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Comparative Analysis of Tubular Type of Heat Exchanger using CFD

Ashish Kushwah[1], Mrigendra Singh[2], Kundan Gupta[3]
M.Tech Scholar, Mechanical Engineering Department, Lakshmi Narain College of Technology, Indore-453331, India[1]
Head of Department, Mechanical Engineering Department, Lakshmi Narain College of Technology, Indore-453331, India[2]
Associate Professor, Mechanical Engineering Department, Lakshmi Narain College of Technology, Indore-453331, India[3]
ashishkushwah47@gmail.com[1], mrigendra.rits@gmail.com[2], gupta.kundan660@gmail.com[3]

Abstract: *Heat exchanger is a widely used device used for transfer of heat energy of hot fluid to the cold fluid. The heat is transferred in form of conduction and convection. Conduction occurs inside the material whereas convection occurs from materials to fluid and from fluid to fluid. The common application of the heat exchangers are like condenser, cooling tower, intercooler, refrigeration, and many other industrial applications.*

There are many types of heat exchangers wherein parallel and counter flow heat exchangers are extensively used in parallel flow heat exchanger hot and cold fluids are passes through the tubes in the same direction where as in counter flow heat exchanger both the fluids are passes in opposite direction to produce the desired effect. Baffles are sometimes used in heat exchanger to enhance heat transfer efficiency of heat exchangers.

The Double pipe heat exchanger and one Shell and two pass Heat Exchangers are designed in present work in which different mass flow rates of fluid were taken and study is carried out for the optimum mass flow rates and also the temperature distribution will be studies for those mass flow rates.

Keywords: *Shell and Tube Heat Exchanger, Conduction, Convection, Parallel flow, Counter flow,Hot and cold inlets, Temperature distribution, ANSYS.*

1. INTRODUCTION

A heat exchanger is a device that transfers the heat from one medium to another it can either used for heating a certain area or also can cool it as per the requirement.

To select heat exchanger for a certain application one needs to know the following points:

1. Fluid type of primary circuit, temperature and rate of flow (generally hot fluid).
2. Actual requirement from primary circuit (Either to dissipate heat or to achieve a desired outlet temperature).
3. Fluid type of secondary circuit, its temperature and rate of flow (generally cold fluid).

Some common applications of heat exchangers are chemical reactors (jackets, internal heat exchangers, preheating feeds, distillation column re-boilers, distillation column condensers, air heaters for driers, double cone driers, evaporators, crystallizers, production support services – HVAC, heat transfer fluids etc.air, water or oils at different physical, chemical and thermal states are used as working fluids.The materials are generally used to make fins and heat exchanger tubesare. Copper and low-alloyed copper**,** brass**,** copper-tin-tellurium and phosphorous alloys**,** copper chromium alloy**,** copper zinc alloy**,** aluminium etc.

2. LITERATURE SURVEY

Imen et. al. (2017), [1] presented a solution for the flow in a heat exchanger. An analytical approach is developed and validated by a numerical simulation using the ANSYS CFX code module. **Gowthaman, P. S. et.al.[2]** In this work developed a model to evaluate the analysis of a spiral and segment impingement heat exchanger as well as the comparative analysis of the thermal parameters between the segment angle and the spiral angle.**Abdolbaqi, M. K. et al. (2015) [3]** introduces and analyzes numerically the heat transfer enhancement of nanofluids with different volume concentrations under turbulent flow through a straight channel with a constant heat flux condition. **Raj, R. T. K et al (2012) [4].** In this work attempts were made to investigate the impacts of various baffle inclination angles on fluid flow and the heat transfer characteristics of a shell-and-tube heat exchanger for three different baffle inclination angles namely 0°, 10°, and 20°.**I Tomic, M. A., et al (2014) [5]**performed numerical simulations to determine the heat transfer coefficient of a perforated plate with square arranged cylindrical perforations.. **Sundar L S et al (2001) [6]**Turbulent fully developed flow heat transfer coefficient and friction factor of Al2O3 nanoparticles are dispersed in water and ethylene glycol in circular tube is discussed in this paper. **Florez-Orrego et al (2012) [7]**An empirical correlation for the determination of average Nusselt number along the duct, with Reynolds ranging between 4300 and 18600 has been developed. The experimental results have been compared with those obtained with the correlation.

