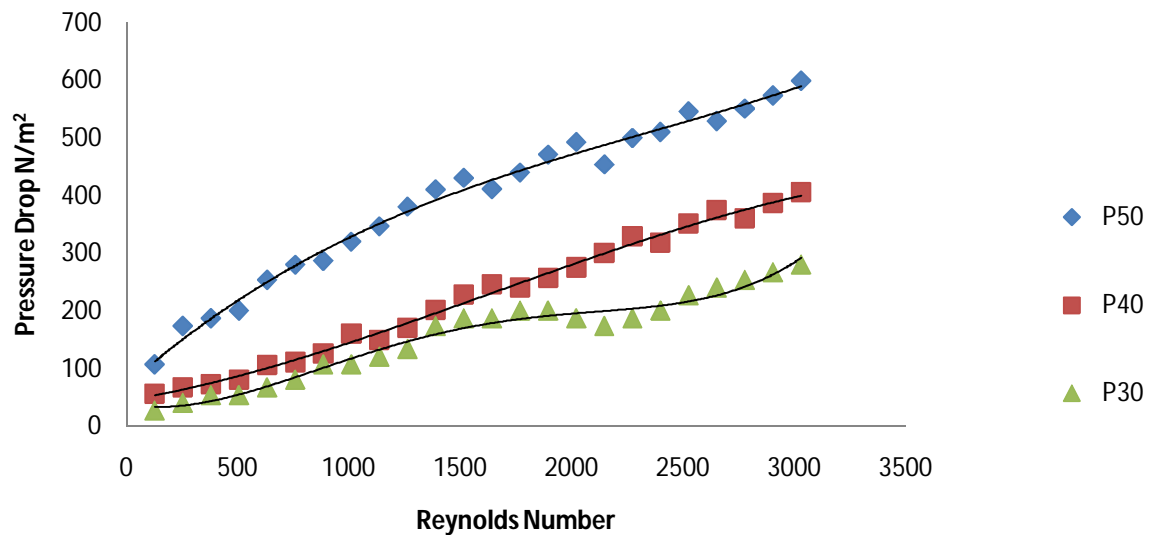


Fig.1. Variation of Pressure Drop with Reynolds number for 40% Glycerine Solution

The Fig.1. represents the variation of pressure drop with Reynolds number, when 40% Glycerine solution was run in the wavy corrugated plate heat exchanger. The trend is increasing in nature and the for a given Reynolds number, the value of pressure drop is maximum for 50° corrugation angle and minimum for 30° corrugation angle.

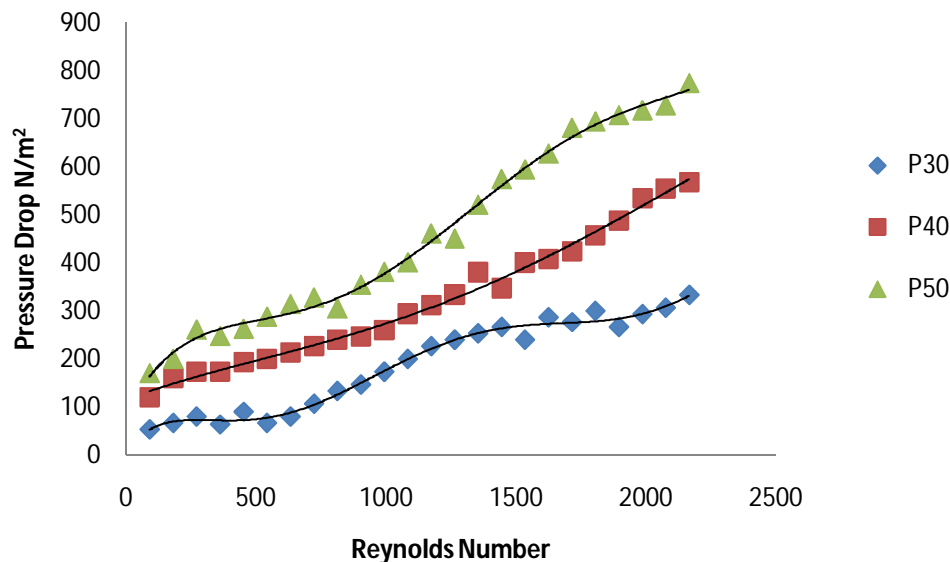


Fig.2. Variation of Pressure Drop with Reynolds Number for 50% Glycerine Solution

The test fluid of 50% concentrated Glycerine solution was considered and the pressure drop values with flow rate were noted and consequently the plot shown in Fig.2. was developed. On comparing the results in the three corrugation angles of 30°, 40° and 50° corrugation angles, the increasing nature the variation is noted and this is maximum for 50° corrugation angle and minimum for 30° corrugation angle.

