Hydraulic and Thermal Analysis of Corrugated and Smooth Double Pipe Heat Exchanger using Computational Fluid Dynamics

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Abstract: The effectiveness of the heat exchangers depends on the geometry, working fluids, type and arrangement of the flow through heat exchangers. In the present work, a double pipe heat exchanger with corrugated pipes are studied to enhance the thermohydraulic performance of the heat exchangers. As the surface area of contact is increased, the heat transfer rate is expected to be increased. An investigation is done in the present work to find the pressure drop and heat transfer in the double pipe corrugated heat exchanger (DPCHE) using Computational Fluid Dynamics (CFD). A commercial computational code namely ANSYS is used for the purpose of solving the general governing equations using finite volume method. The various geometric parameters as well as operating parameters like Mass flow rates, temperature, and other fluid properties are considered for the analysis. The findings are compared with a similar analysis on Smooth double pipe heat exchangers to ascertain the enhancement in properties. Further, due to the corrugations in the pipes, the rise in pressure drop expected. This pressure drop in the DPHE would contribute to the performance of the compressor/pump in a system thereby increasing the pumping power required. The said increases are also ascertained for both smooth and corrugated geometries. Friction factors and Nusselt Numbers applicable to Corrugated Double Pipe Heat Exchangers (DPCHE) are investigated and comparisons are made against Smooth Double Pipe Heat Exchangers (SPHE) thus depicting the increases in heat transfer as proposed.

Key terms: Computational Fluid Dynamics (CFD), DPCHE, SPHE, ANSYS.

