Design and Analysis of Double Tube Helical Baffle Heat Exchanger for Heat Transfer Enhancement

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Abstract - *Temperature can be characterized as a measure of the energy of a substance. The main objective of this work is to perform of the study of three dimension CFD analysis and its mathematical relation of DPHE (double pipe heat exchanger), prepare different computational model of double pipe heat exchanger. To perform CFD analysis for heat transfer in the DPHE under different operation conditions and compare the result of all design DPHE (double pipe heat exchanger). The hot water flows inside the heat exchanger tube, while the cold fluid flows in the outer side in the direction of counter flow. Mass flow rate cold fluid was varied from 0.1 kg/s to 0.3 kg/s while the flow rate in the inner tube i.e. hot water was kept constant at 0.1 kg/s. the inlet temperature of hot fluid taken as 40oC while Cold fluid inlet temperature taken as 15oC. The fluent software is used to calculate the fluid flow and heat transfer in the computational domains. The governing equations are iteratively solved by the finite volume formulation with the SIMPLE algorithm. Results show that that the maximum temperature drop of 10.9 ^{o}C for hot fluid and the maximum temperature rise of 11.9 ^{o}C for cold fluid are observed at 0.3 kg/sec mass flow rate for double pipe heat exchanger with double helical baffles. It has been also observed that the heat transfer coefficient increasing with the increasing in the mass flow rate of cold fluid. The overall heat transfer coefficients differ significantly by 20.4 % at same mass flow rate, because the considerable difference between heat transfer surface area on the inner and outer side of the tube resulting in a prominent thermal enhancement of the cold fluid.*

Key Words: CFD, helical baffle, ANSYS, heat exchanger, DPHE.

1. INTRODUCTION

Temperature can be characterized as a measure of the energy of a substance. With heat exchangers, this energy is transferred from one substance to another. In handling units it is important to control the temperature of the duct and outflows. These streams can be gases or liquids. Heat exchangers raise or lower the temperature of these streams by displacing heat to or from the stream. Heat exchangers are a device that exchanges heat between two liquids at different temperatures, isolated by a powerful divider. Temperature inclination or temperature contrasts affect this movement of heat. The movement of heat occurs in three ways: radiation, conduction and convection. Radiation occurs when using heat exchangers. In terms of conduction and convection, however, radiation does not play an important role.

2. LITERATURE REVIEW

Yue Sun et al. [1] in this paper presented are a shell and chamber heat exchanger with inclined clover leaf septa (STHX-IT) is proposed and a digital conversation is carried out to analyze the current and heat exchange properties. The results show that the STHX-IT thermal displacement coefficient and crush factor drop are lower than that of the regular STHX-SG at 23.89% and 44.19%, respectively.

K. Ashok Kumar Raju et al. [2] this article presents heat exchangers that are increasingly being considered for their applications in space heating, air conditioning, cooling, power plants, technical systems, petrochemicals and flammable gas systems. In this work, the manufacturers attempted to power the heat exchanger for more salient utility by altering the Perplex plane. In total, five different diversion plans were considered to conduct the CFD exam and find the best accommodation.

V. Patel et al. [3] this article introduces shell and tube heat exchangers, which are the best known types of heat exchangers and which are widely used in many modern applications. Keeping the cost of these heat exchangers low is an important goal for stylists and customers.

K. Raj et al. [4] In this examination, an endeavor was made to explore the impacts of various event focuses on fluid stream and the heat development properties of a shell and cylinder heat exchanger for three distinctive pattern focuses, for example at 0°, 10° and 20°. For their portrayal, the consequences of the guideline of some shell and cylinder heat exchangers are dissected, one with divided disarray confronting the fluid stream and two with slanted fragmentary disarray in the fluid flow bearing.

3. OBJECTIVE

There are following objective are to be expected from the present work

1. To perform of the study of three dimension CFD analysis and its mathematical relation of DPHE (double pipe heat exchanger).