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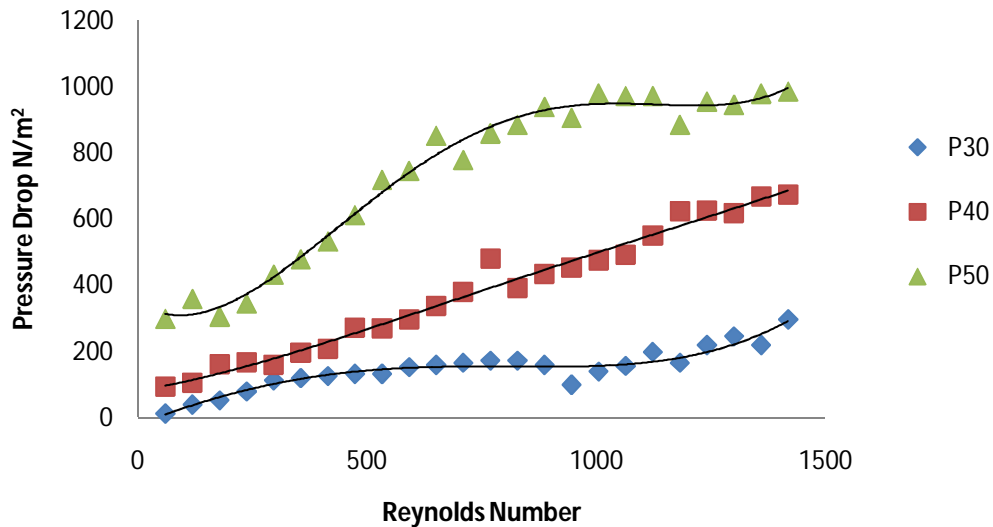
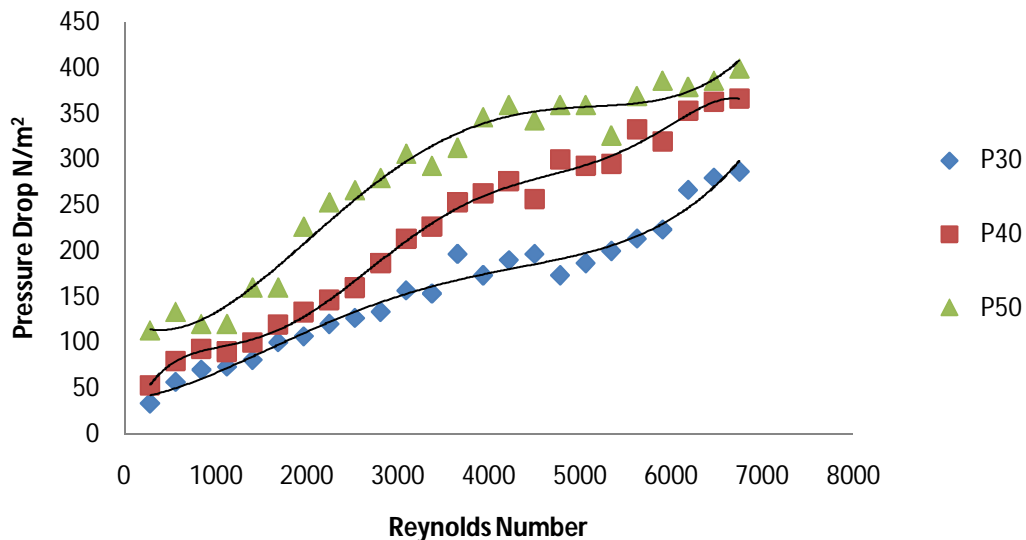


Fig.3. Variation of Pressure Drop with Reynolds Number for 60% Glycerine Solution

The plot represented by Fig.3. depicts the increase in pressure drop with Reynolds number when being tested with 60% Glycerine solution. The minor fluctuations might be due experimental conditions. However, the plot clearly shows that the pressure is minimum for 30° corrugation angle and maximum for 50° corrugation angle.



(d)

Fig.4. Variation of Pressure Drop with Reynolds Number for Water

Fig.4. represents the variation of pressure drop with water when water was used as the test fluid. When compared to the glycerine solutions, relatively lower values for pressure drop are obtained for water.