3. MATHEMATICAL APPROACH

For the purpose of analytical approach we have select double pipe heat exchanger. The following parameters are described with their value for model of heat exchanger.The dimension Specifications for Modelling of Shell and Tube Heat Exchanger are : The diameter of the inner pipe in which cold fluid is flowing d = 15mm, Length of the heat exchanger. L = 400mm, Diameter of the annulus or shell .D = 25mm, Thickness of the inner tube and shell t = 1mm., Mass flow rate of the cold fluid ṁw =0.5kg/s., Mass flow rate of the hot fluid or oil ṁo =0.8kg/s., Average temperature of the cold fluid Tw =45°C., Average temperature of the hot fluid To = 80 °C. Thermal Properties of water corresponding 45 °C are Density of the water 990 kg/m^3, Thermal conductivity 0.637 W/m-k, Corresponding. Pr .number=3.91, Kinematic viscosity0.602×10-6m^2/sec.

Thermal Properties of hot fluid (oil) corresponding 800°C.Density of the oil 852 kg/m3, Thermal conductivity 0.138 W/m-k, Corresponding Pr number 4.90,Kinematic-viscosity3.794×10^{-5} m^2/sec

Overall heat transfer coefficient U is given by relation.

1/U= (1/hi + 1/ho)

Where hi & ho represent the heat transfer coefficient for inner and outer surface respectively.

Hydraulic diameter of circular tube is the diameter of the tube itself

Dh = D = 1.5cm = 0.015m.

The average velocity of the water is given by ṁw = Vw×Ai×□ w (1)

Vw is the average velocity of the water in the pipe.

Ai cross sectional area of the inner tube.

□ w is density of the water.

From equation 1st

$0.5= Vw\times\frac{\pi}{4}(0.015)2\times990.01$

Vw = 2.86 m/s

Reynolds number corresponding average velocity

$Re = \frac{\rho v D}{□}$

Here □ is the dynamic viscosity of the water.

After calculation we get Re = 7118.4.

The Reynolds number obtained from calculation is less than the 10000; therefore the flow of water is laminar. Assuming flow to be fully developed, the Nusselt number can be determined from

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

Where h is the heat transfer coefficient and k be the thermal conductivity of the fluid.

$Nu = \frac{hD}{K} = 0.023(Re)\ 0.8(Pr)\ 0.4$

$Nu = \frac{hD}{K} = 0.023(7118.4)\ 0.8(3.91)0.4$

$Nu = \frac{hD}{K} = 47.91$ (2)

From equation (2) we will put the value of all parameter and get the value of heat transfer coefficient h = 2034.9 W/m2-k.

Now repeat the analysis for the hot fluid,

Hydraulic diameter for the annular space is given by

Dh = (Do - Di) = (0.025 – 0.015) = 0.01

Average velocity of the hot fluid is given by ṁo = Vo×Ao×□ o

Average velocity of the hot fluid is given by Vo = 3.32 m/sec

Reynolds number $Re = \frac{\rho v D}{□}$

After calculation we get Re = 1312.433

Re is less than the 2300, therefore the flow of oil or hot fluid is laminar. Assuming fully developed flow the Nusselt number on the tube side of the annular space corresponding

Di/Do is equal to 0.6

It can be determined from the empirical relation the value of Nusselt number

Nu = 12.38

And heat transfer coefficient for outer surface ho = (k/Dh)Nu = 526.15 W/m2-k.

The overall heat transfer coefficient for this heat exchanger becomes

1/U= (1/hi + 1/ho)

1/U= (1/2034.9 + 1/1526.15)

After simplification the above equation we get the value of overall heat transfer coefficient as 418.057 W/m2-k.

It has been seen for our case that the temperature difference of hot fluid is possible up to 30 0C for achieving effectiveness of heat exchanger at their higher side.

