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NUMERICAL INVESTIGATIONS OF DOUBLE PIPE HEAT EXCHANGER WITH DIFFERENT HEAT TRANSFER FLUIDS

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ABSTRACT

Heat exchangers are the most useful systems which are being used in different industries now-a-days as a purpose of cooling in order to prevent the damages of the various equipment and volatile substances from overheating. Double Pipe Heat Exchangers are very popular among various types of heat exchangers for their flexible manufacturing and low cost for implementation and maintenance. As a result, various researches have been done on the basis of performance analysis of double pipe heat exchangers. This experimentation is simulation based and has been done on Solidworks 2020. The primary motive of this experiment is to evaluate the heat transfer performance of double heat exchanger with variation of fluid temperatures and Reynold's No. The pressure drop behavior of DPHE has also been studied. Thus, the efficiency of double pipe heat exchangers has also been examined.

Keywords: Counter Flow; Double Pipe Heat Exchanger; Pressure Drop; Reynold's No

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NOMENCLATURE

DPHE	Double Pipe Heat Exchanger
LMTD	Logarithmic Mean Temperature Difference
Re	Reynold's Number
Nu	Nusselt Number
Pr	Prandtl Number

1. INTRODUCTION

Energy is the important factor of our lives. Everyone is worried about the decreasing natural resources of energy day by day. Having limited resources and vast applications the energy should be used effectively and efficiently in the industries. In chemical processes heat exchanger is the simplest and the most effective system. For maximum heat transfer rate and for minimum heat loss these heat exchangers are being operated in the industries. A heat exchanger is a mechanical device that interchanges the heat between two fluids of diverse temperatures which are segregated by a rigid wall. The temperature difference causes this transfer of heat. Convection mode of heat transfer is accountable for the maximum contribution of heat transfer among the others in a heat exchanger. In a double pipe heat exchanger, forced convection permits the transition of heat from one moving fluid to another moving fluid. Since the convection mode of heat transfer is in charge of transferring the heat through the pipe surface, it is combined into the stream. Thus, the flow of the stream eliminates the heat which is transferred.

Heat exchangers are extensively used in the industries like thermal power plants, nuclear reactors, food-processing units, pharmaceutical industries and air-conditioning systems because they need some heating, cooling, and energy recovery systems.

The double-pipe heat exchangers are entitled as the easiest types of heat exchangers. Because, in this form of heat exchanger one liquid or gas flows inside the pipe and the other liquid or gas flows within that pipe and other pipe that encloses the first. A double pipe heat exchanger is a type of tube construction in which the hot liquid flowing through the inner pipe transfers its heat to cool the water flowing through the outer pipe. The overall process is in steady state until the circumstances changes, like flow rate and inlet temperature. Sensible heating or cooling of fluids takes place in double pipe heat exchangers.

There are two flow configurations in this heat exchanger. When the flow of the two streams is followed by the identical direction then is called parallel flow and when the flow of the streams is followed by the reverse directions then it is called counter flow.

Because of easy design, less maintenance costs, low installation costs and flexibility double pipe heat exchangers are being operated in various industries. They work efficiently in low scale industries where the total heat surface area is less than 500 square feet.

1.1. Literature Review

Shiva Kumar et al. [1] In this study of experimentation was done with warm and cool fluid in the inner and outer tube separately in a double pipe heat exchanger. After comparing results with bare heat exchanger which experimentation results got by doing experimentation using triangular, rectangular and concave parabolic finned arrangement on the outside body of inside tube. So, after many comparisons of finned and unfinned one the thermal characteristics are more on finned one.

Bharath Naik [2] This study shows an enhancement of heat transfer using different nanofluids and also which have particles (Al_2O_3, Cu, Ag, TiO_2, SiO_2, Fe) of volume fraction ($0.02<0<0.05$). The double pipe heat exchanger model was done on the software solid works. The CFO analysis was used for the numerical. When we see the results the heat transfer of heat rate increases with rise in flowrates and it also increases with rise in operating temperature and also by the cluster of nanoparticles.

