Numerical Analysis of Spiral Coil Heat Exchanger and Finding the Co-Relation

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Abstract - *Flow parameters such as pressure drop, temperature variation, heat transfer rate have been found out for spirally coiled heat exchanger. Fluid entering the heat exchanger is considering at 299K and wall is assumed to be at 323K/343K/363K. Mass flow rate has been varied from 02Kg/s, 0.4 Kg/s, 0.6Kg/s and 0.8 Kg/s & the diameter of coil has been considered as 6mm, 8mm, 10mm & 12mm. Standard k- turbulence model has been considered for handling turbulence. Reynolds number, Euler number, temperature variation, pressure drop and heat transfer rate have been found out & compared for all the cases.*

Key Words: **Spiral coil heat exchanger, Heat transfer coefficient, Nusselt Number, Dean Number, Computational Fluid Analysis.**

1.INTRODUCTION

For almost a century with the introduction of the curved tubes heat exchanger, much attention has been lately drawn towards the augmentation techniques in mass and energy transfer of spiral coil heat exchanger [1]. Today, with the growth in technology and science, spiral tube heat exchangers are becoming recognized in countless thermal applications all over the world [2]. A heat exchanger is a mechanical device that is used to transfer heat between two fluids, where the contact may be direct or indirect when both fluids are flowing through the device. They are widely used in refrigeration, air conditioning, power stations, chemical plants, petrochemical plants, petroleum refineries, natural-gas processing, sewage treatment, etc. [3]. The design analysis of spiral tube heat exchangers varies with their functionality. For example, considering the case of geothermal application, heat exchangers are available in two forms namely: Open and closed type heat exchangers. The first is a direct system between the system and ground whereas a closed heat exchanger is an indirect type of system wherein pipes are buried in a horizontal or vertical system [4]. The condition of the fluid nearby determines the correctness of the horizontal versus vertical ground heat exchanger. Although heat exchangers have several applications and advantages, one of the critical issues encountered in heat exchangers is the sudden pressure drop which can have a significant impact on efficiency as well as the overall heat transfer coefficient (h) of the heat exchanger. Certain effects are analyzed of operating variables or parameters causing pressure fluctuation, affecting the overall heat transfer coefficient (U). In general, the two types of flows include co-current and counter concurrent flows. Comparisons of the overall heat transfer coefficients have been made between shell and tube and the spiral coil heat exchangers [5]. It was seen that the major effect was because of the mass flow rate, which affected the overall heat transfer coefficient. Apart from this, the counter-current flow proved to be efficient in comparison with the co-current flow with optimum overall heat transfer coefficient (U). Found in a study, 2702.78 W/m2. K was the maximum overall heat transfer coefficient (Umax) for the spiral coil heat exchanger with the counter-flow which showed greater heat transfer efficiency in comparison to the shell and tube heat exchanger. Temperature profiles were studied by Shah and Sekulic in two different heat exchangers, highlighting the two major drawbacks in the design of parallel flow. The large temperature variation at the ends resulted in huge thermal stresses. The contraction of the materials used for construction purposes and opposing expansion due to a difference in fluid temperatures could gradually fail the material [6]. Also, the temperature of the cold fluid moving out of the heat exchanger remains at a lower temperature than the hot fluid which is at the lowest temperature and this can be made better by optimizing the various parameters. The flow patterns proving to be effective to a greater extent are seen in the counter-flow heat exchanger. To add on, due to the highest log mean temperature differences (LMTD), it has the least surface area, as they have an indirect relation between them. In comparison, lesser heat is transferred in a parallel flow heat exchanger than in a counter flow heat exchanger. LMTD method can be used for the determination of overall heat transfer coefficient (U) from experimental values taking the help of inlet and outlet temperatures as well as the fluid flow rates [7]. Parameters such as the number of coils, mass flow rate, the orientation of coil, and coil gap/pitch of diameter are some of the factors influencing heat transfer [8,9]. Convection plays a principal role when we refer to heat exchangers [10]. Several configurations of coil structure exist, but the one with helical coils stacked vertically is an ordinary type, where the entry and exit of hot and cold fluid are served by inlet and outlet manifolds respectively. Helical Coil Heat Exchanger is a type of heat exchanger that has a shell called an annulus and inside which there is a helical coil. It is found that the heat transfer in helical circular tubes is higher as compared to the straight tube due to their shape [11]. Helical coils are preferable over straight tube heat exchanger due to their compactness too, increased surface area, and heat transfer coefficient [12], as it is observed by fluid in the streamline motion in a pipe that is curved, the primary motion that is along the pipe is accompanied by the development of secondary flow which decreases the flow rate