From the set of plots represented by Fig.1 to Fig.4., it is observed that the pressure drop varies with Reynolds number with a clearly increasing trend. For a given flow rate, that is, for a fixed Reynolds number, the value of

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pressure drop is maximum for a 50° corrugation angle, while it is minimum for 30° corrugation angle. It takes a moderate value for 40° corrugation angle.

The values of friction factor are calculated from the pressure drop readings plotted above, using equation the rearranged Darcy's equation. The plots for Friction Factor versus Reynolds number are developed. In the following plots' legends (Fig.5. to Fig.8.), the notation 'f 40,30' represents the value of friction factor for 40% glycerine solution in 30° corrugation angle and so on.

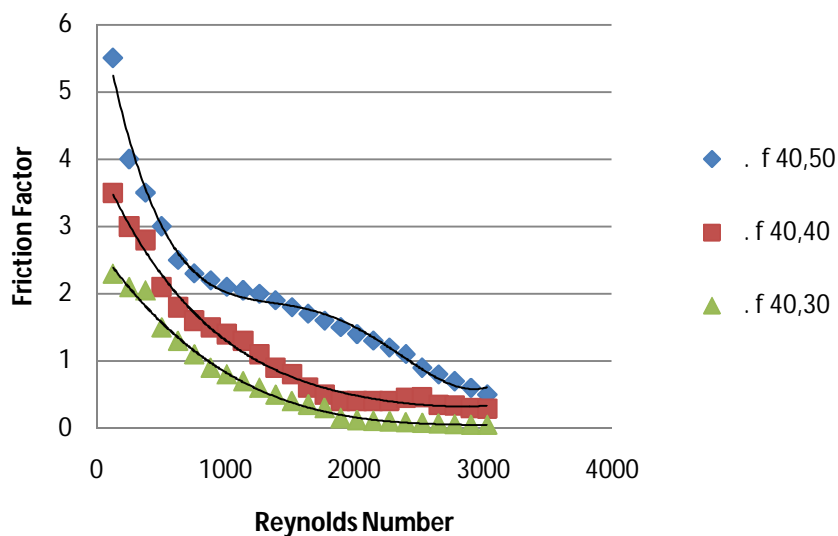


Fig.5. Friction Factor versus Reynolds Number for 40% Glycerine Solution

For 40% Glycerine solution, the plot for friction factor versus Reynolds number shows a decreasing trend as shown in Fig.5. The 30° corrugation angle yields low values of friction factor while 50° corrugation angle yields higher values. The value of friction factor yielded by 40° corrugation angle is moderate.

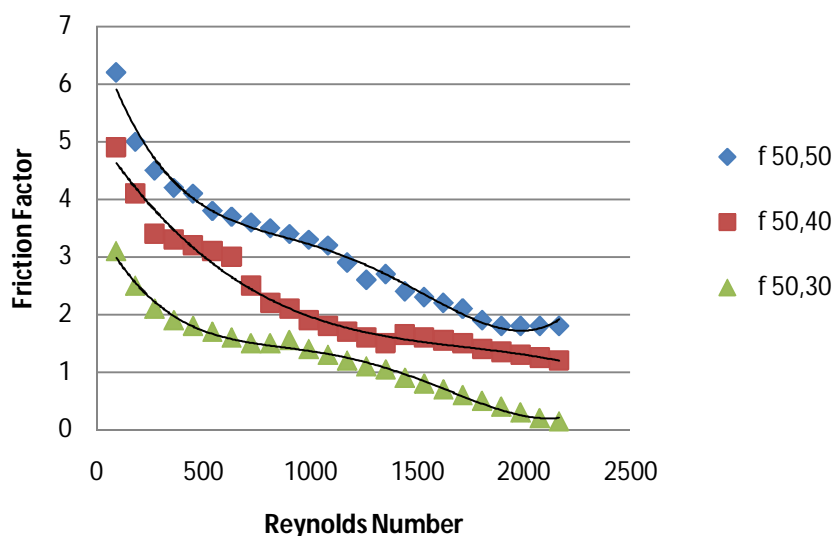


Fig.6. Friction Factor versus Reynolds Number for 50% Glycerine Solution

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When 50% Glycerine solution was considered, the plot obtained for friction factor versus Reynolds number indicates a decreasing trend, as shown in Fig.6. The variations for the three corrugation angles of 30°, 40° and 50° corrugation angles are also shown, which tell us that the value of friction factor is moderate for a 40° corrugation angle.