Fatih Selime Fendigil [3] In this work, the experiments and numerical investigation was done using SiO_2 nanoparticles. The numerical investigation was conducted to get the effects on flowrate, temperature, overall heat transfer coefficient and different solid particle volume fractions by flowing the nanofluid in the inner setup. The overall heat transfer coefficient was increased by including all nano particles and also found increasing in volumetric flow rate of nanofluid. The effective thermal conductivity was included by Brownian effect.

Mohammad Hussein Bahmani [4] they gave full clarifications on characteristics on transfer of heat in Double pipe heat exchanger in simple arrangement. The important investigation was carried out on transfer of heat flow inside Double pipe heat exchanger through CFD. The data available was used in consideration with the observations made an understanding of effects and dependency of inner pipe in heat transfer. This makes the specific small aspect ratio for inner pipe which is beneficial to heat transfer.

N. Targui, H. Kahal Erras [5] In this study, the numerical was done base on characteristics of double pipe heat exchanger with porous arrangement when transfer of heat takes place. the main porous construction is insisted in clearance of two arrangements on the inner cylinder and outer cylinder in a staggered fashion. The modelling of the porous region was purely done by the Darcy-Brinkman-Forchheimer model as the Governing equations was solved by finite volume method. By considering all the effects of different parameters and found that the maximum transfer of heat was occurred when porous construction was obtained in arrangement of cylinder which is outside. Particularly these rates are increased at places where narrow clearance and high thickness.

Hamed Sadighi Dizaji, Samad Jafar Madar, Farokh Mobadersani [6] The experimental investigation of heat transfer, pressure drop, and effective ness in double pipe heat exchanger was carried out and which is made up of corrugated outer and inner tubes. The investigation was through new arrangement of convex and concave corrugated tube. The determination of heat transfer coefficient was determined using Wilson plots. The temperature of 4- and 8-degree centigrade are used in hot (inner) and cold(outer) tube inlets. The range of Reynolds number used was 3500-18000 based on the space arrangement on the hydraulic diameter of the two tubes. The results found that the outer tube configuration and arrangement type of corrugated tubes have significant effect on thermal and frictional characteristics. Maximum convex and concave corrugated outer and inner tubes.

Mehdi Bahiraei , Morteza Hangi [7] The study on water-based mg-zn ferrite magnetic nanofluids in an outer flow double pipe heat exchanger under magnetic nanofluids was investigated. The hot and cold-water flows in tube side and annulus side respectively. The experimentation observations are on some parameters such as magnitude of the magnetic field, Reynolds number, concentration, size of the particles. The following main observations are concentration is higher at central regions of the tube because of non-uniform distribution of particles and then magnetics field make the distribution of particles which results in uniformity.

Mohamad Omidi et al. [8] his analysis on the improvement process of double pipe heat exchanger and transfer of heat extent methods have also been clearly explained. Later different studies on subjects using nanofluids in double pipe heat exchanger are explained in individual facts. This assessment presents, the mutual relation between Nusselt number and pressure drop coefficient.

M. Sheikholeslami et al. [9] They presented analysis of forced convective turbulent hydrothermal in a double pipe heat exchanger. Turbulators pierced with holes are used in annulus region. The analysis shows temperature gradient decreases with increase in pitch ratio and the thermal performance intensify increase with adding of open area ratio. NSGII was used for making of design.

Milad Setareh, Majid Saffar-Avval, Amir Abdullah [10] They discussed about the investigation which was done experimentally and numerically on transfer of heat improvement in a double pipe heat exchanger in the presence of ultrasonic vibrations for this experimental study the construction of test setup was made of two pipes which are same centered and for applying ultrasonic vibrations a bolted Langevin ultrasonic transducer push to the inner pipe was used. They took open foam software to perform numerical study on transfer of heat improvement. There is an increasing acoustic power Qc and Qh was shown in the results of the experiment and outlet temperature increases for cold fluid and decreases for hot fluid. There for enhancement factors increases as the constant at Qc. The mechanism for understanding transfer of heat was totally found by numerical investigation.

2. METHODOLOGY

The CAD model of DPHE has been designed on Solidworks 2020 by considering the following dimensions and different materials as well as different boundary conditions have been selected for the investigation of heat transfer performance on the heat exchanger with different kinds of heat transfer fluids. Water has been chosen as a cold fluid on the other side, Ethanol as a hot fluid has been considered.