produced by a pressure gradient, and hence the region moves outward where there is maximum primary flow [13]. Due to curvature, secondary flow takes place because of centrifugal force, which results in the proper mixing of fluid, hence increasing the heat transfer. Secondary flow developed increases the turbulence of the flow thus increasing the heat transfer coefficient. Amongst all heat exchangers, spiral coil heat exchangers are said to occupy the least space [14]. This is the main reason as to why spiral coils are curved coil which has been widely used in engineering applications like in radiators in the automobile industry, environmental control systems in aircraft, geothermal heat pumps avionics, chemical plants, steam generators, extraction of oil and gas as well as cryogenic separation and liquefaction of air, etc. [15]. The spiral coil heat exchanger is designed in such a way that it has a uniform cross-section which creates “swirling motion” in the fluid which helps to increase the heat transfer rate. It is also observed that the fluid inside is turbulent at a low velocity when compared to the straight tube heat exchanger, where the fluid passes through a constant velocity throughout the tube. By this, the boundary layer problems are solved [16]. Now it's stipulated in many studies that helically coiled tubes are loftier than straight tube heat exchangers [17]. In certain studies, a mathematical model is designed [18] to analyze data obtained from CFD and experimental results to take care of the different effects of different variables like pitch/ gap between the concentric coils, coil diameter, and tube diameter affecting the heat transfer. According to a particular study of a flat spiral coil wherein the diameters were taken to be 6, 8.025, and 10 mm respectively [8]. So according to the results obtained, it was observed as rightly mentioned that coil diameter varies directly with the heat transfer rate. Hence it was minimum for diameter 6 mm and maximum for diameter10 mm. So as there is an increase in cross-sectional area, there is linear variation in both as obtained graphically as well. Similarly, the flow rate is dependent upon the dimensional quantity known as Reynolds’ Number. Therefore, on a similar basis, Reynold’s Number will be higher for the one with a larger diameter and lower for the one with a smaller diameter. The fluid temperature continuously increases from inlet to outlet. As water flows through the coil, it gets heated up. The difference is pressure, or drop as we call it observed to increase from inlet to outlet. For the constant mass flow rate, pressure drop increases with the coil diameter, therefore the Euler number also increases [18]. In comparison with a tube type heat exchanger, a physical model was designed for temperature measurements wherein the mass flow rate variation was 0.049kg/sec to 0.298 kg/sec for hot fluid and 0.029kg/sec to 0.225kg/sec for cold fluid [19]. After experimentation, effects on different parameters were investigated on the heat exchanger and the results were found out to be encouraging, as again the heat transfer rate was varying linearly with the increase in Reynold’s Number. Taking the case of medium cold water flow rate (0.029kg/sec), the heat transfer was maximum. A study on circular flat spiral coil structure effect on wireless power transfer system performance reveals when that when circular flat spiral coils are used in a system called wireless power transfer (WPT). Certain coil design variables like inner radius, channel width outer radius and the number of turns of the coil are thoroughly studied to improve the performance of the system with a particular value of maximum outer radius used for practical purposes. A double coil WPT system was built to verify the design analysis, and the results of experiments show appreciable consistency with the theoretical results with calculations, showing that the design parameters of the coil have an important impact on the performance of the system, even though the coil size is kept constant. For this experiment, when the coils were wound tightly with no gap in between them to make the coil size maximum, the coil-system efficiency was observed to be 62.6% with about 4.5 W load power only [20]. However, the efficiency optimization of the coil improved the coil system drastically the efficiency to 91.2% keeping the outer radius the same. Besides, when the amount and transfer of power efficiency are considered simultaneously, the system was able to achieve 1279 W load power along with the efficiency of 85.14% coil system [21]. CAD modeling has been done on software called Solid works whereas all experimental calculations, results are formulated by using the software, Ansys Fluent [22]. Copper has been chosen as the material for the construction of the spiral tube and water has been taken as the fluid [23,24]. For the last few years, the determination of the convective heat transfer coefficient (h) between the surrounding fluid and surface has been a key question. Therefore, our main objective is to study the outlet temperature, calculating the Heat Transfer Coefficient and using it to find a correlation between the Nusselt number and Dean number. Existing Correlation is seen to result in huge discrepancies with the increase in pitch/gap between the concentric coils in comparison with the experimental results. Hence, some non-dimensional numbers such as Reynolds number, Nusselt number, Euler number, Prandtl number, etc. are found out [26]. Temperature, pressure and velocity contours, etc. have been plotted as well.

