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CFD Analysis for Heat Transfer Enhancement in a Triangular Corrugated Plate Heat Exchanger

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***Abstract*- Over the past decades, environmental concerns with respect to thermal, air, and water pollution, as well as the disposal of waste, have motivated the need for energy savings and the increased exploitation of renewable energy sources. These facts have increased the emphasis on the use of high efficiency heat exchangers and have led to the development of more compact heat exchangers.**

Plate heat exchangers (PHEs) are categorized at the lower end of the compactness spectrum, and they are widely used for numerous industrial applications, featuring compactness, effectiveness, design flexibility and low cost. The corrugated plate heat exchanger has a great flexibility than the other types of heat exchangers; both its heat transfer area and its cooling flow could be increased or decreased easily, so; it is commonly used for enlargement and upgrading works..

By using CFD simulation, the performance of plate heat exchanger can be optimized and at the same time, it can reduce the operation cost and time when using experimental analysis. CFD simulations of turbulent forced convection heat transfer in a triangular corrugated channel subjected to uniform heat flux were carried out and compared with semi-circular corrugated plate. The computations were performed for a symmetrical triangular corrugated channel with varying Reynolds numbers (10000 ≤ Re ≤40000), volume fractions (6%). Based on the results obtained by the CFD calculations it is found that: From the CFD analysis it has been observed that in case of triangular corrugated plate heat exchanger the Nusselt number increased by 10.52 % as compared to semi-circular corrugated plate heat exchanger. Friction factor decreased by 6.36 % as compared to semi-circular corrugated plate heat exchanger.

Index Terms- Plate Heat Exchanger, Corrugated Plate, Reynold’s number, Nusselt number, Friction factor, CFD.

I. INTRODUCTION

Heat exchangers are heat transfer devices that exchange thermal energy between two or more mediums. Heat exchangers play a significant role in the operation of many systems such as power plants, nuclear reactors, process industries and heat recovery units. The development of heat exchangers design, reliability and maintainability is always a required matter to enhance the overall systems performance. Broadly there are two types of heat exchangers: Direct contact type heat exchanger and indirect contact type heat exchanger.

The principal types of heat exchanger used in the chemical process and allied industries are listed below:

1. Double-Pipe Exchanger: used For Cooling and Heating.
2. Shell and tube exchangers: used for all applications.
3. Plate and frame exchangers (plate heat exchangers): used for heating and cooling.
4. Plate-fin exchangers.
5. Spiral heat exchangers.
6. Air cooled: coolers and condensers
7. Direct contact: cooling and quenching.
8. Agitated vessels.
9. Fired heaters.

Plate heat exchangers have been widely applied in numerous industrial applications since their first commercial exploitation in the 1920s.Plate-type heat exchangers are usually built of thin plates (all prime surface). The plates are either smooth or have some form of corrugation, and they are either flat or wound in an exchanger. Generally, these exchangers cannot accommodate very high pressures, temperatures, or pressure and temperature differences. Plate heat exchangers (PHEs) can be classified as gasketed, welded (one or both fluid passages), or brazed, depending on the leak tightness required. Other plate-type exchangers are spiral plate, lamella, and plate coil exchangers.

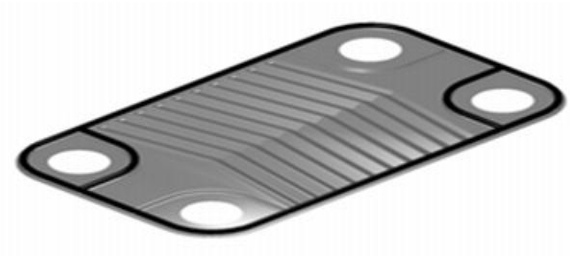

Figure 1: An individual plate for a heat exchanger

Enhancing the thermal-hydraulic performance of plate heat exchangers is of crucial importance for the energy conversion as well as for the improvement of the system economy, through savings in the capital investment. The efficiency of a plate heat exchanger can be improved either by optimizing its geometry or using heat transfer enhancement techniques.

The maximum cooling capacity of a plate heat exchanger depends on several factors:

- The inlet temperature of the hot and cold medium.
- The flow rate of the hot and cold medium.
- The media used.