2. To prepare different computational model of double pipe heat exchanger.
3. To perform CFD analysis for heat transfer in the DPHE under different operation conditions.
4. To compare the result of all design DPHE (double pipe heat exchanger

4. METHODOLOGY

4.1 Algorithm used for Computational fluid dynamics analysis

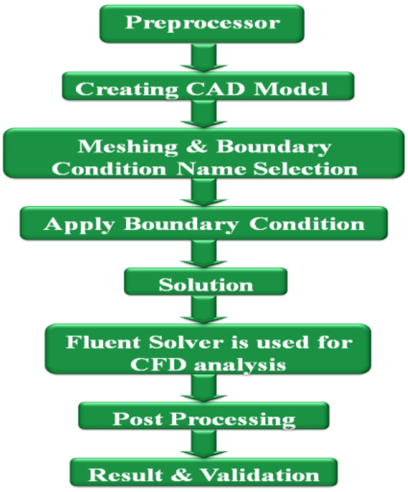

Fig -1: Algorithm used for Computational fluid dynamics analysis

4.2 Governing Equations

a. Conservation of mass or continuity equation

The equation for conservation of mass, or continuity equation, can be written as follows:

$$\frac{\partial \rho}{\partial t} + \nabla.(\rho\, \vec{v}) = S_m$$

Where S_m= mass added to the continuous phase or any user defined sources.

For 2D axisymmetric geometries, the continuity equation is given by

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x}(\rho v_x) + \frac{\partial}{\partial r}(\rho v_r) + \frac{\rho v_r}{r} = S_m$$

Where x is the axial coordinate, r is the radial coordinate, v_x is the axial velocity, and v_r is the radial velocity.

4.3 Boundary conditions

1. To determine the temperature distribution need to on energy equation.
2. Turbulent model is K-epsilon realizable, scalable wall function is used.
3. Working fluid water liquid with density of 998.2 kg/m^3 and heat exchanger pipe material is stainless steel having thermal conductivity is k =15.2W/mk.
4. Cold inlet having mass flow rate is 0.1, 0.2 and 0.3 kg/sec, temperature 288K.
5. Hot inlet having mass flow rate is 0.1, 0.2 and 0.3 kg/sec, temperature 313K.
6. For the outlet boundary condition the gauge pressure needs to be set as zero because the fluid flowing inside the heat exchanger(hot & cold) is atmospheric
7. Rest of all surface treated as wall with no slip conditions set for solid walls where the heat flux is set as zero for the outer side wall to make adiabatic condition, while the inner tube walls and baffles is coupled.
8. The second order upwind scheme is used for the momentum energy turbulence and its dissipation rate.
9. The Fluent solver is used for CFD analysis.

4.4 Computational fluid dynamics analysis for double tube heat exchanger

4.4.1 CAD model of double tube heat exchanger without baffle

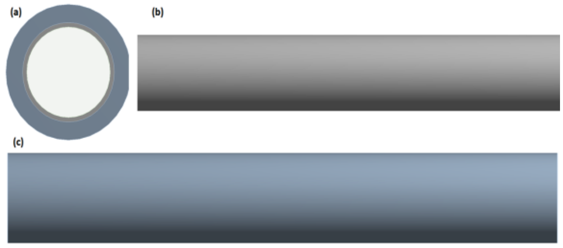

Fig -2: CAD model of double pipe heat exchanger without baffle; (a) Face side (b) Baffle (c) Volume of cold flow

Meshing: Meshing is a critical operation in finite element analysis in this process CAD geometry is divided into large numbers of small pieces called mesh. The total no of nodes generated in the present work is 3289731 and total No. of Elements is 3021078 as shown in figure 3.

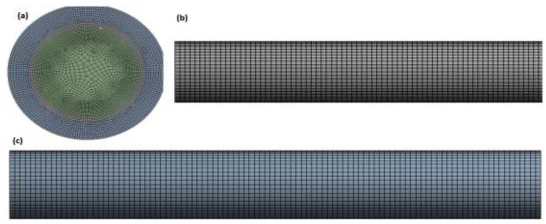

Fig -3: Meshing of double pipe heat exchanger without baffle (a) Face side (b) Baffle (c) Volume Mesh

4.4.2 CAD model of double tube heat exchanger with single baffle at pith B = 0.033 m

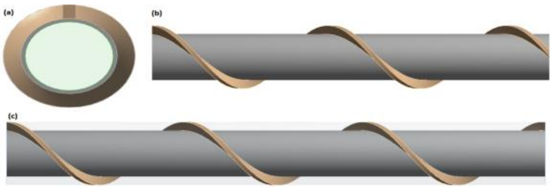

Fig -4: CAD model of double pipe heat exchanger with single baffle at B = 0.033 m; (a) Face side (b) Baffle (c) Volume of cold flow

Meshing: The total no of nodes generated in the present work is 2879962 and total No. of Elements is 2455782 as shown in figure 5.