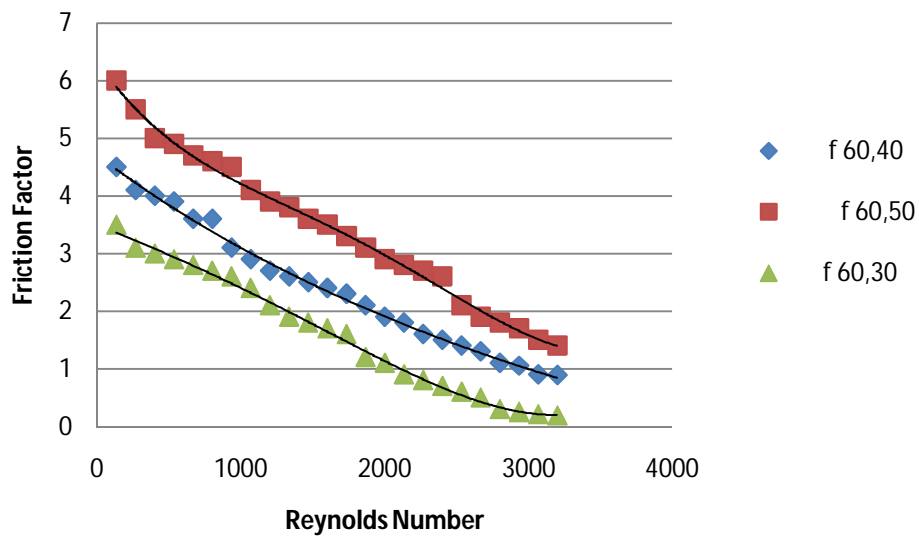


Fig.7. Friction Factor versus Reynolds Number for 60% Glycerine Solution

On studying the behaviour of friction factor with Reynolds number by taking the test fluid as 60% glycerine solution, the plot as shown in Fig.7. is obtained, where the trend is clearly decreasing in nature. The values of friction factor at a given Reynolds number are minimum for 30° corrugation angle and maximum for 50° corrugation angle.

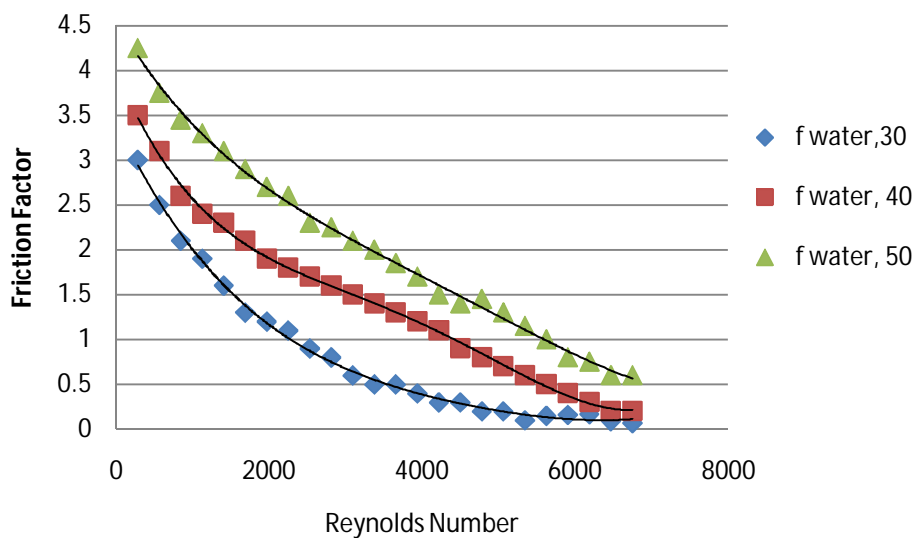


Fig.8. Friction Factor versus Reynolds Number for Water

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Fig.8. demonstrates the variation of friction factor with Reynolds number when water is considered as the test fluid. The trends are decreasing in nature. Moreover, the characteristic is closely matched by that of 40% Glycerine solution. The decreasing nature of the plot reveals the moderate values of friction factor taken by 40° corrugation angle, highest values taken by 50° corrugation angle and least values taken by 30° corrugation angle.