The heat transfer is given by

Q = UAdT

Q = 2.21 KW.

Now we will repeat the similar process for ONE SHELL AND TWO PASS heat exchanger

Overall heat transfer coefficient U is given by relation.

1/U= (1/hi + 1/ho)

Where hi & ho represent the heat transfer coefficient for inner and outer surface respectively.

Hydraulic diameter of circular tube is the diameter of the tube itself

Dh = D = 0.01m.

The average velocity of the water is given by ṁw = Vw×Ai×□ w (1)

Vw is the average velocity of the water in thepipe.

Ai cross sectional area of the inner tube.

□ w is density of the water.

From equation 1st

$0.5 = Vw \times \frac{\pi}{4} (0.01)2 \times 852$

Vw = 6.42 m/s

Reynolds number corresponding average velocity

$Re = \frac{\rho v D}{?}$

Here ? is the dynamic viscosity of the water.

After calculation we get Re = 10677.6

The Reynolds number obtained from calculation is greater than the 10000; therefore the flow of water is turbulent. Assuming flow to be fully developed, the Nusselt number can be determined from

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

Where h is the heat transfer coefficient and k be the thermal conductivity of the fluid.

$Nu = \frac{hD}{K} = 0.023(Re)\ 0.8(Pr)\ 0.4$

$Nu = \frac{hD}{K} = 0.023(10677.6)0.8(3.91)0.4$

$Nu = \frac{hD}{K} = 66.27$

(2)

From equation (2) we will put the value of all parameter and get the value of heat transfer coefficient hi = 2814.66 W/m2-k.

Now repeat the analysis for the hot fluid,

Hydraulic diameter for the annular space is given by

Dh = (Do - Di) = (0.025 – 0.0075) = 0.0175

Average velocity of the hot fluid is given by ṁo = Vo×Ao×□ o

Average velocity of the hot fluid is given by Vo = 7.46 m/sec

Reynolds number $Re = \frac{\rho v D}{?}$

After calculation we get Re = 1968.65

Re is less than the 2300; therefore the flow of oil or hot fluid is laminar. Assuming fully developed flow the Nusselt number on the tube side of the annular space corresponding Di/Do is equal to 0.3

It can be determined from the empirical relation the value of Nusselt number

Nu = 17.13

And heat transfer coefficient for outer surface ho = (k/Dh)Nu = 727.75 W/m2-k.

The overall heat transfer coefficient for this heat exchanger becomes

1/U= (1/hi + 1/ho)

1/U= (1/2814.66 + 1/727.75)

After simplification the above equation we get the value of overall heat transfer coefficient as 578.24 W/m2-k. And it has been seen for our case that the temperature difference of hot fluid is possible up to 30 0C for achieving effectiveness of heat exchanger at their higher side.

The heat transfer is given by

Q = UAdT

Q = 3.06 KW.

4. MODELING AND SIMULATION

The two different models of heat exchanger are being made in CATIA V5R12 software to the dimensioning scale taken from a standard book of heat and mass transfer by Yunus A. Cengel. The first model is a double pipe heat exchanger and the second model is of one shell and two pass heat exchanger. The geometric representation of the two are shown in figures

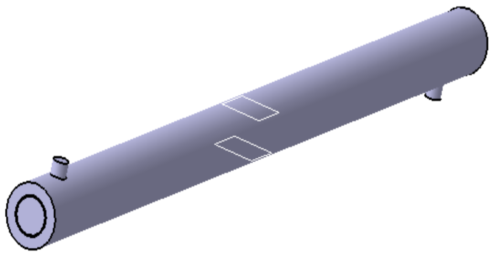


Figure 4.1: Model of Double pipe heat exchanger

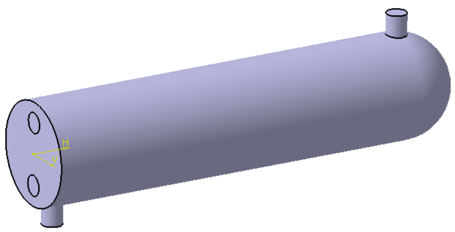


Figure 4.2: Model of one shell and two pass heat exchanger

4.1 Steps used for modeling & Simulation

The following steps are being followed in the analysis of the heat exchanger models made inside the modeling and simulation software.