Table 1 Design Specifications

Parameter	Inner Pipe	Outer Pipe
Length	1500 mm	1200 mm
Diameter	50mm	90 mm
Thickness	10 mm	10 mm

Table 2 Material and fluid selection.

Tube	Material	Fluid
Inner Tube	Cooper	Ethanol
Outer Tube	Brass	Water

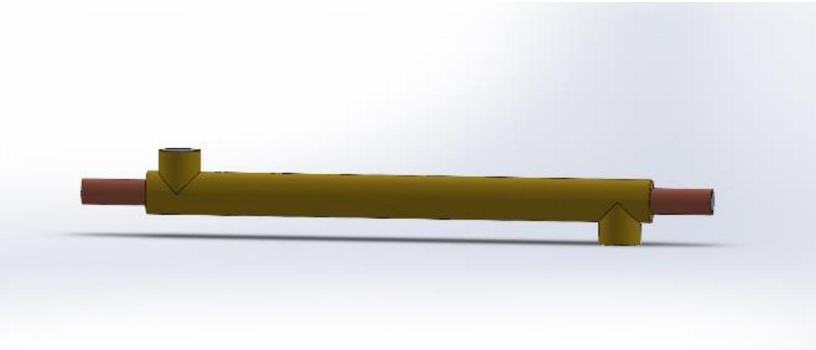


Figure 1 CAD model of DPHE.

2.1. Boundary Conditions

Three sets of boundary conditions have been taken into consideration for the investigation of Double Pipe Heat Exchanger. The boundary conditions are shown below:

Table 3 Boundary conditions.

Set No.	Fluid	Inlet Temperature (℃)	Mass Flow Rate Kg/s
1	Hot Fluid (Ethanol)	70	0.15
	Cold Fluid (Water)	30	0.1
2	Hot Fluid	80	0.15

	(Ethanol)		
	Cold Fluid (Water)	40	0.1
3	Hot Fluid (Ethanol)	90	0.15
	Cold Fluid (Water)	45	0.1

3. RESULTS AND DISCUSSIONS

In this investigation, the counter flow configuration of DPHE has been taken into consideration and different materials and fluids for inner tube and outer tube have been selected. Three different sets of boundary conditions e.g.- inlet temperature, mass flow rate for hot fluid and cold fluid have been introduced for the CFD simulation of DPHE as discussed earlier. The output results of DPHE according to the inlet boundary conditions have been studied to determine the heat transfer performance as well as pressure drop characteristics of DPHE. Moreover, relations between various parameters to evaluate the investigation have been discussed in this chapter.

Table 4 Outlet temperatures of DPHE after CFD simulation.

Set No.	Fluid	Inlet Temperature (°C)	Outlet Temperature (°C)	Mass Flow Rate Kg/s
1	Hot Fluid (Ethanol)	70	68.34	0.15
	Cold Fluid (Water)	30	30.80	0.1
2	Hot Fluid (Ethanol)	80	78.31	0.15
	Cold Fluid (Water)	40	40.83	0.1
3	Hot Fluid (Ethanol)	90	88.11	0.15
	Cold Fluid (Water)	45	45.97	0.1

