Comparative Analysis and Simulation of Helical & Segmented Baffles in Shell & Tube Heat Exchanger using CFD Method

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Abstract - *The shell and tube heat exchanger is the most common type heat exchanger widely used in the oil refinery and other large chemical processes because it suits a high-pressure application. The process of solving shell and tube heat exchanger in simulation consists of modeling and meshing the basic geometry using CFD package ANSYS 16.0. The objective of this simulation is to design of shell and tube heat exchanger with helical baffle and study the flow and hat transfer rate inside the shell using ANSYS software tools. In most recent two decades numerous specialized, experiment and numerical models are being introduced on shell and tube heat exchanger by researcher. This paper centers on computational fluid examination of shell and tube heat exchanger with various sort of baffles. The shell and tube heat exchanger with segmental baffles and baffles are modelled and analysed on Ansys cfx. The heat and pressure driven execution of both heat exchangers is compared with same working conditions. The flow and temperature fields inside the shell and tubes are solved by utilizing CFD fluent analysis software thinking about the plane symmetry. The heat exchanger with helical baffle gives more effectiveness than segmental baffles heat exchanger. Likewise the pressure drop gets decreased in helical baffle heat exchanger than segmental baffles heat exchanger. An arrangement of CFD a simulation is performed for a single shell and tube bundle and is compared with and the experimented outcomes*

Key Words: CFD simulation, heat transfer rate, helix heat exchanger, Ansys cfx, shell & tube heat exchanger.

1. INTRODUCTION

HEAT EXCHANGER

A Heat Exchanger may be defined as equipment which transfers energy from a hot fluid to a cold fluid, either maximum or minimum rate within minimum investment and running cost. In this process never two fluids mixed with each other. This device provides a flow of thermal energy between two or more fluids at different temperatures. Shell and tube heat exchangers are most versatile type of heat exchanger; they use in a wide variety of engineering applications like power generation, waste heat recovery, manufacturing industry, air-conditioning, refrigeration, space applications, petrochemical industries etc.

Heat exchanger is that devices which are used for the transferring heat between different temperature fluids which may be directly in contact or may be flowing separately in two tubes or in two channels. Numerous applications of heat exchangers can be observed in our day today life, to say a few are condensers and evaporators used in refrigerators and air conditioners and in case of thermal power plant heat exchangers are used in, condenser, boilers, air coolers and chilling towers. In case of automobiles heat exchangers are in the form of radiators or in the form of oil coolers in engine. Large scale process industries and chemical industries use heat exchangers for the transferring heat between different temperature fluids which are single phase and two phases.

The heat exchangers are characterized upon the accompanying components:

- Construction
- Flow pattern
- Number of shells
- Contact between the preparing streams
- Compactness
- Heat transfer system

1.1 Organization of the Paper

Step 1: Gives the short presentation of heat exchanger, shell and tube heat exchanger.

Step 2: Describes about computational liquid flow and familiar cfx program for performing investigation.

Step 3: Gives a concise writing about the subject and research which are identified with my present work.

Step 4: Describes about adopted methodology for analysis.

Step 5: Describes the mathematical formula and equations utilized as a part of analysing various parameters.

Step **6:** Modelling of the shell and tube heat exchanger with segmental and baffle.

Step 7: Deals with the outcomes and finish of my exploration work.

2. LITERATURE REVIEW

In the literature survey, It was found that so much work had been done to enhance the heat transfer rate in heat exchanger. However, there is no computational work has been done using flower baffle to achieve higher heat transfer rate with respect to power consumption. In my work I designed flower baffles and compare with segmental baffle keeping in mind that it should increase heat transfer rate and lesser pressure drop in shell and tube heat exchanger.

3. METHODOLOGY

The shell-and-tube heat exchanger with segmental baffles (SB-STHX) have numerous drawback, for example, high pressure drop, low heat transfer proficiency, Therefore, another kind of STHX utilizing distinctive sorts of baffles may accomplish higher heat transfer effectiveness and lower pressure drop. In this research we focus on design of a shell and tube heat exchanger (STHX) with flower baffles also to perform computational fluid dynamics investigations.

3.1 Methodology Adopted

CFD codes have been produced and enhanced for quite a long time. ANSYS gives a system level modeling, meshing and complex flow simulations. The 3D geometry created by "Solidworks" is modified by utilizing "design Modular" into two computational zones for meshing. Then modeled is imported in cfx window where boundary conditions are defined at inlet and outlet condition in order to get heat transfer coefficient and pressure drop. CFD-Post are utilized to exhibit the results of simulations in a graphical frame.