1. Material Selection
2. Importing the model of heat exchanger in ANSYS workbench
3. Providing the named selection for defining boundary conditions
4. Meshing
5. Set up module
6. ANSYS solver
7. Viewing Results

4.2 Analysis Results

Figure 4.3 to figure 4.5 represents the results for double pipe heat exchanger model temperature contour model of double pipe heat exchanger, figure 4.3 and figure 4.4 provides the temperature and velocity distribution corresponding 0.5 kg/sec. Figure 4.5 provides the wall shear stress value for the double pipe heat exchanger.

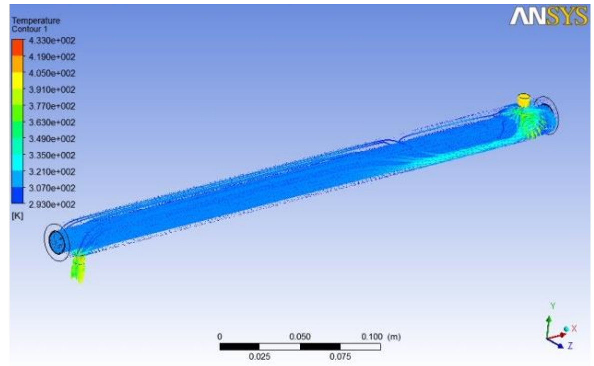


Figure 4.3: Temperature contour model of double pipe heat exchanger

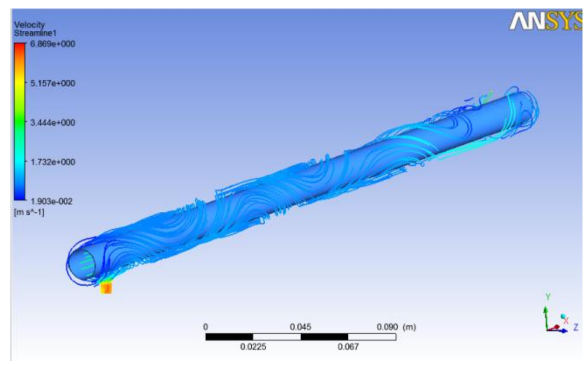


Figure 4.4: Streamline velocity distribution of double pipe heat exchanger corresponding 0.5 kg/s

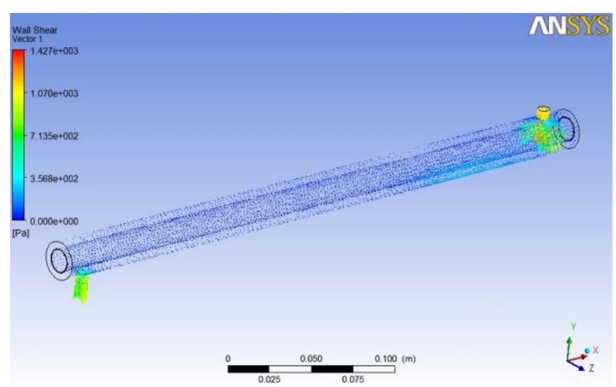


Figure 4.5: Wall shear stress distribution of double pipe heat exchanger

Figure 4.6 to figure 4.8 provides the values of temperature distribution velocity distribution and wall shear stress distribution for one shell and two pass heat exchanger respectively.