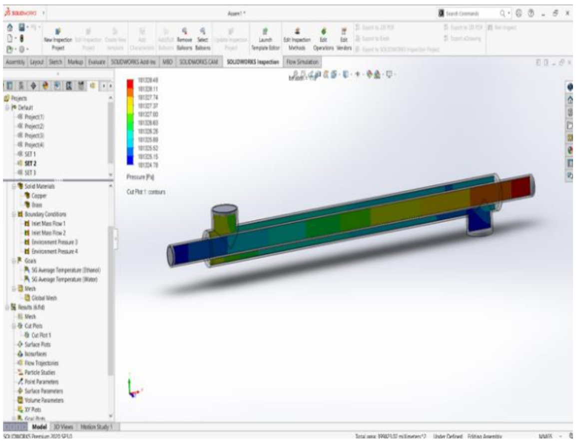


Figure 2. Cut Plot of pressure in Double Pipe Heat Exchanger. in Double Pipe

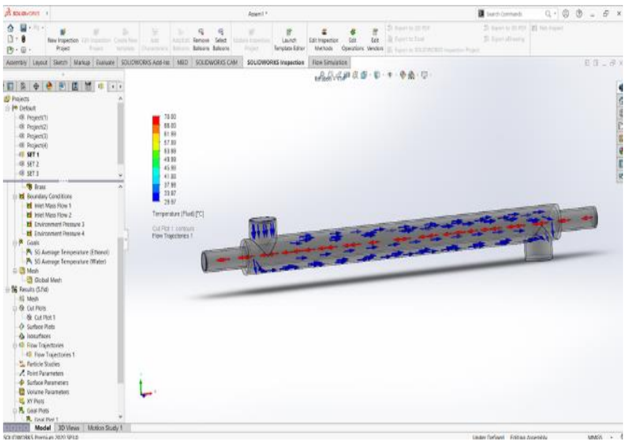


Figure 3. Flow Trajectories of fluid temperature Heat Exchanger.

3.1. Velocity

Velocity of hot fluid (Ethanol) and cold fluid (Water) has been calculated by using following equation:

$$V = \frac{m}{\rho A} \qquad \text{eq. – 1.1}$$

The cross-sectional area of inner and outer tube is calculated as follows:

$$A_h = \frac{1}{4}\pi D_i^2 \qquad \text{eq. – 1.2}$$

$$A_c = ¼\, \pi(D_0^2 - D_i^2) \qquad \text{eq. – 1.3}$$

Here, D_h is taken as hydraulic diameter of outer tube which is,

$$D_h = D_o - D_i \qquad \text{eq. – 1.4}$$

Table 5 Velocities of hot and cold fluid according to cross-sectional areas.

Set No.	Fluid	Velocity (V) m/s	Cross Sectional Area (A) m^2
1	Hot Fluid (Ethanol)	0.023	0.00196
	Cold Fluid (Water)	0.012	0.0044
2	Hot Fluid (Ethanol)	0.023	0.00196
	Cold Fluid (Water)	0.014	0.0044
3	Hot Fluid (Ethanol)	0.023	0.00196
	Cold Fluid (Water)	0.015	0.0044

Velocity of Ethanol remains constant and there is a slight increase in velocity of cold fluid for different sets of data have been observed.

3.2. Reynold's Number

It is a dimensionless parameter, termed as the ratio of inertia forces to the viscous forces. As the flow configuration in pipes mainly relies on different properties like flow velocity, surface geometry, surface roughness, type of fluid among other characteristics, it is used to evaluate the flow configuration whether the flow is laminar or turbulent. If the Reynold's number is smaller than 2400, the flow is said to be laminar and if the Reynold's number is greater than 4000, the flow is said to be turbulent.

Reynold's number for hot fluid and cold fluid has been calculated by using the following equation:

$$\text{Re} = \frac{VD}{\nu} \qquad \text{eq. – 2}$$

Table 6 Reynold's No. for different sets of boundary condition.

Set No.	Fluid	Reynold's No (Re)
1	Hot Fluid (Ethanol)	7152.88
	Cold Fluid (Water)	1149.28
2	Hot Fluid (Ethanol)	809.97

	Cold Fluid (Water)	1395.84
3	Hot Fluid (Ethanol)	769.79
	Cold Fluid (Water)	1525.70

It is found that Reynold's No. increases in case of cold fluid and decreases in case of hot fluid as temperature varies according to different sets of data. The flow configurations come out as laminar except for the hot fluid in first data set by observing the Reynold's No.

3.3. Prandtl Number

Prandtl Number is a dimensionless quantity which signifies the thermal boundary layers and the relative thickness of the velocity. Prandtl no. for the hot fluid and cold fluid has been calculated as follows:

$$\mathrm{Pr} = \frac{\rho C p v}{K} \qquad \text{eq.- 3}$$

The results of Prandtl No. have been shown in following table:

Table 7. Prandtl No. for different sets of boundary condition.

Set No.	Fluid	Prandtl No. (Pr)
1	Hot Fluid (Ethanol)	$4.263e^{-6}$
	Cold Fluid (Water)	$3.056e^{-5}$
2	Hot Fluid (Ethanol)	$3.916e^{-5}$
	Cold Fluid (Water)	$2.645e^{-5}$
3	Hot Fluid (Ethanol)	$4.242e^{-5}$
	Cold Fluid (Water)	$2.289e^{-5}$

3.4. Nusselt Number

It is a dimensionless quantity which signifies the improvement of transfer of heat through a layer of fluid by the convection relative to conduction across the same layer of fluid. It helps to find out the heat transfer co-efficient of the heat Exchanger.