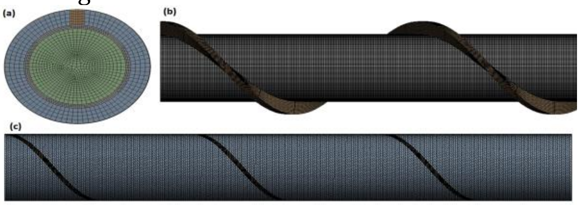

Fig -5: Meshing of double pipe heat exchanger with single baffle at B = 0.033 m; (a) Face side (b) Baffle (c) Volume Mesh

4.4.3 CAD model of double tube heat exchanger with single baffle at pith B = 0.025 m

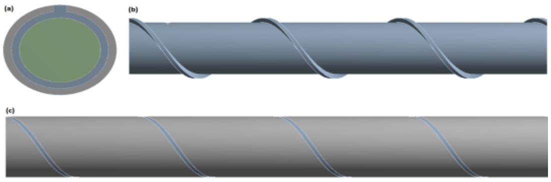

Fig -6: CAD model of double pipe heat exchanger; (a) Face side (b) Baffle (c) Volume of cold flow

Meshing: The total no of nodes generated in the present work is 1108028 and total No. of Elements is 3184242 as shown in figure 7.

Fig -7: meshing of double pipe heat exchanger (a) Face side (b) Baffle (c) Volume Mesh

4.4.4 CAD geometry of double tube heat exchanger with double helical baffles at pith B = 0.025 m

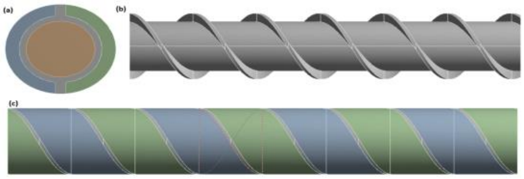

Fig -8: CAD model of double pipe heat exchanger with two baffels; (a) Face side (b) Baffle (c) Volume of cold flow

Meshing; The total no of nodes generated in the present work is 2944774 and total No. of Elements is 2819506 as shown in figure 9.

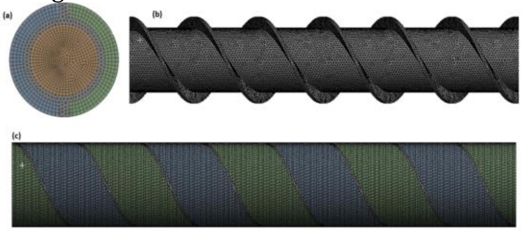

Fig -9: Meshing of double pipe heat exchanger with two baffels; (a) Face side (b) Baffle (c) Volume Mesh

4.4.5 Grid independent test

Heat transfer by hot fluid:

$$Q_h = \dot{m}_h c_{p,h} (T_h^{in} - T_h^{out})$$

Heat gain by cold fluid:

$$Q_c = \dot{m}_c c_{p,c} (T_c^{out} - T_c^{in})$$

A series of grid independent tests were carried out to ensure that optimized computational mesh was obtained. There are total six sets of grids (37771, 81874, 257140, 1627641, 3021078 and 3239750 elements) are computed. It was found that the difference in the rate of heat transfer between 3021078 and 3239750 is almost similar that is why the grid system 3021078 elements were adopted.

4.4.6 Interpolation relation

Linear interpolation relation is used to find the intermediates value of specific heat of hot and cold water.