3.2 Analysis Procedure

- Modelling of shell and tube heat exchanger
- Material selection
- Defining zones
- Meshing
- Boundary conditions
- Solution methods
- Solution initialization
- Iteration
- Solution
- Plot results and contours

4. MATHEMATICAL FORMULA AND EQUATION

4.1 Shell Side Calculation

From equation number 1 we get shell side heat transfer coefficient

$$\frac{1}{Uo} = \frac{1}{ho} + \frac{do}{di*hi} \qquad (1)$$

Where **Uo** is over all heat transfer coefficient, **hi** is tube side heat transfer coefficient, **ho** is shell side heat transfer coefficient,

4.2 Overall Heat Transfer Calculation

Overall heat transfer coefficient achieved based on heat transfer correlation

$$Uo = \frac{Qavg.}{Ah*\Delta Tlm} \qquad (2)$$

Where **Ah** is heat transfer area in m2, ΔTlm is logarithmic temperature difference (LMTD). $\mathbf{Q_{avg}}$ is average heat flux of cold and warm fluid.

ΔTlm is the log mean temperature difference and can be calculated by using the equation

$$(\Delta T2-\Delta T1)/\ln(\Delta T2/\Delta T1) \qquad (3)$$

Where ΔT1 and ΔT2 are

$$\Delta T2 = T(hot, in) - T(cold,out),$$

And

$$\Delta T1=T(hot,out)-T(cold,in) \qquad (4)$$

$$A_h=\pi*d_0*L_{effe*N} \qquad (5)$$

Leff is effective length of tube used for heat transfer, **do** is outer diameter of tube, and **N** is number of tubes.

4.3 Pressure Ratio Calculation

$$P = \frac{Tc2-Tc1}{Th1-Tc1} \qquad (6)$$

Since **Th1** is shell side fluid inlet temperature, **Th2** is shell side fluid outlet temperature, **Tc1** is tube side fluid inlet temperature, **and Tc2** is tube side fluid outlet temperature.

Shell Side and Tube Side Heat Transfer

Shell side and tube side heat transfer achieved by using following correlation.

$$Q= m * Cp *\Delta T \qquad (7)$$

M is fluid mass flow rate, kg/s; **Cp**, specific heat under constant pressure, **ΔT** is temperature difference.

4.4 Nusselt Number calculation

Nusselt number can be calculated using this equation

$$Nu = \frac{\frac{f}{2}(Re-1000)*Pr}{1+12.7\left(\frac{f}{2}\right)^{1/2}*(Pr^{\frac{2}{3}}-1)} \qquad (8)$$

Nu is Nusselt number, **Pr** is Prandtl Number, **Re** Reynolds Number and **f** is friction factor.

4.5 Tube Side Heat Transfer Coefficient Calculation

$$Nu = \frac{hi*k}{di} \qquad (9)$$

Friction factor calculated by

$$f= (1.35* \ln (Re) -3.28)^{-2} \qquad (10)$$

Reynolds number is achieved from the following equation.

$$Re= (\rho* u *di)/ \upsilon \qquad (11)$$

5. COMPUTATIONAL MODEL OF HEAT EXCHANGER

5.1 Geometrical Modelling

Modelling is a pre-processor tool, geometry of the model is created in solidwork's using part file .the shell and tube heat exchanger models contains two part one is shell which is hollow and other one is tube bundles with baffles.Two different shell and tube heat exchanger have been modeled one with segmental bafflesSecond with helical baffles.

5.2 Dimension Of Heat Exchanger

Table-1: Component details of SG-SHTX

Shell inner dia	132mm
Tube oveall length	1000mm
Shell side fluid flow	cool water
Number of tube	20
Number of baffles	10
Spacing between baffles	85mm
Tube inner dia	9mm
Tube outer dia	13mm
Tube side fluid	warm water
Heat transfer area	0.82 m^2