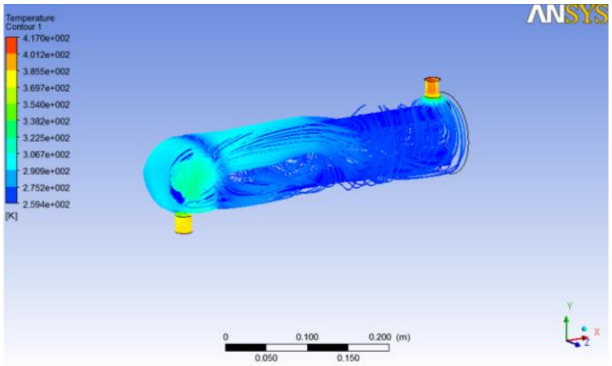


Figure 4.6: Temperature contour of one shell and two pass heat exchanger

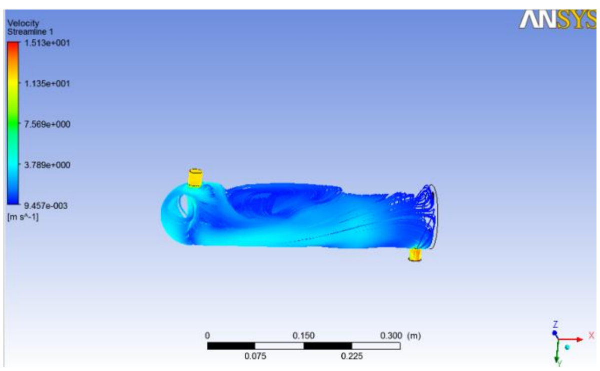


Figure 4.7: Streamline velocity of 1 shell and two pass heat exchanger corresponding 0.5 kg/s

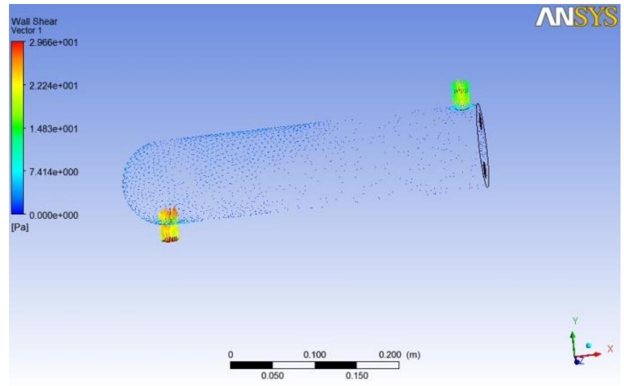


Figure 4.8: Wall shear stress of one shell and two pass heat exchanger

5. RESULTS:

Shell and tube type of heat exchanger with double pipe and two pass are investigated analytically and with the help of simulation software. The values of velocity, Reynolds number and Nusselt number have been calculated for mass flow rate of 0.5 kg/s. the following observations are drawn by mathematical calculations.

Table 5.1: Calculation table for mass flow rate (starting from0.5 kg/s) of cold fluid for double pipe heat exchanger

Sr. no.	Mass flow rate of cold fluid in kg/sec	Velocity of cold fluid in m/s	Reynolds number of cold fluid	Nusselt number of cold fluid
1	0.5	2.856	7118.4	47.91

Table 5.2: Calculation table for mass flow rate (starting from0.8 kg/s) of hot fluid for double pipe heat exchanger

Sr. no.	Mass flow rate of hot fluid in kg/sec	Velocity of hot fluid in m/s	Reynolds number of hot fluid	Nusselt number of hot fluid
1	0.8	5.31	1312.433	12.399

Table 5.3: Calculation table for different mass flow rates of cold and hot fluid for double pipe heat exchanger

Parameters	Values				
Mass flow rate in kg/s (Cold fluid)	0.5	0.6	0.7	0.8	0.9
Velocity (Cold fluid)	2.85	3.4	3.99	4.57	5.14
Mass flow rate in kg/s (Hot fluid)	0.5	0.6	0.7	0.8	0.9
Velocity (Hot fluid)	3.31	3.9	4.64	5.31	5.97

Table 5.4: Calculation table for mass flow rate (starting from0.5 kg/s) of cold fluid for one shell and two pass heat exchanger

Sr. no.	Mass flow rate of cold fluid in kg/sec	Velocity of cold fluid in m/s	Reynolds number of cold fluid	Nusselt number of cold fluid
1	0.5	6.42	10677.6	66.27

Table 5.5: Calculation table for mass flow rate (starting from 0.8 kg/s) of hot fluid for one shell and two pass heat exchanger