The plate fin exchangers are mainly employed for liquid-to-gas and gas-to-gas applications. Due to the low heat transfer coefficients in gas flows, extended surfaces are commonly employed in plate-fin heat exchangers. By using specially configured extended surfaces, heat transfer coefficients can also be enhanced. While such special surface geometries provide much higher heat transfer coefficients than plain extended surfaces.

II. LITERATURE REVIEW

Numerous works has been done on Plate Heat Exchangers (PHEs) and their data related to thermal and hydraulic characterization are available in open literature. But there is a widespread discrepancy in these reported correlations and before commencing the present study, it was necessary to analyse the experimental facilities and procedure, data reduction methods, results and conclusions of some of the important past works.

Junqi et al. (2018) has experimentally investigated the thermal hydraulic characteristics for three types of fluids (R245fa, glycol & water) on plate heat exchanger surface. To overall evaluate the enhanced heat transfer, concept of pump power is provided. Using multiple regression method, dimensionless correlation equation of Nusselt number & friction factor are given. It is concluded that the plate chevron angle affect thermal hydraulic performance. Heat transfer increases with increase in chevron angle & vice versa.

Sharif Asal et al. (2018) used Computational Fluid Dynamics approach with the Reynolds stress model to investigate the influence of the apex angle on the thermal and hydraulic features of triangular cross-corrugated heat exchangers. The Reynolds number was varied from 310 to 2064. The numerical results varied by 5% than experimental results. On increasing the apex angle, pressure forces increase which lead to pressure drop along with heat exchanger coefficient. It is concluded that on increasing apex angle from 45^0 to 150^0, vorticity magnitude & pressure forces along the direction of flow increase which lead to higher heat transfer.

Khavin G. (2018) studied about the different height of corrugation for heat exchangers with a circular plate. For designing of such heat exchanger, use of plates with different corrugation heights along hot and cold side can prove to be very helpful. Due to this design, resistance to contamination increases.

Johnson et.al (2017) studied the analytical design of the heat exchanger which has been also numerically analyzed. On the basis of standard k- ε modelling CFD analysis have been done. The solution of the problem yields when the optimum values of flow rate, outer diameter of pipe and inner diameter of pipe to be used at an effective length for a double pipe heat exchanger. When the stream processes for specified flow rates then it was treated for a given inlet to outlet temperature. From the result it has been found that the design and analysis of the double pipe heat exchanger would be a great success.

R K Ajeel et.al (2017) studied CFD study on turbulent forced convection flow of Al2O3-water nanofluid in semi-circular corrugated channel. Computational Fluid Dynamics (CFD) simulations of heat transfer and friction factor analysis in a turbulent flow regime in semi-circle corrugated channels with Al2O3-water nanofluid is presented. Simulations are carried out at Reynolds number range of 10000-30000, with nanoparticle volume fractions 0-6% and constant heat flux condition. The results for corrugated channels are examined and compared to those for straight channels. Results show that the Nusselt number increased with the increase of nanoparticle volume fraction and Reynolds number. The Nusselt number was found to increase as the nanoparticle diameter decreased. Maximum Nusselt number enhancement ratio 2.07 at Reynolds number 30,000 and volume fraction 6%.

Hasanpour et al. (2016) have experimentally studied a double pipe heat exchanger with inner tube corrugated filled with various categories of twisted tapes from conventional to modified types (perforated, V-cut and U-cut). The twist ratio, the hole diameter, the width and depth ratio of the cuts have been varied and the Reynolds number has been changed from 5000 to 15000. Overall more than 350 experiments were carried out. Nusselt number and friction factor for corrugated tube equipped with modified twist tapes are found out to be higher than typical tapes.

Goodarzi et al. (2015) experimentally investigated the influence of different functional covalent groups on the thermal physical properties of carbon nanotubes – base fluid. Thermal properties such as convection heat transfer coefficient, Nusselt no., friction loss, pressure drop & pumping power were calculated for corrugated plate heat exchanger. Variation in Reynold's no. was done & nano-fluids properties were measured experimentally.

III. RESEARCH OBJECTIVES

The objectives of this study are:

1. To study the heat transfer performance of plate heat exchanger for heating.
2. To observe which configurations and parameters that gives the best results.
3. To study and modeling the heat transfer of corrugated plate heat exchanger using CFD simulation.
4. To simulate the flow and temperature fields in plate fin heat exchanger passages and to establish heat transfer and flow friction correlations of finned surfaces.