$$y = y_1 + (x - x_1)\frac{y_2 - y_1}{x_2 - x_1}$$

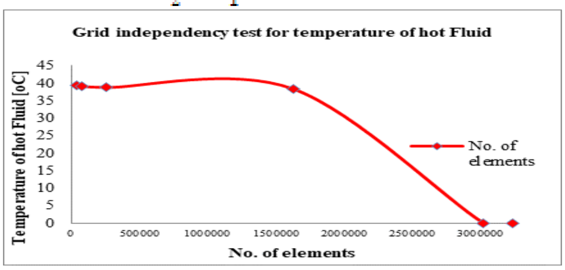

Chart -1: Grid independency test for temperature of hot Fluid

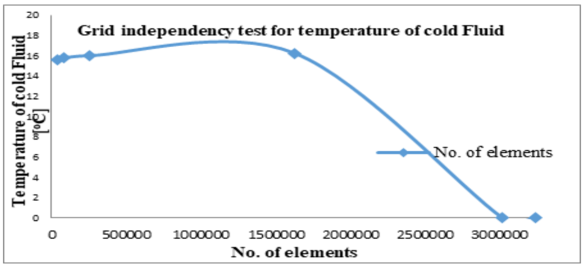

Chart -2: Grid independency test for temperature of cold Fluid

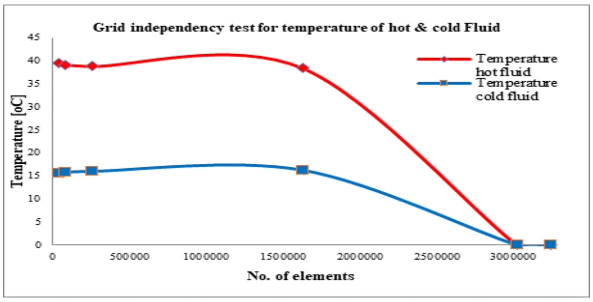

Chart -3: Grid independency test for temperature of hot & co0ld Fluid

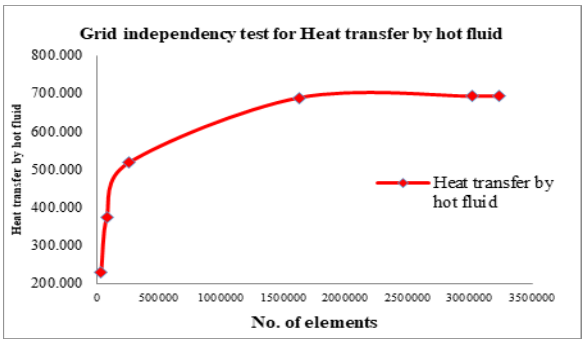

Chart -4: Grid independency test for temperature of hot & cold Fluid

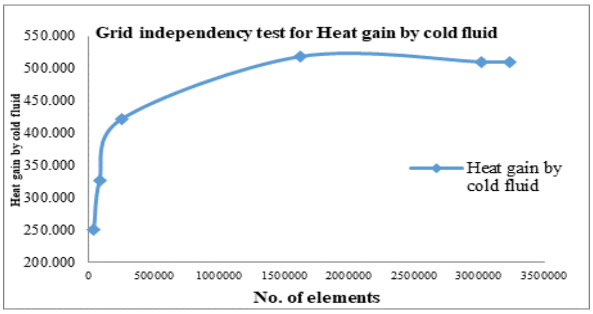

Chart -5: Grid independency test for Heat gain by cold fluid

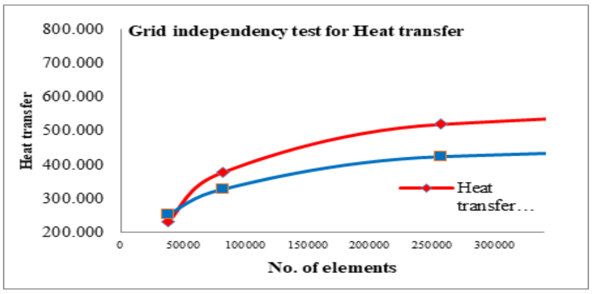

Chart -6: Grid independency test for Heat transfer

5. Results

5.1 Computational fluid dynamics analysis for double pipe heat exchanger without baffles at 0.1 kg/sec mass flow rate:

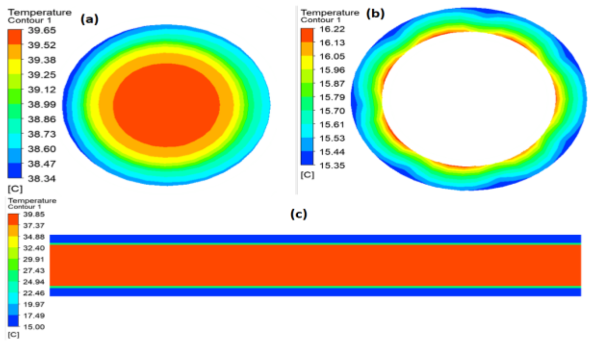

Fig -10: temperature distribution for mass flow rate of cold fluid at 0.1 kg/sec (a) hot fluid at outlet (b) cold fluid at outlet (c) heat exchanger mid plane