I. INTRODUCTION

From the literature survey two major techniques used for the improving the effectiveness of heat exchange in heat transfer devices were identified, one is the active method which involves using external sources for improving effectiveness and other is the passive method which involves modifying surface geometries or addition of fluid additives. Corrugated geometry is one of the many suitable passive techniques to enhance the heat transfer in thermal energy transfer devices by intermittently destroying the momentum and thermal boundary layers on the inner and outer walls of it. Saeedan et al. [1] have explored numerically the heat execution of a helically perplexed Heat exchanger joined with a 3D fine tube worked with Nano-liquids. At various volume concentrations Nano-particles of Cu, CuO, and CNT have been considered in water-based Nano-liquids. It has been examined that how temperature change and pressure drop are influenced by the Reynolds number and volume fixation. It has been found from the outcomes that both Heat exchange and weight drop increments with the expansion in the volume fixation and Reynolds number. Sheikholeslami et al. [2] have done numerical and test examination on turbulent stream and Heat move in a twofold pipe air to water exchanger has been finished utilizing cone shaped ring. Two clusters (Direct cone shaped ring (DCR) exhibit and Reverse conelike ring (RCR) exhibit) are considered. Exploratory investigation has been done in the wake of considering diverse estimations of Reynolds number (6000-12,000), It has been seen from the outcomes that the Nusselt number found to diminish with increment in open territory proportion and pitch proportion while it grows with improves of Reynolds number. It has been finished up from the examination that heat execution ascends with enlargement of funnel shaped plot for tapered ring exhibit. Zarrella et al**.** [3] have completed a relative examination among a helical-molded pipe and a twofold U-tube ground heat exchanger. By thinking about an equal electrical circuit of thermal resistance and capacitances, the trouble identified with heat exchange were fathomed. Demir et al. [4] completed a computational examination by taking constant temperature of wall performed on forced convection stream of Nano-liquids comprising of water with TiO_2 and Al_2O_3 Nano-particles in a flat tube. Mehran et al. [5] have revealed that as opposed to utilizing cylindrical shaped tube, cone shaped tube has been utilized as a novel enhanced geometry for twofold pipe heat exchangers. Different funnel shaped tube clusters with assorted stream headings were explored. Mehran et al. [6] have revealed that as opposed to utilizing cylindrical shaped tube, cone shaped tube has been utilized as a novel enhanced geometry for twofold pipe heat exchangers. Different funnel shaped tube clusters with assorted stream headings were explored. It has been discovered that entropy generation, entropy generation number, heat exchanger reversibility norm (HERN), heat exchange change number and effectiveness– NTU are the imperative ideas which have been considered for cases. The outcomes indicate 55% and 40% augmentation in effectiveness and Heat exchange change number at the ideal condition. Han et al. [7] thought about the procedure parameters, the characteristic numbers for heat exchange (Nu), obstruction(f) and general Heat exchange efficiency(n) computed by CFD, and are filled in as target capacities to the RSM (Nusselt number for folded tube (Nuc), Nusselt number for smooth tube (Nus), fanning factor for ridged tube (fc), Nuc/Nus, fc/fs and general Heat exchange coefficient (η)). The outcomes of optimal design are an arrangement of different optimal arrangements, called 'Pareto optimal arrangements'. As per the Pareto ideal bends, the ideal parameters of twofold pipe heat exchanger with inward corrugations with of Nuc/Nus ≥ 1.2 are observed to be P/D = 0.82, H/D = 0.22, r/D = 0.23, Re = 26,263, comparing to the most extreme estimation of η = 1.12. Appadurai et al. [8] have examined the Heat exchange utilizing Nano liquids in a twofold pipe heat exchanger which has been registered through Computational Fluid Dynamics (CFD) approach. Heat exchange execution of an inside balance in a round tube has been tentatively investigated. For various Reynolds number running from $2.0x10^4$ to $5.0x 10^4$, wall temperature, mass liquid temperature, and weight drop along the axis of the finned tube were estimated. It has been found from the investigation that there is increment of the heat execution of Nano liquids contrasted with water. Huminic and Huminic [9] have completed a 3-D examination in to ponder the Heat exchange attributes of a twofold tube helical Heat exchangers utilizing nanofluids. Nanoparticles with volume groupings of 0.5– 3 vol.% like CuO and TiO_2 having breadths of 24 nm scattered in water has been utilized as the working liquid. The mass stream rate of the water from the annulus was set at either half, full, or twofold the esteem and the mass stream rate of the Nano-liquid from the inward tube was kept steady. Nano liquids and water temperatures varieties alongside heat exchange rates and Heat exchange coefficients at the inward and external tubes have been appeared. For a similar mass stream rate through the internal tube and annulus, it has been discovered that the Heat exchange rate of Nano liquid was about 14% more prominent than the unadulterated water when 2% of CuO Nano-particles were included the water. From the examination, it has been presumed that the convective Heat exchange coefficients of the Nano-liquids and water is found to increment with expanding of the mass stream rate and with the Dean number. The outcomes have been approved by examination of recreations with the information by experimental conditions. Sivakumar and Rajan [10] examined the execution of Heat exchange and adequacy of the twofold pipe heat exchanger with two stream headings (one is parallel stream and counter stream). A business CFD bundle (ANSYS) has been utilized for this examination to create the 3D demonstrate heat exchanger

II. EXPERIMENTAL METHODOLOGY

In order to perform Thermohydraulic Analysis of Double Pipe Heat Exchanger with Corrugated Tubes as well as of smooth pipe heat exchanger computational studies have been done. The corrugated fluid domain for inner and outer flow in DPHE is generated using ANSYS FLUENT 15.0 design module. A cut section diagram depicting the tube structure is shown below in Fig 1. Inner corrugated fluid domain represents the flow of hot water where it enters from the left-hand side and exiting at the right side. The outer corrugated fluid domain indicates the flow of cold water which enters from the right side and exiting from the left side. It also shows the cross section of inner and outer corrugated fluid domains. As the two fluids flow in their domains there is heat exchange as well as variation of pressures and velocity due to corrugations. This localized pressure and velocity variations setup eddies which destroy the boundary layers between the fluid domains thus enhancing the heat transfer efficiency.