The following correlation is used to determine the Nusselt No. for hot fluid and cold fluid:

$$\mathrm{Nu} = 0.023\ \mathrm{Re}^{0.8}\ \mathrm{Pr}^{0.4} \qquad \text{eq.- 4}$$

The following table shows the results of Nusselt No. for hot and cold fluid:

Table 8 Nusselt No. for different sets of boundary condition.

Set No.	Fluid	Nusselt No. (Nu)
1	Hot Fluid (Ethanol)	0.1982
	Cold Fluid (Water)	0.1009
2	Hot Fluid (Ethanol)	0.0843
	Cold Fluid (Water)	0.1113
3	Hot Fluid (Ethanol)	0.0835
	Cold Fluid (Water)	0.1128

It has been observed that Nusselt No. for hot fluid decreases and it increases in case of cold fluid as temperature varies according to different sets of data.

3.5. Heat Transfer Co-efficient

Heat transfer coefficient is an important factor to calculate the heat transfer rate of the Double Pipe Heat Exchanger. The heat transfer co-efficient for inner tube (h_i) and outer tube (h_o) has been calculated as follows:

$$\mathrm{Nu} = \frac{hD}{K} \qquad \text{eq.- 5}$$

The results of heat transfer co-efficient have been shown below.

Table 9 Heat Transfer Co-efficient for different sets of boundary condition.

Set No.	Tube	Heat Transfer Co-efficient(h) W/m^2K
1	Inner Tube	1526.14
	Outer Tube	274.95
2	Inner Tube	649.11
	Outer Tube	303.29
3	Inner Tube	642.95
	Outer Tube	307.38

It has been found that there is an increment of heat transfer co-efficient in outer tube and a decrement in case of inner tube as temperature changes according to the different sets of boundary condition.

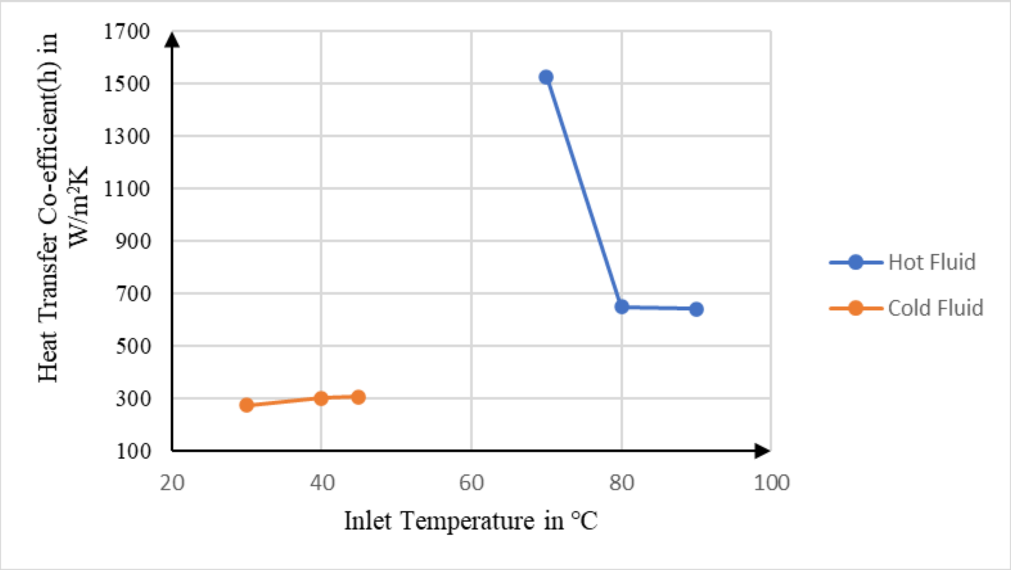


Figure 5 Graph of Inlet Temp. vs Heat Transfer Co-efficient.