5.2 Computational fluid dynamics analysis for double pipe heat exchanger without baffles at 0.2 kg/sec mass flow rate

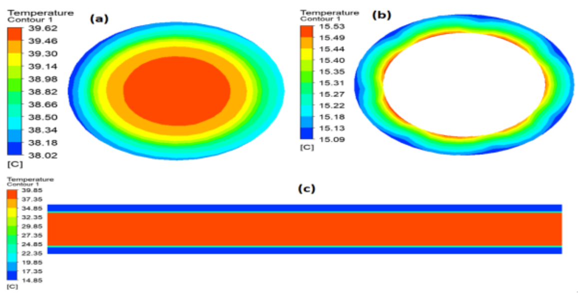

Fig -11: temperature distribution for mass flow rate of cold fluid at 0.2 kg/sec (a) hot fluid at outlet (b) cold fluid at outlet (c) heat exchanger mid plane

5.3 Computational fluid dynamics analysis for double pipe heat exchanger without baffles at 0.3 kg/sec mass flow rate

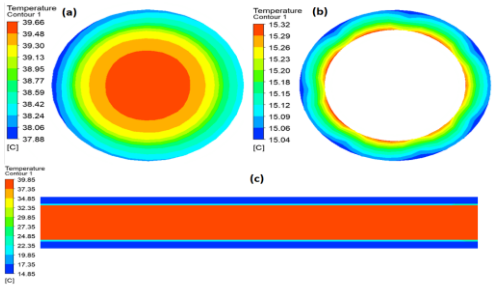

Fig -12: temperature distribution for mass flow rate of cold fluid at 0.3 kg/sec (a) hot fluid at outlet (b) cold fluid at outlet (c) heat exchanger mid plane

5.4 Computational fluid dynamics analysis for double pipe heat exchanger with single baffles of 25 mm pitch length at 0.1 kg/sec mass flow rate

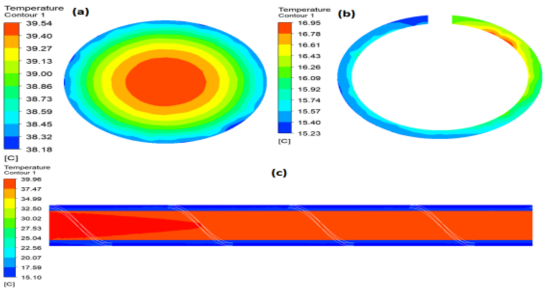

Fig -13: Temperature contours for B = 25 mm at mass flow rate 0.1 kg/s (a) hot fluid at outlet (b) cold fluid at outlet (c) heat exchanger mid plane

5.5 Computational fluid dynamics analysis for double pipe heat exchanger with single baffles of 25 mm pitch length at 0.2 kg/sec mass flow rate

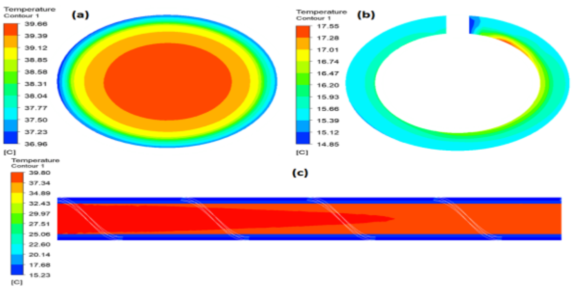

Fig -14: Temperature contours for B = 25 mm at mass flow rate 0.2 kg/s (a) hot fluid at outlet (b) cold fluid at outlet (c) heat exchanger mid plane

5.6 Computational fluid dynamics analysis for double pipe heat exchanger with single baffles of 25 mm pitch length at 0.3 kg/sec mass flow rate

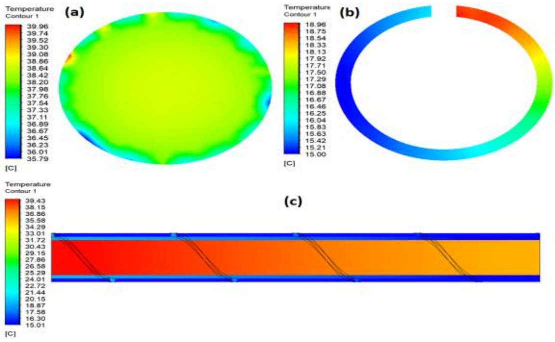

Fig -15: Temperature contours for B = 25 mm at mass flow rate 0.3 kg/s (a) hot fluid at outlet (b) cold fluid at outlet (c) heat exchanger mid plane

5.7 Computational fluid dynamics analysis for double pipe heat exchanger with double baffles of pitch length 25 mm at 0.1 kg/sec mass flow rate