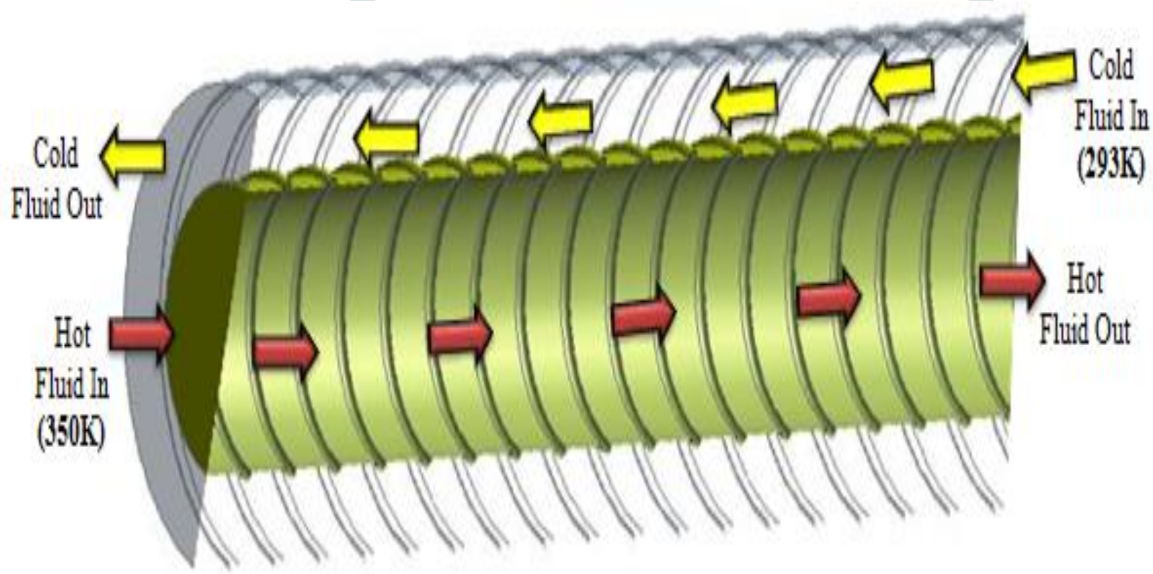

Fig. 1 Cross-sectional View of the corrugated fluid domains

The specifications of these fluid domains for corrugated pipes are enlisted in Table 1

Table 1 Geometrical specifications of Fluid domains of DPCHE

Length of DPHE ***(mm)***	**Inner pipe Dia** ***(mm)***	**Outer pipe Dia** ***(mm)***	**Corrugation Pitch** ***(mm)***	**Corrugation Depth** ***(mm)***
518	32	52	10	1

The table 2 below shows the various input properties of hot and cold water.

Table 2 Input characteristics of hot and cold fluid

Properties / Fluid	Temperature (K)	Viscosity (kg/ms)	Density (kg/m^3)	Specific heat(J/kgK)	Thermal conductivity (W/mK)
Hot water	350	0.000369	974.00	4193.2	0.6683
Cold water	293	0.001005	998.51	4182.3	0.5980

Water is used as a working fluid wherein it flows through the inner corrugated pipe at a temperature of 350K and in the outer corrugated pipe at the temperature of 293 denoted by hot water and cold water in further analysis. Analysis of smooth pipes is done using similar boundary conditions. Water is used as a working fluid in both types of analysis that is for smooth as well as corrugated pipes and the temperatures of water is kept ambient for both hot and cold fluid to negate the phase change effects.

III.RESULTS AND DISCUSSION

The outputs of the Computational fluid dynamics were used to find out the various other heat transfer and flow characteristics of the fluid in both the conduits. The section ahead represents the mathematical expressions those have been used to make the data available more meaningful in order to evaluate friction factor, Reynold's number, pressure drop, pumping power and Nusselt number.