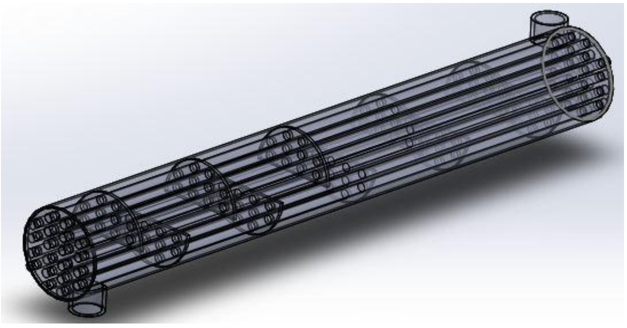

Fig- 1: shell and tube heat exchanger with segmental baffle

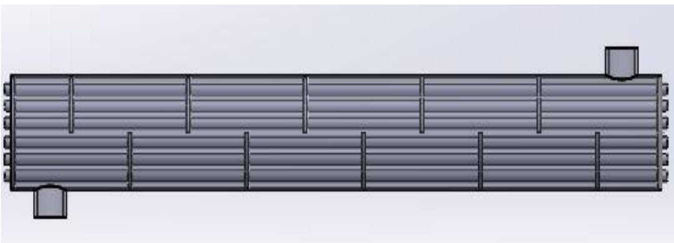

Fig-2: Assemble model of shell and tube heat exchanger

5.3 Meshing

The three-dimensional model is then discretized in ICEM CFD. Keeping in mind the end goal to catch both the hydraulic and thermal parameters, the meshing of model is automatically generated and the whole model is discretized utilizing triangular mesh components . Fine control on the triangular mesh near the wall surface allows capturing the boundary layer gradient accurately.

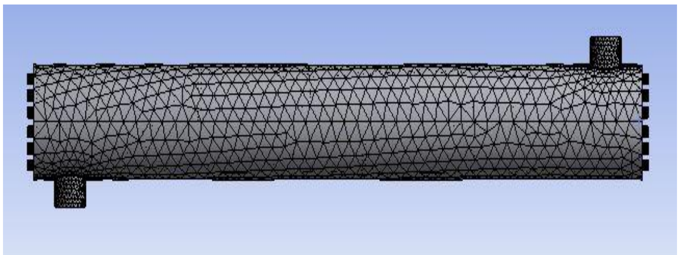

Fig-3: Meshed model of HB-SHTX

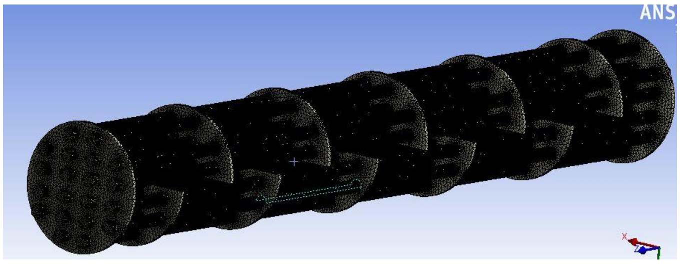

Fig-4: Meshed Model of SG-STHX

5.4 Boundary Conditions

These are boundary conditions parameters which were given in Ansys cfx for obtaining results and the boundary condition values are adopted from experimental work

Table-2: Conditions given in the fluent for obtaining results

Cold inlet : Velocity inlet	0.708 m/s
Cold inlet :Temperature	303 K
Hot inlet : Velocity outlet	0.89 m/s
Hot inlet :Temperature	338 K
Hot outlet : Pressure outlet	P 1 bar
Cold outlet : Pressure outlet	P 1 bar

5.5 Problem Setup

Simulation was done in ANSYS® FLUENT® v16. In the Fluent, solver Pressure Based type was chosen, absolute velocity formation and steady time were chosen for the simulation. In the default domain option energy calculation was on and the viscous was set as standard k-e, standard wall function (k-epsilon 2 eqn.). In cell zone liquid water-fluid was chosen and copper, aluminum were chosen as materials for simulation.