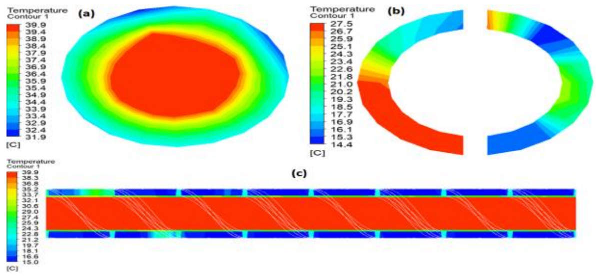

Fig -16: Temperature contours for double baffle at B = 25 mm at mass flow rate 0.1 kg/s (a) hot fluid at outlet (b) cold fluid at outlet (c) heat exchanger mid plane

5.8 Computational fluid dynamics analysis for double pipe heat exchanger with double baffles of pitch length 25 mm at 0.2 kg/sec mass flow rate

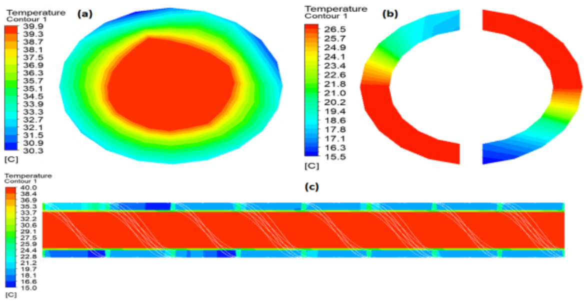

Fig -17: Temperature contours for double baffle at B = 25 mm at mass flow rate 0.2 kg/s (a) hot fluid at outlet (b) cold fluid at outlet (c) heat exchanger mid plane

5.9 Computational fluid dynamics analysis for double pipe heat exchanger with double baffles of pitch length 25 mm at 0.3 kg/sec mass flow rate

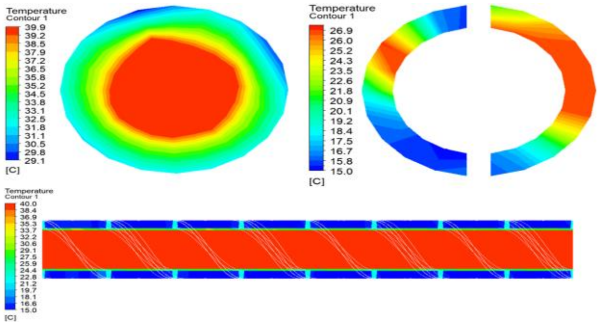

Fig -18: Temperature contours for double baffle at B = 25 mm at mass flow rate 0.3 kg/s (a) hot fluid at outlet (b) cold fluid at outlet (c) heat exchanger mid plane

5.10 Comparative result analysis of double pipe heat exchanger

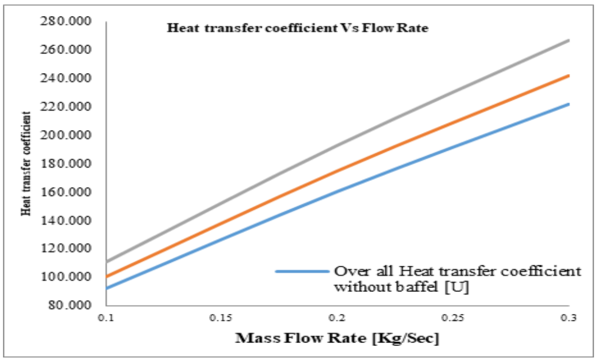

Chart -7: Heat transfer coefficient Vs Flow Rate

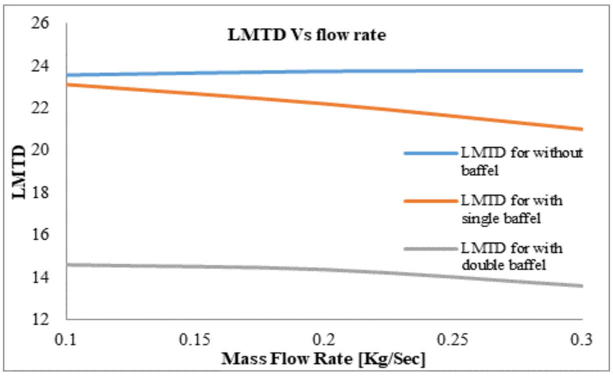

Chart -8: LMTD Vs flow rate

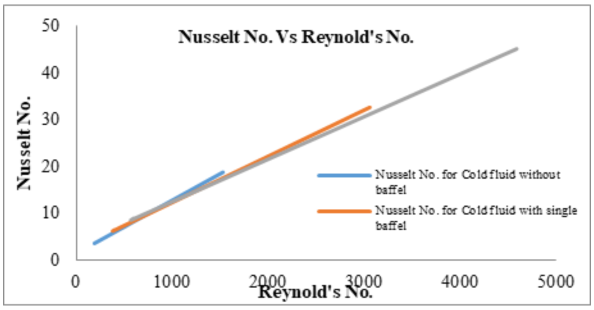

Chart -9: Nusselt No. Vs Reynold's No.