3.1 Calculation for Reynolds Number

Reynolds Number can be estimated as,

$$Re = \frac{D_h V_{avg} \rho}{\mu} \quad [1]$$

Where V_{avg} = Average velocity of flow in the pipe (*m/s*)

ρ =Density (*kg/m^3*)

D_h = Hydraulic Diameter (*m*)

μ = coefficient of viscosity

in terms of mass flow rate the Reynolds number can be calculated as follows

$$Re = \rho D A \frac{l}{t \mu A}$$

or $$Re = \rho D \frac{V}{t \mu A}$$

or $$Re = D \frac{\dot{m}}{\mu A} \quad [2]$$

Where $\dot{m}$ = mass flow rate

D_h= hydraulic diameter = 4 flow area/wetted perimeter = $\frac{4\pi D^2}{4\pi D}$ = D (Diameter of pipe)

μ = coefficient of viscosity

V= volume of fluid

l = length being considered

The various values for Reynolds number calculated from eq [2] for hot and cold fluid in case of double pipe corrugated heat exchanger (DPCHE) and its smooth counterpart (SPHE) are depicted in tables 3 and 4 below. Owing to higher mass flow rates for hot fluid in both corrugated as well as Smooth pipe as well as lower viscosity of water at higher temperatures the Reynolds number is higher for hot fluid in comparison to the cold one for both the pipe configurations as is depicted from the tables presented below.

Table 3 Reynolds number values for hot fluid in DPCHE and SPHE

Mass flow rate (kg/s)	**Diameter (m)**	**Area (m^2)**	**Viscosity (kg/m-s)**	**Reynolds No.**
0.09	0.032	0.000804	3.69E-04	9709.138
0.08	0.032	0.000804	3.69E-04	8630.345
0.07	0.032	0.000804	3.69E-04	7551.552
0.06	0.032	0.000804	3.69E-04	6472.758
0.05	0.032	0.000804	3.69E-04	5393.965

Table 4 Reynolds number values for cold fluid in DPCHE and SPHE

Mass flow rate (kg/s)	**Diameter (m)**	**Area (m^2)**	**Viscosity (kg/m-s)**	**Reynolds No.**
0.065	0.02	0.000314	1.01E-03	4119.530
0.055	0.02	0.000314	1.01E-03	3485.756
0.045	0.02	0.000314	1.01E-03	2851.982
0.035	0.02	0.000314	1.01E-03	2218.208
0.03	0.02	0.000314	1.01E-03	1901.321

3.2 Calculation for Friction Factor

In fluid dynamics, the Darcy–Weisbach equation is an empirical equation, which relates the head loss, or pressure loss, due to friction along a given length of pipe to the average velocity of the fluid flow for an incompressible fluid. Friction factor values have been calculated by using the formula for pressure drop which is found out from computational results

$$\Delta p = \frac{f \rho L v^2}{2D_h}$$

Or $$f = \frac{\Delta p 2D_h}{\rho L v^2}$$ [3]

Where Δp = Pressure Drop (Pa),

f = Friction Factor,

L = Length of pipe (m),

D_h = Hydraulic Diameter (m),

v = velocity of flow

The values of Friction factor as ascertained from the above equation [3] for DPCHE and SPHE for fluids at higher and lower temperature are depicted in tables 5 to 8. The friction factor increases along the tables as we go from top to bottom with the decrease in pressure drop. This is attributed to the fact that the velocity also decreases along the table which has an inverse square relation with friction factor thus leading to its increase.

Table 5 friction factor values for DPCHE hot fluid

Pressure drop (Pa)	**Diameter (m)**	**Density (kg/m^3)**	**Length (m)**	**Velocity (m/s)**	**friction factor**
7.968	0.032	974	0.518	0.1149	0.0765
6.709	0.032	974	0.518	0.1022	0.0815
5.504	0.032	974	0.518	0.0894	0.0874
4.493	0.032	974	0.518	0.0766	0.0971
3.501	0.032	974	0.518	0.0638	0.1089

Similar trend can be observed from table 6 below which depicts the various values used for finding the friction factor for cold fluid flowing in the outer annulus region in DPCHE. The friction factor increases from top to bottom owing to dominant effect of velocity over diminishing pressure drop.