2. Mathematical modeling

In our system we are giving constant temperature to the spiral coil by using heated liquid and that heat is absorbed by the working fluid, that is water. The heat exchanger/coil is a flat spiral coil having pitch/ gap as 20 mm, diameters 10mm, 12mm 14mm, and 16mm respectively, at different outer temperatures of spiral 50°C, 70°C, and 90°C. We are taking inlet temperature as constant at 26°C and varying different outer wall temperatures by giving different mass flow rates as 0.2 Kg/sec, 0.4 Kg/sec, 0.6 Kg/sec & 0.8 Kg/sec respectively. In this particular tubular spiral coil, the coils are having high thermal conductivity and strength compared with other coils, which are cheaper to other materials as well, in comparison. Therefore, it is convenient to use copper. In our present study, we have used heat flux (ϕ) by using the constant temperature by maintaining it outside the spiral receiver. Using the spiral coil has proved to be beneficial as compared to a straight tube heat exchanger as it has a higher rate of heat transfer coefficient (h), and has a compact design too.

Length of the spiral tube can be expressed as,

$$L = \pi . n . \frac{D_o + D_i}{2}$$
(1)

The number of turns can be expressed as,

$$n = \frac{D_o - D_i}{2(d+g)}$$
(2)

Velocity can be calculated by using the mass flow rate equation expressed as,

$$m^{\cdot} = \delta . A . V$$
(3)

Log mean temperature difference can be expressed as,

$$LMTD = \frac{\Delta T_1 - \Delta T_2}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)}$$
(4)

Heat Transfer can be expressed as,

$$Q = mC_p\Delta T = hA\Delta Tm$$
(5)

Nusselt number can be expressed as,

$$N_u = \frac{hD}{K}$$
(6)

Reynold's number can be expressed as,

$$R_e = \frac{\rho VD}{\mu}$$
(7)

Dean number can be expressed as,

$$D_e = R_e\sqrt{\frac{D}{2R_c}}$$
(8)

3. Characteristic of spiral shaped coil

3.1. Geometrical characteristics

The spiral-shaped coil is attributed to many geometrical configurations, some of which include pipe diameter, number of turns, inner/inlet diameter, the outer diameter of the outermost coil, compact size, curvature, bigger thermal conduction space, etc. Many other factors like mass flow rate, pitch/gap of the coil, the orientation of the coil, etc. affect the heat transfer efficiency, hence their effects on the performance of the coil and heat transfer rate are discussed.

How each of the above-mentioned parameters affects heat transfer?

In an experiment, the authors had taken five turns of spiral coil and tube diameter as 8 mm which was made of copper material. Working fluid was taken as water. The conclusion was Nusselt number and pressure drop, both values are higher for spiral coil than straight tube heat exchanger [8]. In a study by Manoj Kumar, Vishal Gupta and Samarjeet Bagri had experimented that the velocity of fluid increases with the increase in the diameter of the coil, and hence Euler number increases. It was also observed that Reynold's number increases with the mass flow rate. Hence the highest diameter has the highest Reynold's number [16]. In an experiment, N D Shirgede, and Vishwanath Kumar had experimented that the centrifugal force is governed by the curvature of the coil, whereas the torsion is influenced by pitch/helix angle, and the geometry affects the heat transfer rate, as it increases the convective heat transfer coefficient (h) [17]. An author, Pramod Deshmukh had experimented that pipe and coil dimensions as well as temperature influences the heat transfer rate. Different effects of types of flow were studied ranging from laminar to turbulent flow through a transitional flow. Copper has a high value of conductivity (k) and was chosen for better results [24]. Another one had experimented that different helix values affect the rate of heat transfer and hence give higher Nusselt number by plotting velocity, pressure, and temperature contours [23].