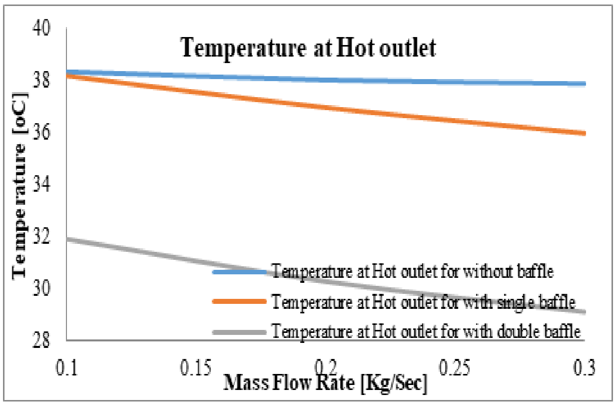

Chart -10: Temperature at Hot outlet

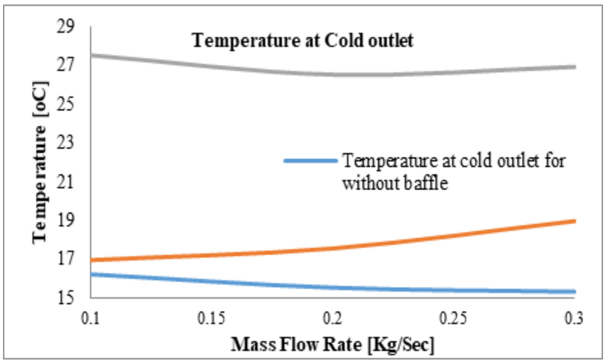

Chart -11: Temperature at Cold outlet

6. CONCLUSIONS

In the present work computational fluid dynamics analyses have been performed for double pipe exchanger used helical baffles with different spacing on the hot fluid pipe. For this analysis double pipe heat exchangers are divided into three different domains such as two fluid domains hot fluid in the inner tube and cold fluid in the outer pipe and a solid domain as helical baffles on inner tube of hot fluid. Mass flow rate cold fluid was varied from 0.1 kg/s to 0.3 kg/s while the flow rate in the inner tube i.e. hot water was kept constant at 0.1 kg/s. the inlet temperature of hot fluid taken as 40°C while Cold fluid inlet temperature taken as 15°C. Mathematical and computational fluid dynamic analyses have been performed and compared the results. There are following conclusive points drawn from this work.

1. After performing computational fluid dynamics analysis of double pipe heat exchanger without baffles, cold fluid flowing at 0.1 kg/sec. The hot fluid temperatures drop of 38.34 °C & cold fluid temperature rise of 16.22 °C.
2. After performing computational fluid dynamics analysis of double pipe heat exchanger without baffles, cold fluid flowing at 0.2 kg/sec. The hot fluid temperatures drop of 38.02 °C & cold fluid temperature rise of 15.53 °C.
3. After performing computational fluid dynamics analysis of double pipe heat exchanger without baffles, cold fluid flowing at 0.3 kg/sec. The hot fluid temperatures drop of 37.88 °C & cold fluid temperature rise of 15.32 °C.
4. After performing computational fluid dynamics analysis of double pipe heat exchanger with single baffles, cold fluid flowing at 0.1 kg/sec. The hot fluid temperatures drop of 38.18 °C & cold fluid temperature rise of 16.95 °C.
5. After performing computational fluid dynamics analysis of double pipe heat exchanger with single baffles, cold fluid flowing at 0.2 kg/sec. The hot fluid temperatures drop of 36.96 °C & cold fluid temperature rise of 17.55 °C.
6. After performing computational fluid dynamics analysis of double pipe heat exchanger with single baffles, cold fluid flowing at 0.3 kg/sec. The hot fluid temperatures drop of 35.97 °C & cold fluid temperature rise of 18.96 °C.
7. After performing computational fluid dynamics analysis of double pipe heat exchanger with double baffles, cold fluid flowing at 0.1 kg/sec. The hot fluid temperatures drop of 31.9 °C & cold fluid temperature rise of 27.5 °C.
8. After performing computational fluid dynamics analysis of double pipe heat exchanger with double baffles, cold fluid flowing at 0.2 kg/sec. The hot fluid temperatures drop of 30.27 °C & cold fluid temperature rise of 26.5 °C.
9. After performing computational fluid dynamics analysis of double pipe heat exchanger with double baffles, cold fluid flowing at 0.3 kg/sec. The hot fluid temperatures drop of 29.1 °C & cold fluid temperature rise of 26.9 °C.
10. The logarithmic mean temperature difference is decreasing from 23.5°C to 13.59°C with increasing mass flow rate thus resulting increasing in overall heat transfer coefficient.
11. The overall heat transfer coefficients differ significantly by 20.4 % at 0.3 kg/sec mass flow rate, because the considerable difference between heat transfer surface area on the inner and outer side of the tube resulting in a prominent thermal enhancement of the cold fluid.