Table 6 friction factor values for DPCHE cold fluid

Pressure drop (Pa)	**Diameter (m)**	**Density (kg/m^3)**	**Length (m)**	**Velocity (m/s)**	**friction factor**
6.3005	0.02	998.51	0.518	0.2073	0.0113
5.0496	0.02	998.51	0.518	0.1754	0.0126
4.0050	0.02	998.51	0.518	0.1435	0.0150
3.2649	0.02	998.51	0.518	0.1116	0.0202
2.8163	0.02	998.51	0.518	0.0956	0.0237

From table 5 and table 7 it can be inferenced that although the velocities in case of DPCHE and SPHE are same, owing to same mass flow rates the friction factor for a particular mass flow rate is higher for DPCHE in comparison to SPHE. This is attributed to the effect of corrugations in corrugated pipes which leads to higher pressure drop and thus higher friction factor in comparison to pipe without corrugations.

Table 7 friction factor values for SPHE hot fluid

Pressure drop (Pa)	Diameter (m)	Density (kg/m^3)	Length (m)	Velocity (m/s)	friction factor
6.2095	0.032	974	0.518	0.1149	0.0596
5.3864	0.032	974	0.518	0.1022	0.0654
4.5827	0.032	974	0.518	0.0894	0.0727
3.7977	0.032	974	0.518	0.0766	0.0820
2.9720	0.032	974	0.518	0.0638	0.0924

Table 8 below shows the values of friction factor for Cold fluid through smooth pipes. The friction factor increases from top to bottom owing to dominant effect of velocity over diminishing pressure drop.

Table 8 friction factor values for SPHE cold fluid

Pressure drop (Pa)	Diameter (m)	Density (kg/m^3)	Length (m)	Velocity (m/s)	friction factor
4.2057	0.02	998.51	0.518	0.2073	0.0076
3.5051	0.02	998.51	0.518	0.1754	0.0088
2.8166	0.02	998.51	0.518	0.1435	0.0105
2.1415	0.02	998.51	0.518	0.1116	0.0132
1.8122	0.02	998.51	0.518	0.0956	0.0153