IV. METHODOLOGY

4.1 Geometry Setup

Figure 2 shows the geometry of the corrugated channel which will be denoted here as the test section while Figure 3 shows the computational model. The total length of the channel is Ltotal=700mm. The length of the test section is L2=200mm, with an upstream rectangular section of L1=400mm upstream to ensure a fully developed flow at the leading edge. The downstream section has a length of L3=100mm which is used to prevent the occurrence of adverse pressure effects caused by reversed flow which might at the trailing section. The channel height (H) is 10mm while the channel width (W) is 50mm. The triangular corrugated height h= 3.930 mm, corrugated width (w) =5mm with fixed pitch (p= 15mm). The geometry configuration was achieved by using Ansys design modular.

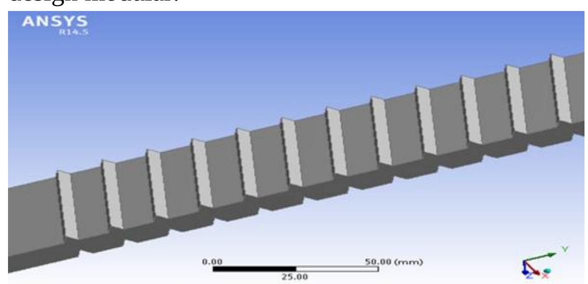

Figure 2 Triangular corrugated channel (test section).

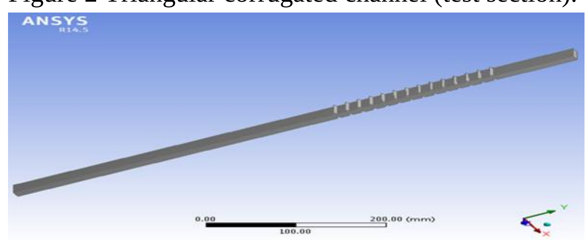

Figure 3 Model of the present study.

4.2 Meshing

The designed model of corrugated plate heat exchanger is meshed in ICEM Meshing. The meshing type have done is tetrahedral. The numbers of nodes that are used are 1429 and the numbers of elements that are used are 4268 in this design model. The mesh model of corrugated plate heat exchanger is shown below:

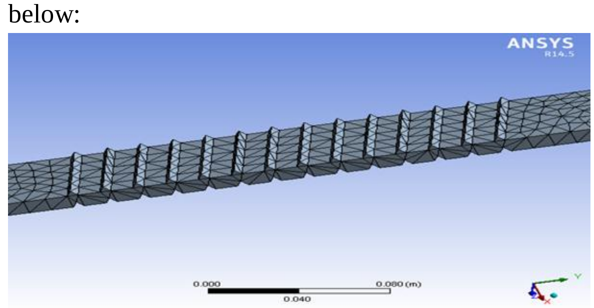

Figure 4 Mesh view of corrugated channel

3 Name Selection

A different part of the corrugated plate heat exchanger and fluid is selected and the names are given to them so that boundary conditions can be applied on different boundary.

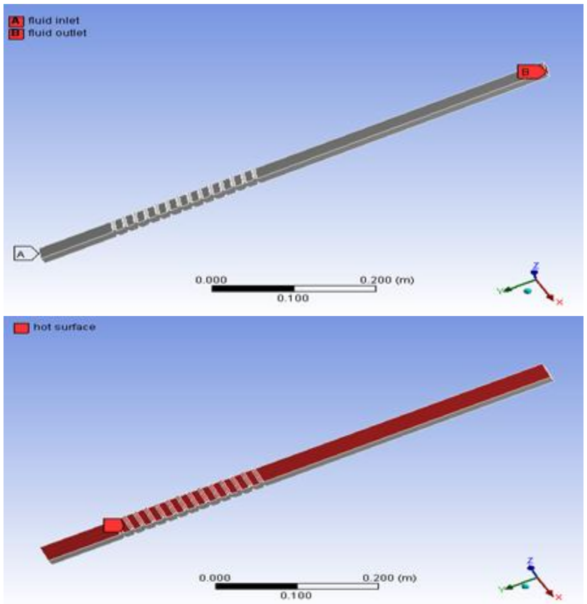

Figure 5 Name selection of corrugated plate heat exchanger

4.4. Model Selection

The governing equations are discretized by finite volume method and solved in steady-state implicit format. The SIMPLE algorithm is used to couple the velocity and pressure fields. The second order upwind scheme is applied and standard k-ε turbulent model with standard wall function is selected.