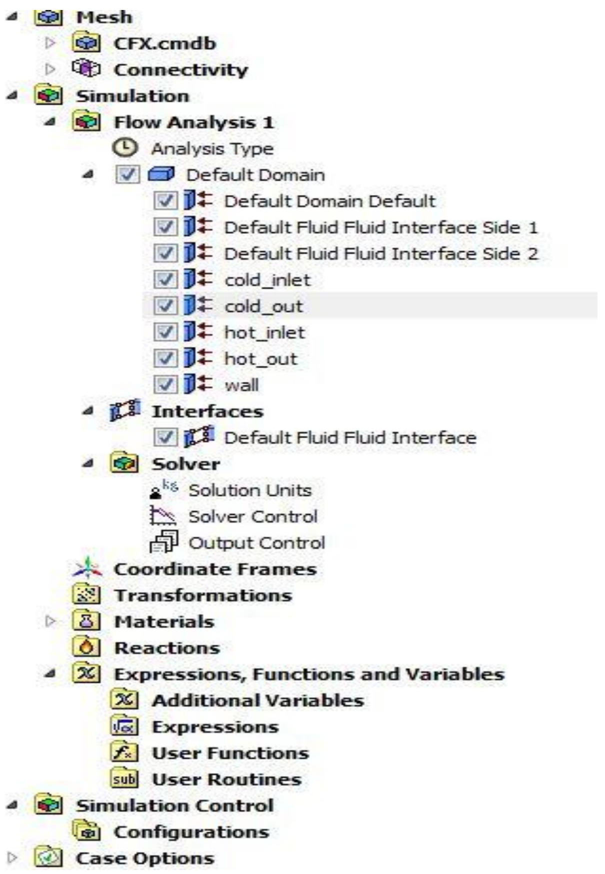

Fig-5: Interface of CFX

5.6 Solution Initialization

After giving the boundary conditions to the inner and outer fluid, and setting problem setup finally we have run the calculations. The number of iteration is set to 1000 and the solution is calculated with different contours, vectors and plots are obtained.

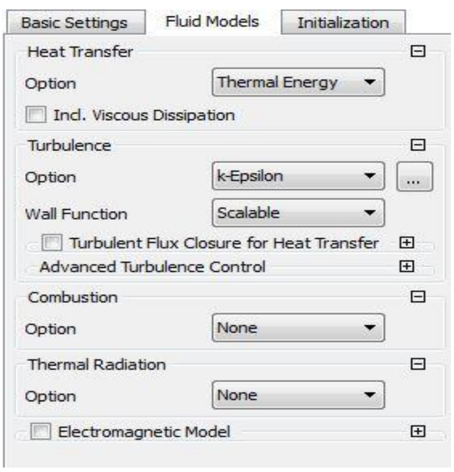

Fig-6: Solution initiation setting

6. Results

An examination of overall heat transfer coefficient and pressure drop got from these models. Knowing the temperatures from CFD results, overall heat transfer coefficient and shell side heat transfer coefficient is obtained from conditions. Because of the accessible test information for correlation, heat transfer coefficient alongside shell side heat transfer coefficient is calculated. While, pressure drop can be computed from CFD and compared with experimental data.

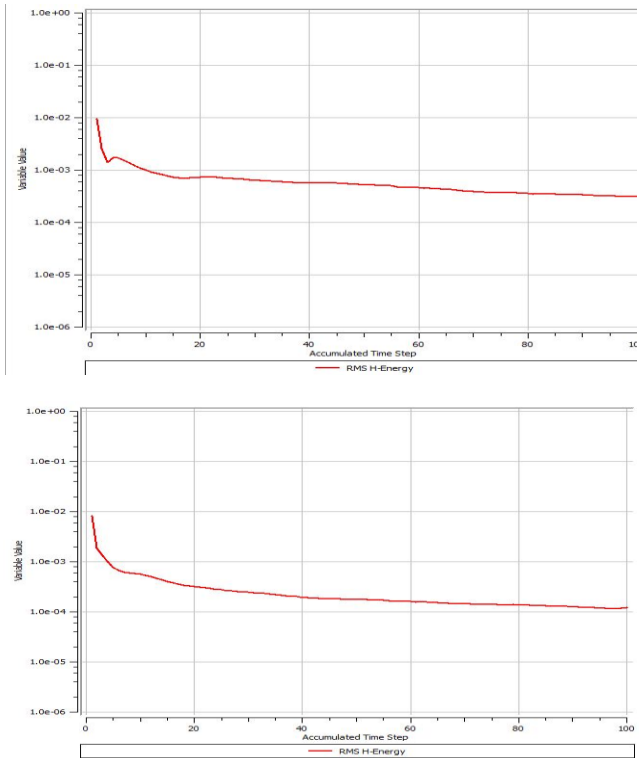

Fig-7: Comparison of Heat transfer rate (a)HB-SGHTX (b) SG-SGHTX

6.1 Comparison Of Overall Heat Transfer Between Two STHTX

The graph shows the variation of Uo (oveall all heat transfer coffecient) with reynolds number,initially value of Uo is staight line up to 1400 Re afterwards it increases linearly with reynolds number. It also shows that as the reynods number increses value of oveall heat transfer coffecient also increases.