3.3 Friction factor and Reynolds number variation

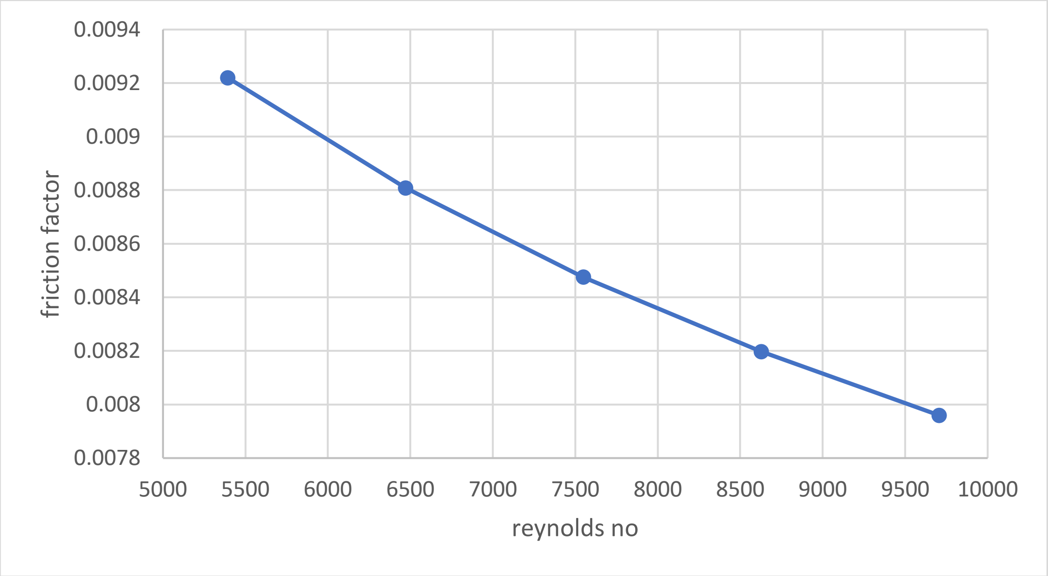

Fig. 7 f vs. Re variation for hot water

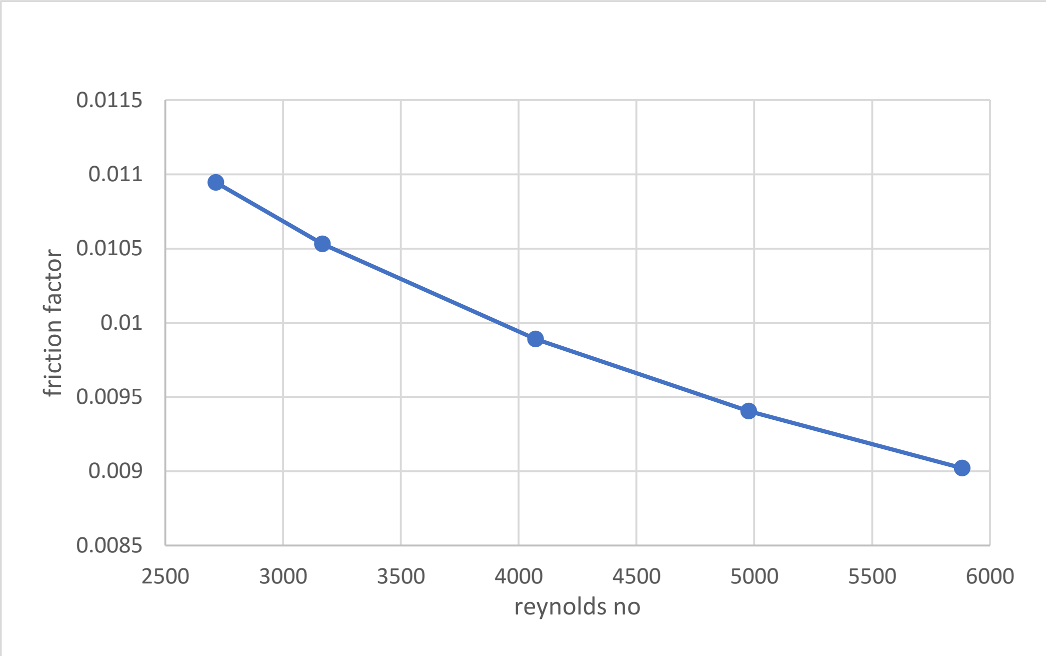

Fig. 8 f vs. Re variation for cold water

From Fig. 7 and Fig. 8, it can be noticed that with the increase in the Reynolds number the friction factor is found to decrease for both hot and cold fluid flow. This implies that the pressure drop will reduce with increase in the Reynolds number.