The above graph shows that heat transfer co-efficient for cold fluid increases with respect to the inlet temperature of cold fluid and it decreases as the inlet temperature of hot fluid increases.

3.6. LMTD

LMTD is known as logarithmic mean temperature difference. It indicates the differences between inlet and outlet temperatures for both hot and cold fluid which are being operated in the heat exchanger.

The following equation is used to calculate the LMTD.

$$LMTD = \frac{\Delta T_1 - \Delta T_2}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)} \qquad \text{eq.- 5.1}$$

As we are considering the counter flow configuration of the heat exchanger,

The term ΔT_1 and ΔT_2 has been calculated as follows:

$$\Delta T_1 = T_{h1} - T_{c2} \qquad \text{eq.- 5.2}$$

$$\Delta T_2 = T_{h2} - T_{c1} \qquad \text{eq.- 5.3}$$

Where, T_{h1} = Temperature of hot fluid at inlet.

T_{h2} = Temperature of hot fluid at outlet.

T_{c1} = Temperature of cold fluid at inlet.

T_{c2} = Temperature of cold fluid at outlet.

The LMTD for different sets of temperatures is shown below.

Table 10. LMTD for different sets of boundary condition

Set No.	**LMTD (°C)**
1	38.77
2	38.74
3	43.57

LMTD has been found as the lowest in the second set of temperatures and highest in the third set of temperatures.

3.7. Overall Heat Transfer Co-efficient

Overall heat transfer co-efficient helps to evaluate the heat transfer rate of the heat exchanger. The overall heat transfer co-efficient is calculated as follows:

$$U = \frac{1}{\frac{D_0}{D_i}\frac{1}{h_i}+\frac{D_0}{2k}\ln\left(\frac{D_0}{D_i}\right)+\frac{1}{h_0}} \qquad \text{Eqn.- 6}$$

Where,

D_i = Diameter of inner tube.

D_o = Diameter of outer tube.

h_i = Heat transfer co-efficient for inner tube.

h_o = Heat transfer co-efficient for outer tube.

The results of overall heat transfer co-efficient has been shown in the following table.

Table 11 Overall heat transfer co-efficient for different sets of boundary condition.

Set No.	Overall Heat Transfer Co-efficient (U) W/m^2K
1	204.70
2	162.86
3	163.36

It has been identified that the highest overall heat transfer co-efficient has come out for the set no.1 and the lowest overall heat transfer co-efficient has come out for the set no.2.

3.8. Heat Transfer Rate

The rate of heat transfer determines the heat transfer performance in the Double Pipe Heat Exchanger. It has been evaluated by using following equation:

$$Q=UA_s\,LMTD \qquad \text{Eqn.- 7.1}$$

Where, Effective Area (As) is calculated as follows:

$$A_s = \pi D_0 L_0 \qquad \text{Eqn.- 7.2}$$

The following table shows results of heat transfer rate for different sets of boundary conditions.

Table 12. Heat transfer rate for different sets of boundary condition.

Set No.	Heat Transfer Rate(Q) kW
1	2.69
2	2.14
3	2.41

The heat transfer rate has been found the highest for the first set of boundary conditions and for the second set of boundary condition it has been found the lowest.

3.9. Pressure Drop

Pressure drop plays a vital role in terms of heat transfer performance in the heat exchanger. The pressure drop characteristic has been determined by using the following equation:

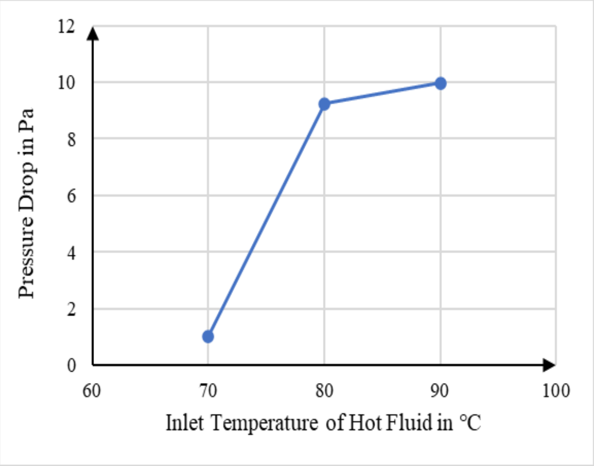
$$\Delta p = \frac{32\rho \nu LV}{D^2} \qquad \text{Eqn.- 8}$$

The pressure drop for different sets of boundary conditions has been shown below.