Few other authors, namely Yamini Y Pawar, Ashish N. Sarode, Rajesh V. Dahibhate had investigated the effect of geometrical parameters, especially the shape influenced the results of their experiment and proved that Nusselt number increased with increase in diameter, which was taken as 9.5 mm [37]. N. A Khan, A.M Khan, and M. Kamil had simulated the results and had found out that air mass flow rate and the temperature of the air at inlet have an impact on increased outlet water temperatures. With the increase in water mass flow rate, outlet and water temperature show a decrease [39]. In another study, it was found out that the Nusselt number and heat transfer coefficient show an increase with the increase in water mass flow rate and helical pitch as well [36].

In our experiment, we have selected parameters such as pitch/ gap of a coil, which is the consecutive distance between the two coils, we have taken it as 1mm diameters 10 mm, 12 mm, 14 mm and 16 mm respectively, mass flow rates, number of loops.

3.2.. Critical Reynolds number

Just like Reynold's number is used to indicate the type of flow in different fluids, such as laminar, transitional, or turbulent, another dimensional parameter called Dean's number is also frequently used by many researchers, which is used to characterize the flow. Other correlations with the help of the Nusselt number are also found out by several researchers.

José Pérez-García, Alberto García, R. Herrero-Martín, and Juan Pedro Solano had experimented on flat spiral coil heat exchangers and found out the dimensionless pitch p/d=[0.25-3.37], dimensionless thickness e/d=[0.071-0.286] and a Reynolds number interval from 50 to 8000, which covered the laminar, transitional and turbulent regime [35].

$$Re = \frac{4G}{\mu \pi d}$$

(9)

Milan ĐORĐEVIĆ, Velimir STEFANOVIĆ, Marko MANČI in their pressure drop and stability inflow in Archimedes'spiral tube experiment had examined the corrugated straight pipe the characteristic flow zones were defined, laminar when Re < 1300, critical when 1300 < Re < 1600, transition 1600 < Re < 4000 and rough (turbulent) when 4000 < Re [38].

Laminar Zone: $$f_{sc} = \frac{64}{Re}$$

(10)

Critical Zone: $$f_{sc} = 0.0045e^{0.002Re}$$

(11)

Transitional Zone: $f_{sc} = 0.0942$ $(6.10^{-9}\ Re^2.\ 6.10^{-5}\ Re + 1.081)$ (12)

Rough Zone: $$f_{sc} = 0.0942$$

(13)

solution for laminar flow f

LS

= 1

It is found out the below correlation in their experiment of spiral tube heat exchangers and concluded that due to the compact design of spiral plate heat exchanger, more heat transfer can be carried out [2].

$$N_u = 0.294 \times Re^{0.63} \times Pr^{0.3} \times {P_t}^{0.25} \times {\mu_v}^{0.14}$$

(14)

Where, $P_t = R_o^{\ 1.92} - R_i^{\ 1.92} / P \times d_i^{\ 0.92}$

and $\mu_v = \frac{\mu_b}{\mu_w}$

4. Numerical Computation

A CFD methodology was used to analyze the spiral coil heat exchanger. In this analysis, a CFD package ANSYS Fluent v2020R2(double precision,3D version) was used. A laptop of specifications with AMD Ryzen 4500 series has been used with 4GB RAM, each run took 4 hours to analyze.

4.1. Computational grid

The Spiral coil geometry was created using SOLIDWORKS 2017 designing software and was saved as a .iges file extension. Later the geometry was imported in ANSYS WORKBENCH v2020R2. To do the analysis the geometry has to mesh first in the CFD FLUENT meshing module. In this geometry, the wall thickness is not considered and hence the geometry is solid has been controlled as the fluid volume only. The naming to the spiral was given as Inlet, Outlet, and Wall respectively. The geometry has meshed with linear element order. The grid was made tetrahedrons for more accurate simulation analysis with an elemental size of 2.103e-002m. The grid for the analysis domain, which includes fluid volume, is shown in Fig, 1.