3.4 Nusselt number vs Reynolds number variation

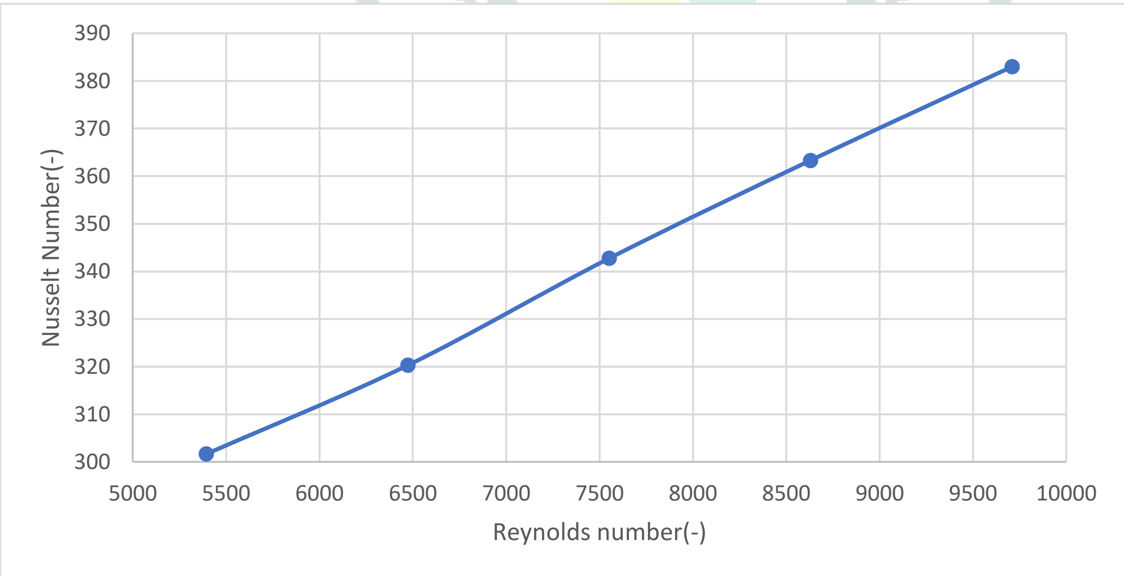

Fig. 9 Nu vs. Re variation for hot water

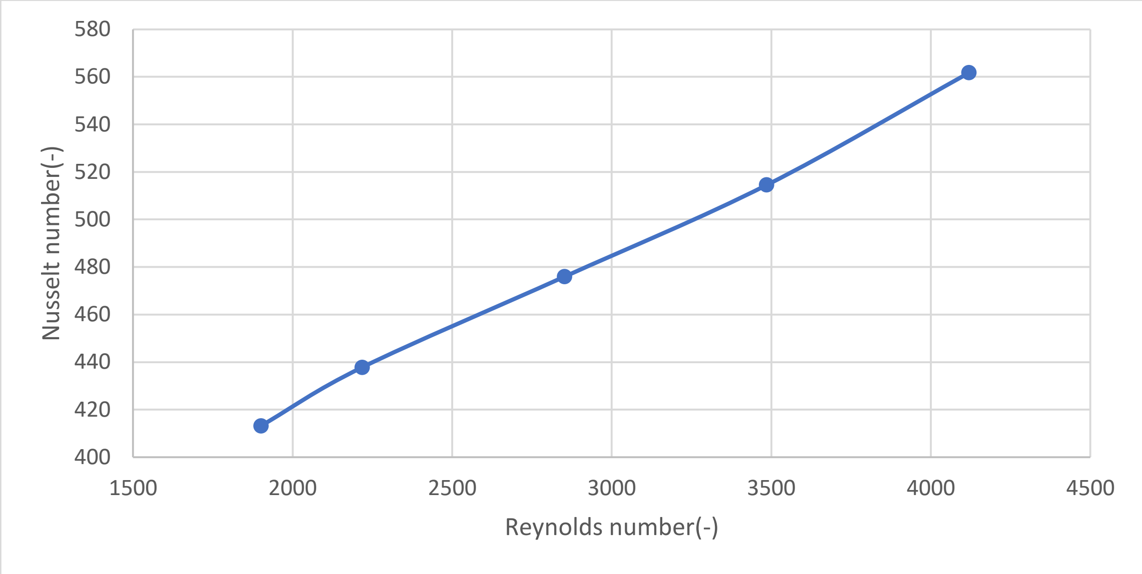

Fig. 10 Nu vs. Re variation for cold water

Fig. 9 and Fig. 10 show the variation in Nusselt number with the Reynolds number for cold and hot water flowing through the outer and inner corrugated pipes of double pipe heat exchangers. It can be observed from the plots that Nusselt number increases with the increase in the Reynolds number. This may be due to the increase in the convective heat transfer coefficient which leads to increase in total heat transfer rates.

3.5 Pumping power variation with flow rate

Fig. 11 and Fig.12 shows pumping power required to pump the hot and cold fluid. It can be noticed that the pumping power is found to increase with the increase in mass flow rate for both hot and cold fluid. This is attributed to the fact that with the increase in mass flow rate the pressure drop increases which will increase the pumping power.