4.5 Boundary Conditions

In the analysis the boundary condition is same as considered by scholar's R K Ajeel et.al (2017) during the previous work. Some of the conditions are shown the boundary conditions that are applied on the model are as below:

Table 1 Boundary conditions for fluid flow.

S.no	Condition	Values
1	Velocity inlet(according to the Reynolds number)	10000,20000.30000,40000
2	Temperature inlet(K)	300k
3	Top and bottom walls subjected to constant heat flux(KW/m^2)	10

Table 2 Thermo physical properties of nanoparticle and base fluid at T=300 K

Material	Density ρ (Kg/m^3)	Dynamic viscosity µ (N-s/m^2)	Thermal conductivity K (W/m-K)	Specific heat CP (J/Kg-K)
Water	998.2	0.001243	0.6	4182
Al_2O_3	3600	------------	36	765

4.6 Solution and Results

After putting the boundary conditions, the solution is initialized and then iteration is applied so that the values of all parameters can be seen in a curve or line graph. After the iteration gets completed final result could be seen.

V. RESULTS AND DICUSIONS

The effect of Reynolds number i.e. 10000, 20000, 30000 and 40000 is expressed in the terms of contours.

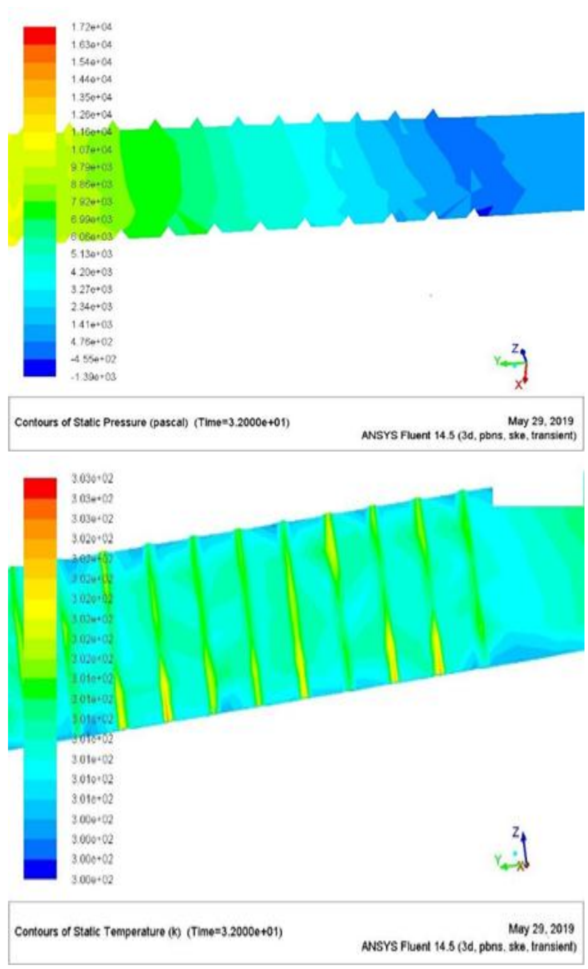

Figure 6 Contours of static pressure and temperature for triangular corrugated at Re=10000