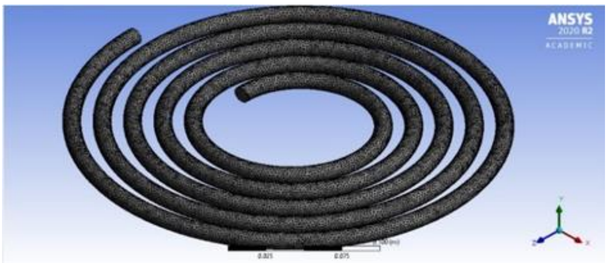


Fig.1

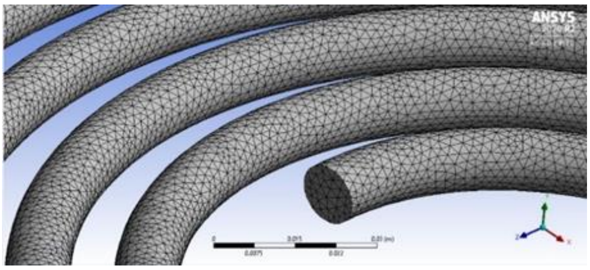


Fig.2

The Grid is composed of 88315 nodes and 409808 elements. The maximum skewness reported is to be 0.83708 and the minimum was0.094278.

4.2. Boundary Conditions and CFD modeling

In this numerical analysis, four spiral tubes were analyzed for diameters 10mm,12mm,14mm, and 16mm. The Steady-state pressure-based solver module was used. In this module, the energy equation was solved. Later the materials were selected as water liquid (Fluid) and Copper (Solid), at constant values of properties. The boundary conditions were defined as 299K and 0 Pascal absolute pressure. In all cases, the cold fluid at 299K temperature was given at the inlet with mass flow rates of 0.2kg/s,0.4kg/s,0.6kg/s and 0.8kg/s. Later the wall temperature was varied for 3 different values of 323k,343k, and 363k.

The mass flow rate was converted into velocity by the below formula;

$$\dot{m} = \rho v A$$

Where, m= mass flow rate

ρ = Density

v = velocity

A = Area

Sr. No.	Diameter (mm)	Inlet Temperature (K)	Temperature (K)			Mass flow rate(kg/s)/ Velocity(m/s)			
						0.2	0.4	0.6	0.8
1	10	299	323	343	363	2.56	5.11	7.69	10.30
2	12	299	323	343	363	1.77	3.54	5.31	7.09
3	14	299	323	343	363	1.30	2.60	3.90	5.21
4	16	299	323	343	363	0.9	1.9	2.9	3.9

Table 1. Boundary Conditions.

After giving the boundary conditions, the solution method was selected. The pressure velocity coupling was kept simple. The grid is now initialized and calculations were initiated for 100 iterations.

4.3. Post Processing

After the calculations were completed, we had the results in the form of contours and were analyzed successfully. We have Temperature and Pressure contours.

Temperature Profiles;

Temperature profiles along the coil for the boundary conditions which were specified earlier are given in Table 2.

Diameter (mm)	Wall Temperature (k)	Flow Rate (kg/s)/Outlet Temperature(k)			
		0.2	0.4	0.6	0.8
10	323	317.7	315	313.65	312.3
	343	333.2	328.3	325.85	323.4
	363	348.8	341.6	338.05	334.5
12	323	318.5	315.7	313.3	310.9
	343	338.6	329.7	327.2	325.2
	363	350.1	343.6	340.2	337.2
14	323	318.2	315.8	313.3	310.9
	343	340.2	329.7	325.3	320.9
	363	350.2	347.7	343.7	330.8
16	323	315.8	313.4	311.5	308.6
	343	330.1	325.6	320.9	317.1
	363	350.2	343.8	337.4	330.9

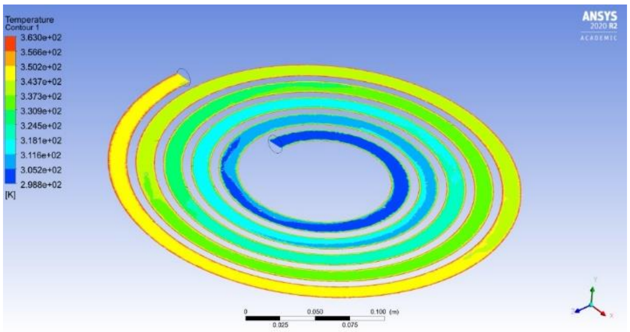


Table 2. Outlet Temperature reading(k)

Fig.3. Temperature contours.