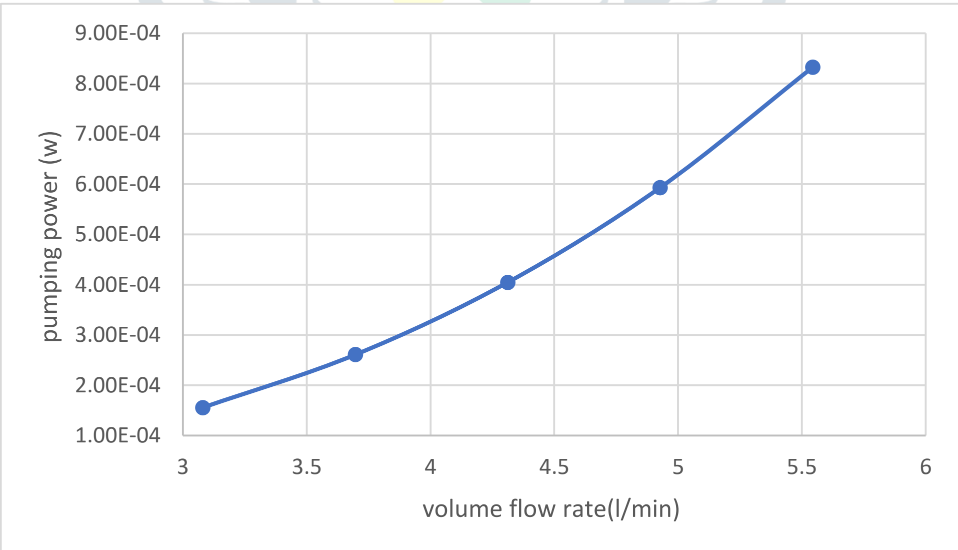

Fig 11 P vs V variation for hot fluid

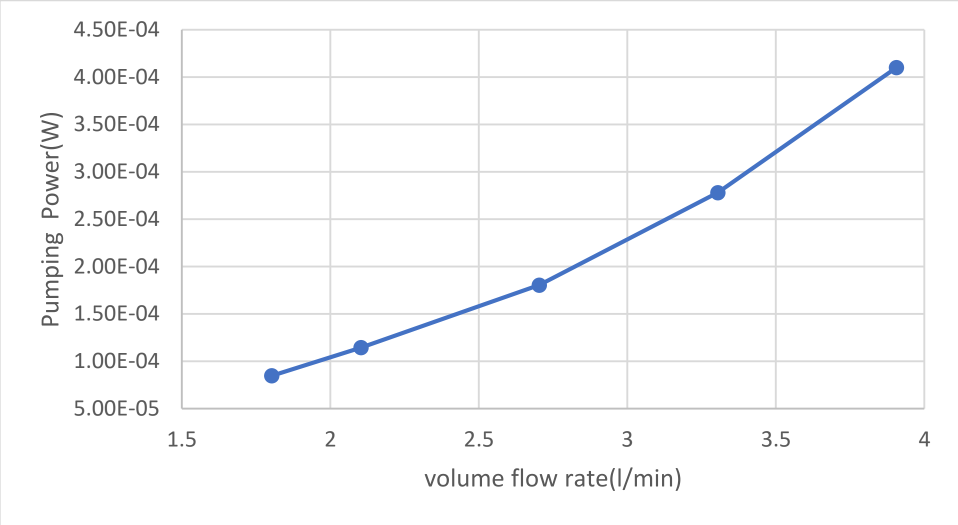

Fig 12 P vs V variation for cold fluid

III. CONCLUSIONS

In the present study, computational analysis on the corrugated double pipe heat exchanger has been done using ANSYS FLUENT 15.0. Corrugated fluid domains were created in the software and flow analysis has been done using Realizable 2 Equation Viscous Model after generating medium meshing. The analysis was performed by considering different mass flow rates of cold and hot fluid at different temperatures

Certain conclusions are made and these are enlisted below:

- It can be concluded that there is a pressure drop of 4-5 Pa for a heat exchanger length of 518 mm.
- It has been found that the pumping power increases with the increase in mass flow rate for both hot and cold fluid.
- Friction factor is found to reduce with the increase in Reynolds number which results in lower pumping power which is required to pump the fluid.
- As Nusselt number is found to increase with Reynolds number therefore it can be concluded that the total heat transfer rates will increase with the increase in the convective heat transfer coefficients.

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