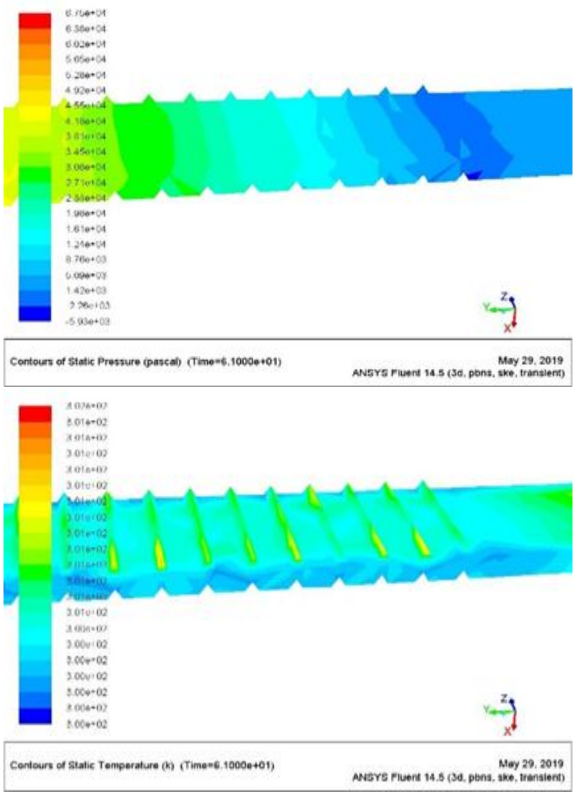

Figure 7 Contours of static pressure and temperature for triangular corrugated at Re=20000

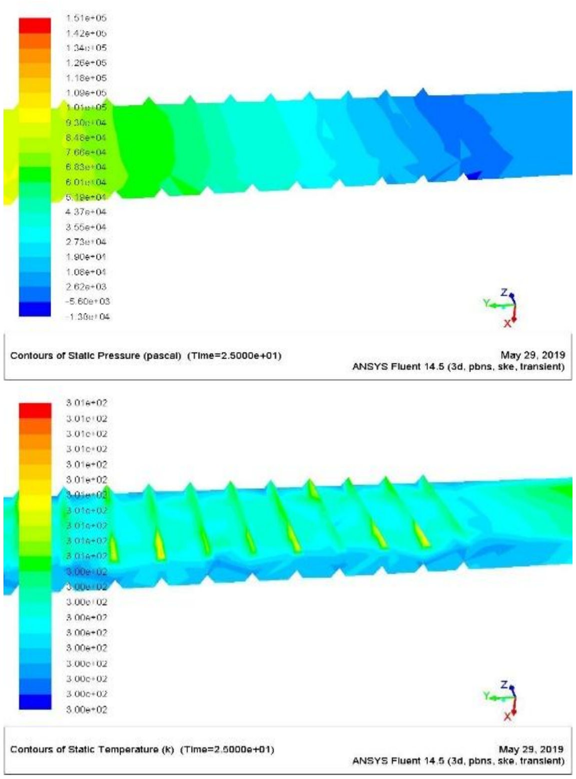

Figure 8 Contours of static pressure and temperature for triangular corrugated at Re=30000

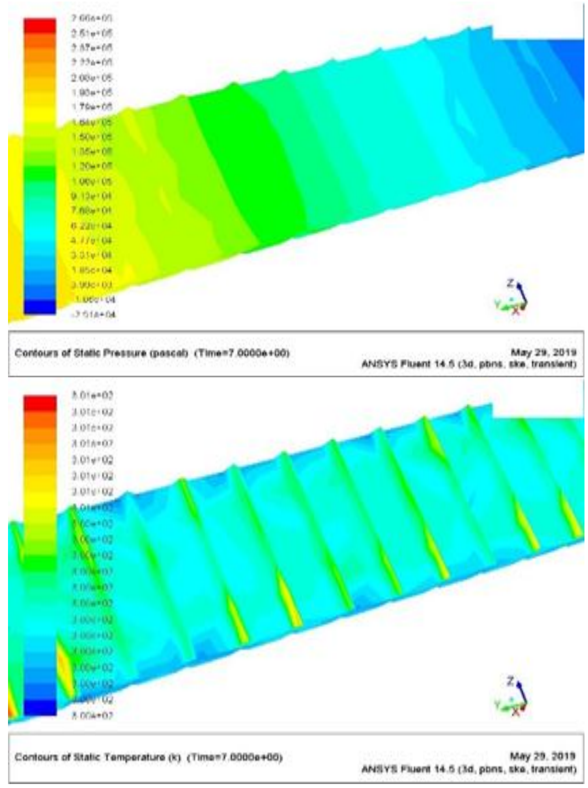

Figure 9 Contours of static pressure and temperature for triangular corrugated at Re=40000

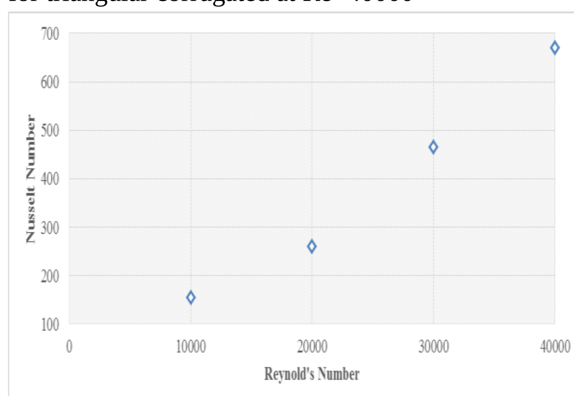

Figure 10 Variation in Nusselt number at different Reynold's number.