It has been observed that the outlet temperature increases to a certain extent concerning the inlet temperature and also does vary with the velocity.

It is noted that as the velocity of fluid increases the temperature rise of fluid is lesser than that o\for the lower velocity/mass flow rate.

Pressure Profiles.

Diameter (mm)	Wall Temperature (k)	Flow Rate (kg/s)/Pressure(pa)			
		0.2	0.4	0.6	0.8
10	323	23900	78660	161400	272000
	343	24160	78660	161400	272000
	363	23900	78660	161400	272000
12	323	13000	42710	86160	141900
	343	13000	41890	85980	142700
	363	13000	42230	85820	143000
14	323	20650	68440	141300	237500
	343	20650	68440	141300	237500
	363	20650	68440	141300	237500
16	323	3600	11760	23670	39330
	343	3206	11680	19610	39250
	363	3637	11680	23670	39350

Table 3. Outlet Pressures(Pa)

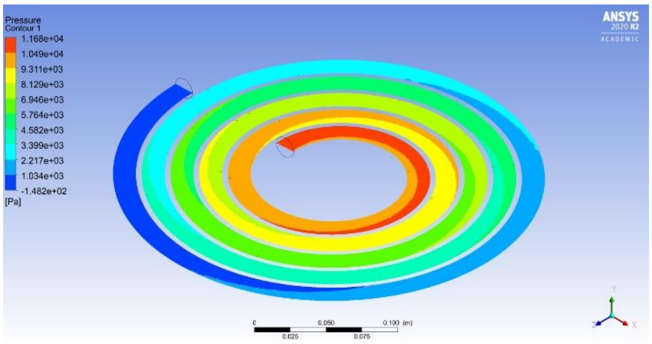


Fig.4.a. Pressure Contours

Calculations for Nusselt no. and Dean no.

- We have an equation;

$$Q = mCp\Delta T = hA\Delta Tm$$

here, Q; Heat energy

m; mass flow rate

Cp; Specific heat

ΔT; Change in temperature

A; Surface area

H; Convective heat transfer

- To calculate the heat transfer coefficient,

Consider, Diameter of spiral: 10 mm

a mass flow rate of 0.2m^3/s

Inlet temperature: 299k

Wall temperature: 323k

Substituting in the above equation;

$$Q = 0.2 \times 4.184 \times 10^3 \times (Tout - Tin)$$

$$Q = 0.2 \times 4.184 \times 10^{\wedge}3 \times (44.7 - 26)$$

$$Q = 15.64KJ$$

- Now we have;

$$Q = hA\Delta Tm$$

ΔTm can be calculated by the LHTD method.

$$= (50 - 26) - (50 - 44.7)/\ln\left(\frac{24}{5.3}\right)$$

$$= 24 - 5.3 / 1.5103$$

$$= 12.5106$$

And, A=0.123276

Substituting values in the above equation;

$$h = 10161.14\, w/m^{\wedge}2k$$

- Now to calculate the Nusselt number, we have;

$$Nu = \frac{hD}{k}$$

Here, D; Diameter of the tube,

K; Thermal conductivity.

$$Bulk\ mean\ temp. = \frac{Wall\ temp. + Inlet\ temp}{2}$$

$$= 33\ K$$

$$Film\ Temp. = \frac{Wall\ temp. + bulk\ mean\ temp.}{2}$$

$$= 41.5\ K$$

- From the above values using the standard thermophysical properties of the water table,

$$K = 0.6412\ W/mk$$

$$Nu = \frac{(10.161 \times 10)}{0.6412}$$

$$Nu = 158.768$$

- To calculate Reynold's number, we have;

$$Re = \frac{4m}{\pi d\mu}$$

Here, m: mass flow rate

d: Diameter of tube

μ: Dynamic viscosity of a fluid.

$$Re = \frac{4 \times 0.2}{3.14 \times 10 \times 0.0007}$$

$$= 46323.13$$

- To Calculate Dean number, we have;

$$De = Re\left(\sqrt{\frac{D}{2Rc}}\right)$$

Here, Re: Reynolds number,

D: Diameter of the tube,

Rc: Radius of Curvature.The results recorded from the software /numerical analysis are to be validated either with the experimental/analytical/literature work.