Sr. no.	Mass flow rate of hot fluid in kg/sec	Velocity of hot fluid in m/s	Reynolds number of hot fluid	Nusselt number of hot fluid
1	0.8	11.95	3149.84	24.95

Table 5.6: Calculation table for different mass flow rates of cold and hot fluid for shell and tube heat exchanger

Parameters	Values				
Mass flow rate in kg/s (Cold fluid)	0.5	0.6	0.7	0.8	0.9
Velocity (Cold fluid)	6.42	7.71	8.99	10.28	11.57
Mass flow rate in kg/s (Hot fluid)	0.5	0.6	0.7	0.8	0.9
Velocity (Hot fluid)	7.46	8.96	10.45	11.95	13.44

Table 5.7: Calculation table for heat transfer for double tube heat exchanger

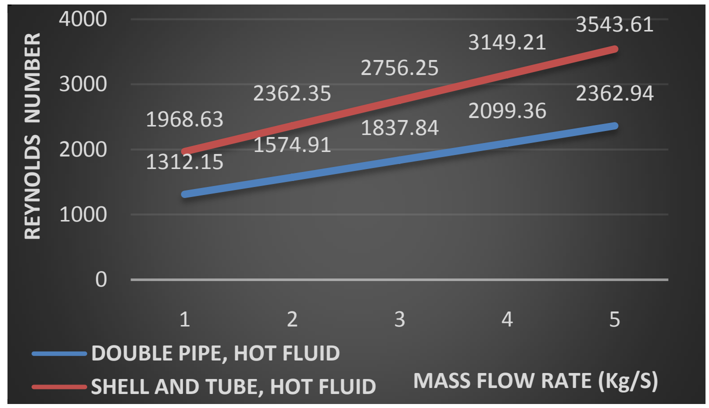
Parameters	Overall Heat Transfer in Watt/m2K				
Tube in tube type heat exchanger	418.057	483.705	547.19	608.88	669.042
One shell and two pass heat exchanger	578.241	669.042	756.852	842.179	925.394
Percentage increase in overall heat transfer of shell and tube over tube in tube heat exchanger	27.71	27.70	27.73	27.70	30.61

Table 5.8: Calculation table for heat transfer for double tube heat exchanger

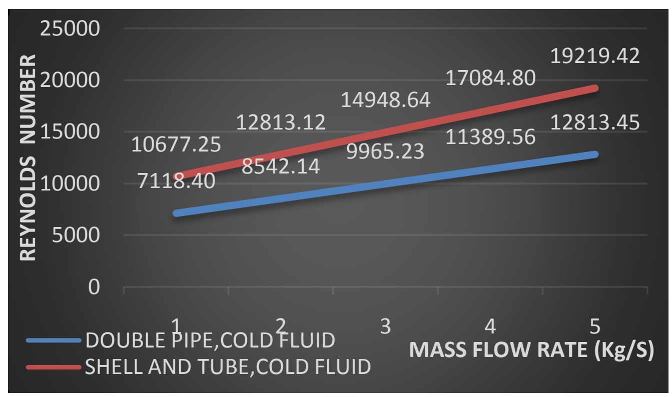
Parameters	Heat Transfer in KW				
Tube in tube type heat exchanger	2.21	2.56	2.90	3.22	3.54
One shell and two pass heat exchanger	3.06	3.54	4.01	4.46	4.90
Percentage increase in heat transfer of shell and tube compare to tube in tube heat exchanger	27.7	27.68	27.68	27.80	27.7