Table 13. Pressure drop for different sets of boundary condition.

Set No.	Pressure Drop(Δp) Pa
1	1.04
2	9.25
3	9.97

Pressure drop has been calculated for the inner tube of the heat exchanger as heat transfer co-efficient of inner tube is greater than the heat transfer co-efficient of outer tube. It has been observed that the pressure drop occurs most for the third set of boundary conditions and on the other side least pressure drop occurs for the first set of boundary conditions.



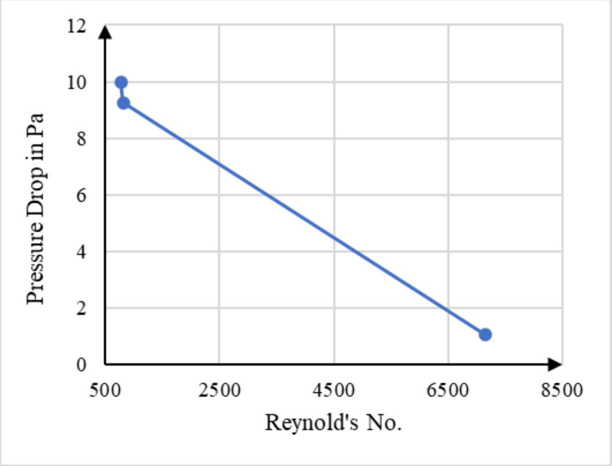


Figure 5. Graph of Inlet Temp. vs Pressure Drop **Figure 6**. Graph of Reynold's No. vs Pressure Drop.

It has been noticed that pressure drop increases when the inlet temperature of hot fluid increases. The highest pressure drop is observed as 9.97 Pa when the inlet temperature of hot fluid is 90°C. Besides, pressure drop decreases gradually with the increment of Reynold's No.

4. CONCLUSION

This numerical study on heat transfer performance of Double Pipe Heat Exchanger has been conducted by doing the simulation of the heat exchanger with different sets of boundary conditions. Ethanol and Water have been considered as hot fluid and cold fluid respectively. Different materials such as Copper for inner tube and Brass for outer tube have been selected for the heat exchanger. The mass flow rate for hot fluid and cold fluid is taken as 0.15 kg/s and 0.1 kg/s respectively. The inlet temperatures of hot fluid are taken as 70°C, 80°C & 90°C. On the other side inlet temperatures of cold fluid are taken as 30°C, 40 °C, 45°C. Different parameters have been analyzed to measure the heat transfer performance of the heat exchanger. The following outcomes of the investigation have been observed:

- The exit temperatures of hot fluid are 68.34°C, 78.31°C & 88.11°C.
- The exit temperatures of cold fluid are 30.80°C, 40.83°C & 45.97°C.

- Reynold's No. increases in case of cold fluid and decreases in case of hot fluid as temperature varies according to different sets of boundary conditions.
- Nusselt No. increases with the increment of Reynold's No.
- Nusselt No. for hot fluid decreases and it increases in case of cold fluid as temperature varies.
- Heat transfer co-efficient for cold fluid increases as the inlet temperature of cold fluid increases and it decreases as the inlet temperature of hot fluid increases.
- The highest LMTD has been calculated as 43.57℃ and the lowest is 38.74℃.
- The highest overall heat transfer co-efficient is found as 204.70 W/m^2K and the lowest is found as 162.86 W/m^2K.
- The heat transfer rate has been found the highest for the first set of boundary conditions which is 2.69 kW and for the second set of boundary condition it has been found the lowest which is 2.14 kW.
- Pressure drop increases when the inlet temperature of hot fluid increases. The highest pressure drop is observed as 9.97 Pa when the inlet temperature of hot fluid is 90℃. Besides, pressure drop decreases gradually with the increment of Reynold's No.

Since, different parameters such as Reynold's No, Nusselt No., heat transfer co-efficient are increasing in terms of cold fluid and in terms of hot fluid these are decreasing, it signifies that energy is being transmitted from the hot fluid to cold fluid.

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