Dia (mm)	Flow Rate / Temp	0.2	0.4	0.6	0.8
	50	23900	78660	161400	272000
10	70	24160	78660	161400	272000
	90	23900	78660	161400	272000
	50	13000	42710	86160	141900
12	70	13000	41890	85980	142700
	90	13000	42230	85820	143000
	50	20650	68440	141300	237500
14	70	20650	68440	141300	237500
	90	20650	68440	141300	237500
	50	3600	11760	23670	39330
16	70	3206	11680	19610	39250
	90	3637	11680	23670	39350

Table 4. Pressure reading(Outlet) in Pa

	coefficient		
0.2	0.4	0.6	0.8
0.010063311	0.014662564	0.01887258	0.021555662
0.010091678	0.014746109	0.01900945	0.021749728
0.010149488	0.014777571	0.01906101	0.021822862
0.009283749	0.013234784	0.01511318	0.015217061
0.012835472	0.013408679	0.01721998	0.020287054
0.008994737	0.013416567	0.01740384	0.020425347
0.007654583	0.011475145	0.01295415	0.013043195
0.018597358	0.011493153	0.01312294	0.013223944
0.007747296	0.013782294	0.01732447	0.013232118
0.005020433	0.007643174	0.00919877	0.008492854
0.005156398	0.007798866	0.00867822	0.008895196
0.006778688	0.010149677	0.01158773	0.011630644

Table 5 Heat Coefficient

RESULTS AND DISCUSSIONS

1.We have to take all the calculated values of Nusselt no., Reynold no. and Dean no. and fit them into the fitting software.

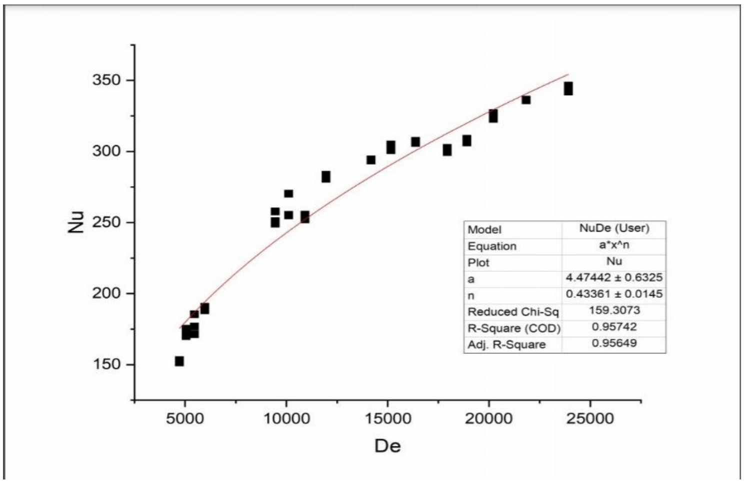
2.The fitting software is called "Origin" software.

3.From the above calculations and observations made, we have obtained the relationship between Nusselt number and dean number.

4.As shown in the calculation tables, we have plotted the values using this software as we get a very precise value.

5. We have got COD of more than 0.90, which shows high precision.

Required correlation equation: $Nu = 4.47442 \times De^{0.46361}$



Graph 1

CONCLUSIONS

- We have found out the required correlation between Nu, Re, Prandtl, and Dean number and now we see the effect of diameter on different mass flow rates such as 0.2, 0.4, 0.6, and 0.8 kg/sec on outlet temperature.
- It is noted that when inlet water and the mean temperature of the tube wall are kept constant, the temperature of the outlet water decreases with an increase in the mass flow of cold water. This is due to the increase in the rate of heat transfer that the bulk flow of water also increases.
- The increase in heat transfer is inferior to the mass flow of cold water. As a consequence, the temperature at the outlet tends to decrease as the mass flow of cold water increases.
- The mean number of Nusselt will increase depending on the increase in cold water mass flow. This is due to the number of Nusselt that is directly dependent on the ability to remove heat from cold water.
- We have obtained the relationship between the Nusselt number and Dean number, both being directly proportional. When Nu increases, Dean no. increases.

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