From the above plots shown in Fig.5. to Fig.8. the variation of friction factor with Reynolds number for glycerine solutions of mentioned concentrations (by volume) is decreasing in nature. In addition, it is clear from the plots that the friction factor decreases with increase in the corrugation angle. The friction factor recorded for 30° corrugation angle takes the least value, while it is medium for 40° corrugation angle. However, the value of friction factor shoots up for the 50° corrugation angle. Also, for higher flow rates, that is, as the Reynolds number increases, the friction factor diminishes and approaches zero. Nevertheless, the x-axis becomes the asymptote for the plot obtained. The behaviour of the solutions is compared to that of water. As the glycerine solution is diluted, its behaviour tends to approach that of water. Moreover, the values of friction factor are recorded relatively low for solutions of high concentration, that is, the friction factor for 60% glycerine solution being run is less than that of 50% and 40% glycerine solutions that has been recorded for a particular Reynolds number and for a given corrugation angle.

Based on the above study, a correlation between friction factor, Reynolds number and cosine of the corrugation angle has been developed. As cosine is a decreasing function, cosine of corrugation angle at 0 degrees corresponds to a flat plate and as corrugated angle increases, its cosine decreases and finally reaches 1, which represents a square channel. Hence, cosine of the angle is considered as it satisfies the conditions theoretically.

$$f = 2.718 Re^{-0.6675} \cos\theta^{0.057}$$

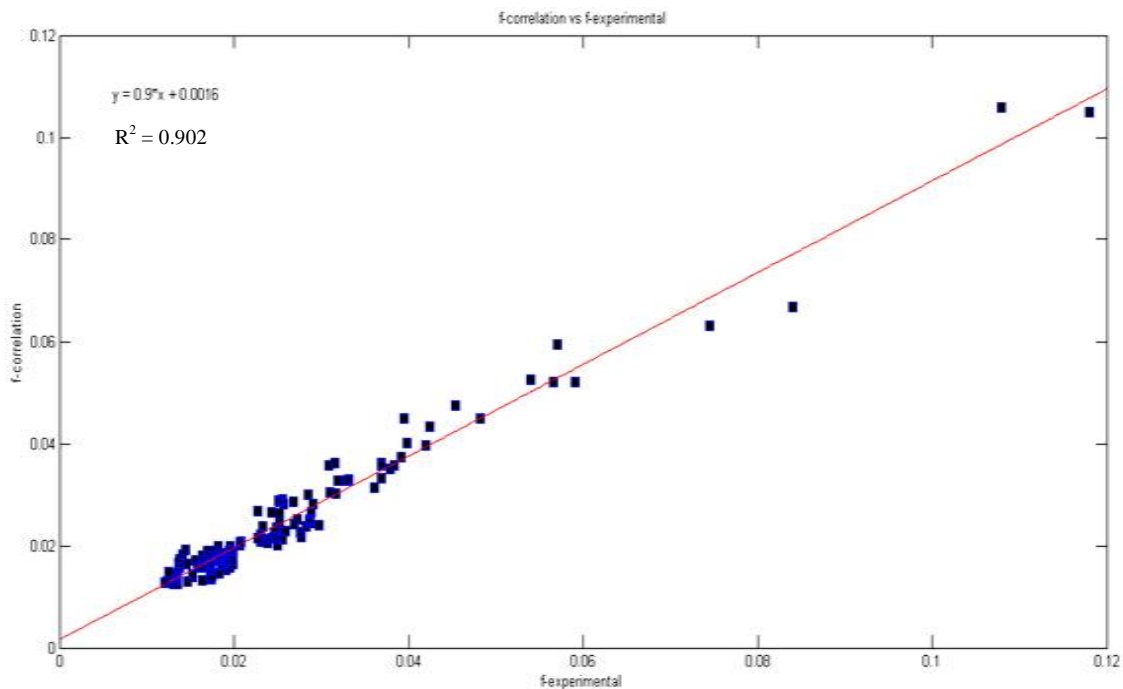


Fig.9. Plot of f-correlation versus f-experimental

Fig.9. Represents the plot of friction factor calculated from the correlation generated (f-correlation) and that obtained by experimental calculations (f-experimental). The distribution of the data points about a straight line is analysed and

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the R^2 was found to be 0.902. This shows that the correlation generated is quite reliable to represent the fluid flow in wavy corrugated plate heat exchangers.

V. CONCLUSION

It can be concluded that in a corrugated plate heat exchanger, friction factor decreases with the increase in Reynolds number. It is observed that the value of friction factor is low for 50° corrugation angle when compared to 30° and 40° corrugation angles. Moreover, value of friction factor is low for high concentration solutions. Moderate values are obtained in case of 40° corrugation angle and 40% concentration of glycerine solution. The correlation for fluid flow in wavy corrugated plate heat exchangers has been developed.

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