6. OBSERVATION

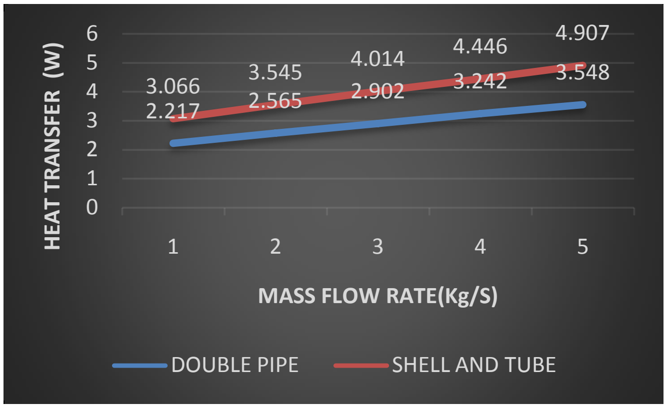
1. Reynolds number is one of the important parameter which reflects that the flow of fluid is either laminar or turbulent, in the concern problem in case of cold fluid the fluid is flowing with Reynolds number greater than 10000 so the flow comes in the range of turbulent flow.
2. Nusselt number help us to predict heat transfer coefficient in convective heat flow, which in turns help us to find out the quantity of heat transfer from hot fluid to the cold fluid.
3. In shell and tube heat exchanger there is a maximum heat transfer which is being carried out in convective mode of heat transfer while very small quantity of heat is transferred through the conduction.
4. It is observed that with increase in the mass flow rate the average velocity of the fluid is also increases which further increase the Reynolds number and flow goes towards turbulent.
5. It has been clearly seen from the mathematical calculation that the overall heat transfer coefficient is greater in case of one shell and two pass heat exchanger, the same can be reflected by simulation result that the magnitude of heat transfer is greater in one shell and two pass heat exchanger.
6. As the result of simulation, the wall shear stress, which has a higher in magnitude in case of one shell and two pass heat exchanger, the wall shear can be validated with the help of numerical solution. It has been found that with increase in wall shear it retards the flow of fluid and the result of which the velocity of hot fluid in shell is reduced.
7. The value of overall heat transfer coefficient is significantly increases with the shell and tube type of heat exchanger and the percentage increase of the same is ranging from 27.7 to 30 %. (approx.) in all cases.
8. The heat transfer rate is also increase up to 27 % (approx.) numerically as compared to double tube type heat exchanger.



Graph 5.1: Comparative value of Reynolds number for cold fluids at different mass flow rates.



Graph 5.2: Comparative value of Reynolds number for hot fluids at different mass flow rates.



Graph 5.3: Comparative value of heat transfer rate at different mass flow rates

7. CONCLUSION

1. As seen from the result table of the velocity and mass flow rate of double pipe heat exchanger in numerical data and simulation results are reflecting almost equal values for mass flow rate of 0.8 kg/s i.e. 5.31 m/s while the same is measured via simulation and found as and 6.8 m/s it is deviated almost in a negligible amount.
2. The streamline velocity value for mass flow rate of 0.8 kg/s is also validated by simulation results as mathematically for shell and tube heat exchanger it is found out to be 11.95 m/s which matches in case of simulation results as 15.13 m/s and so computational fluid dynamic software's are proven to provide the solution without any length calculations and hence saves time by eliminating complex calculation.
3. The one shell and two pass heat exchanger proven to be the best solution where heat transfer rates are to be maximized with compactness in size.
4. We can trace the distribution of temperature correctly inside the shell and tube heat exchanger in both double pipe and one shell and two pass heat exchangers. From software it can be seen that minimum temperature achieved in double pipe heat exchanger is 293 K while the same is found as 259.4 K for shell and tube heat exchanger and so it is more effective.
5. Computationally it is found that the wall shear stresses is directly associated with fluid velocity and friction coefficient it is evident from result obtained that with increase in velocity wall shear stress increases.
6. The flow mechanism of the fluid can easily be visualized in CFD and we can easily trace the recirculation of the fluid.

8. Future Scope

1. By varying the temperature of cold fluid we can predict the performance of the shell and tube heat exchanger.
2. By changing the material of shell and tube of the heat exchanger one can enhance the performance of heat exchanger.
3. In future the coolants can also be varied to see what the different coolant effect the heat exchanger and can suggest the best possible working fluids for maximum heat transfer between the cold and hot medium.
4. In future the heat exchangers used for different applications and purposes can also be modelled and analysed using the CFD approach. One can also use the heat exchanger in passive cooling technology used in green buildings for saving energy.

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