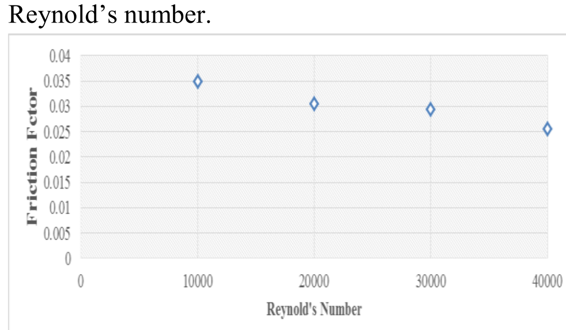

Figure 11 Variation in Friction factor at different Reynold's number.

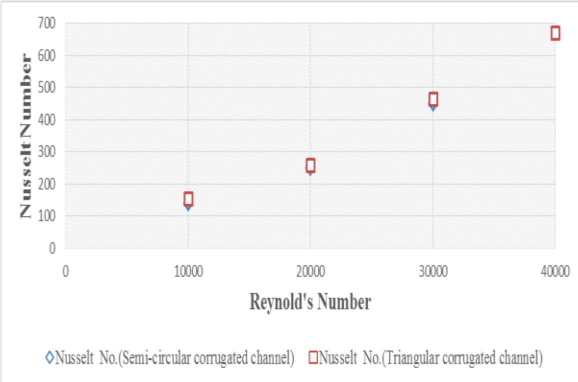

Figure 12 Comparison of Nusselt number at different Reynold's number for Semi-circular and triangular corrugated plate heat exchanger

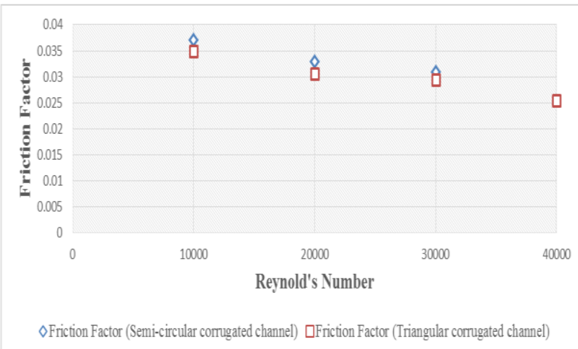

Figure 13 Comparison of Friction Factor at different Reynold's number for Semi-circular and triangular corrugated plate heat exchanger.

VI. CONCLUSIONS

The plate type heat exchangers are economic and efficient enough to be widely spread in many markets now days. With its low cost, flexibility, easy maintenance, and high thermal efficiency. The plate proven design is the main parameter for its high efficiency. In addition to the plate efficiency, corrugation patterns that produce turbulent flows, it is not only cause's unmatched efficiency; it also produces a heat exchanger self-cleaning nature, which in turn reducing the fouling effect.This study presents a CFD investigation for predicting the heat transfer characteristics and performance of a PHE having corrugated plate. Effect of various operating parameters on pressure drop, friction factor are discussed.

CFD simulations of turbulent forced convection heat transfer in a triangular corrugated channel subjected to uniform heat flux were carried out. The computations were performed for a symmetrical triangular corrugated channel with varying Reynolds numbers ($10000 \leq Re \leq 40000$), volume fractions (6%). Based on the results obtained by the CFD calculations it is found that:

- The results of CFD solution showed that Nu increasing with increase in Reynold's number while Friction factor decreases with increase in Reynold's number
- From the CFD analysis it has been observed that in case of triangular corrugated plate heat exchanger the Nusselt number increased by 10.52 % as compared to semi-circular corrugated plate heat exchanger.
- From the CFD analysis it has been observed that in case of triangular corrugated plate heat exchanger the Friction factor decreased by 6.36 % as compared to semi-circular corrugated plate heat exchanger.

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