From the above concluding points it can be summarized that the maximum temperature drop of 10.9 °C (27.25%) for hot fluid and the maximum temperature rise of 11.9 °C (44.23%) for cold fluid are observed at 0.3 kg/sec mass flow rate for double pipe heat exchanger with double helical baffles. It has been also observed that the heat transfer coefficient increasing with the increasing in the mass flow rate of cold fluid. The overall heat transfer coefficients differ significantly by 20.4 % at same mass flow rate, because the considerable difference between heat transfer surface area on the inner and outer side of the tube resulting in a prominent thermal enhancement of the cold fluid

REFERENCES

[1] Yue Sun, Xinting Wang “Numerical Investigation and Optimization on Shell Side Performance of A Shell and Tube Heat Exchanger with Inclined Trefoil-Hole Baffles”, Energies 2019, 12(21), 4138; https://doi.org/10.3390/en12214138.

[2] K. Ashok Kumar Raju, M. Vijay Kumar Redd “Design Optimization of Cross Flow Heat Exchanger”, International Journal of Engineering Research & Technology (IJERT) Vol. 3 Issue 2, February – 2014.

[3] V. Patel and R. Rao, “Design optimization of shell-and-tube heat exchanger using particle swarm optimization technique,” Applied Thermal Engineering, vol. 30, no. 11- 12, pp. 1417–1425, 2010.

[4] K. Raj and S. Ganne, “Shell side numerical analysis of a shell and tube heat exchanger considering the effects of baffle inclination angle on fluid flow using CFD,” THERM SCI Thermsci THERMAL SCI Thermal Science, vol. 16, no. 4, pp. 1165–1174, 2012.

[5] Aslam Bhutta, M.M.; Hayat, N.; Bashir, M.H.; Khan, A.R.; Ahmad, K.N.; Khan, S. “CFD applications in various heat exchangers design: A review”. Appl. Therm. Eng. 2012, 32, 1–12.

[6] Zhang, X.Y.; Liu, Z.C.; Liu, W. “Numerical studies on heat transfer and flow characteristics for laminar flow in a tube with multiple regularly spaced twisted tapes”. Int. J. Therm. Sci. 2012, 58, 157–167.

[7] Liu, W.; Liu, P.; Dong, Z.M.; Yang, K.; Liu, Z.C. “A study on the multi-field synergy principle of convective heat and mass transfer enhancement”. Int. J. Heat Mass Transf. 2019, 134, 722–734.

[8] Milani Shirvan, K.; Mamourian, M.; Abolfazli Esfahani, J. “Experimental investigation on thermal performance and economic analysis of cosine wave tube structure in a shell and tube heat exchanger”. Energy Convers. Manag. 2018, 175, 86–98.

[9] Liu, J.J.; Liu, Z.C.; Liu, W. “3D numerical study on shell side heat transfer and flow characteristics of rod-baffle heat exchangers with spirally corrugated tubes”. Int. J. Therm. Sci. 2015, 89, 34–42.

[10] He, Z.B.; Fang, X.M.; Zhang, Z.G.; Gao, X.N. “Numerical investigation on performance comparison of non-Newtonian fluid flow in vertical heat exchangers combined helical baffle with elliptic and circular tubes”. Appl. Therm. Eng. 2016, 100, 84–97.

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