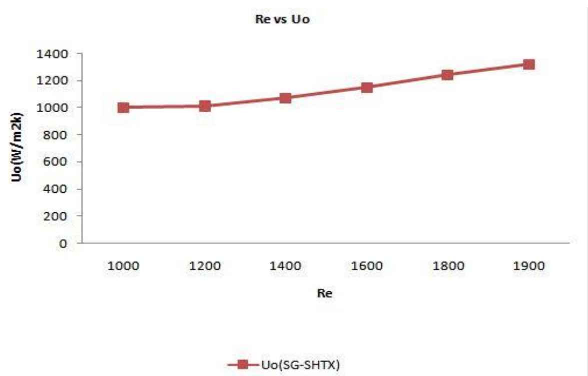

Fig-8: Variation of Uo with Reynolds number in HB-SHTX

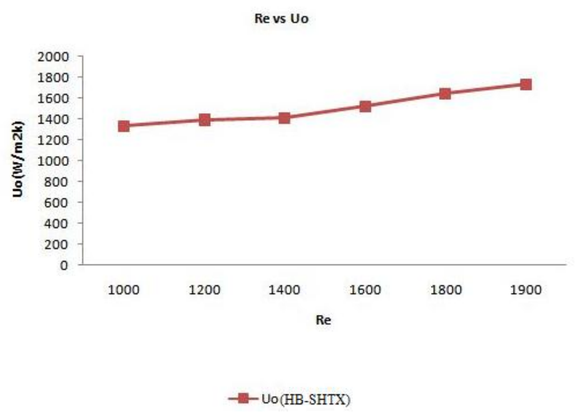

Fig-9: Variation of Uo with Reynolds number in SG-SHTX

When values of Uo for both shell and tube heat exchanger i.e SG-segmental and HB- baffle are compared it is observed that baffle gives more oveall heat transfer coffecient over segmental baffle and more efficient than segmental baffle.

Table -3: Comparison of overall heat transfer

REYNODS NO.	SG-SHTX Uo (w/m2k)	HB-SHTX Uo (w/m2k)	IMPROVEMENT
1000	1002.45	1232.58	23%
1200	1018.97	1292.45	27%
1400	1075.48	1311.91	22%
1600	1152.21	1411.25	23%
1800	1242.67	1544.48	24%
1900	1321.58	1631.66	23%

6.2 COMPARISON OF HEAT TRANSFER COEFFICIENT BETWEEN TWO STHXS

This graph shows the variation of ho(heat transfer coffecient) with reynolds number, it increases linearly with reynolds number. It also shows that as the reynods number increses value of oveall heat transfer coffecient also increases.

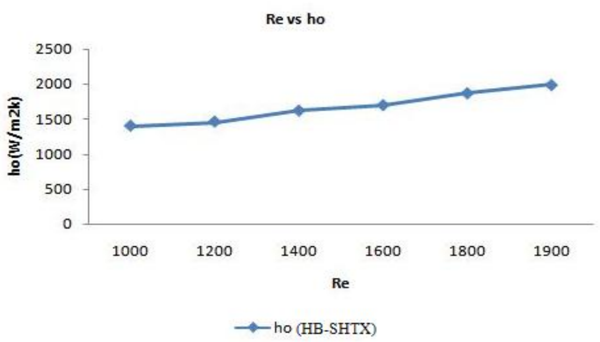

Fig-10: Variation of ho with Reynolds number in HB-SHTX

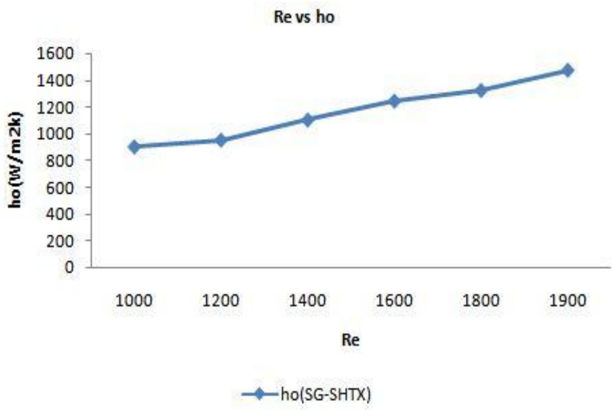

Fig-11: Variation of ho with Reynolds number in SG-SHTX

When values of ho for both shell and tube heat exchanger i.e SG-segmental and HB-baffle are compared it is observed that baffle gives more oveall heat transfer coffecient over segmental baffle and more efficient than segmental baffle.

Table-4: Comparison of heat transfer coefficient

REYNODS NO.	SG-SHTX Ho(w/m2k)	HB-SHTX ho(w/m2k)	IMPROVEMENT
1000	905.61	1442.88	55%
1200	952.79	1463.15	53%
1400	1115.33	1628.05	47%
1600	1242.18	1755.29	37%
1800	1322.57	1866.45	41%
1900	1476.28	1995.09	35%

6.3 Comparison of CFD Generated Results with Experimental Results

The good thing about these outcomes is the consistent contrast from trial results and consistency with the genuine frameworks, i.e. with higher pressure drop, higher heat transfer is accomplished.

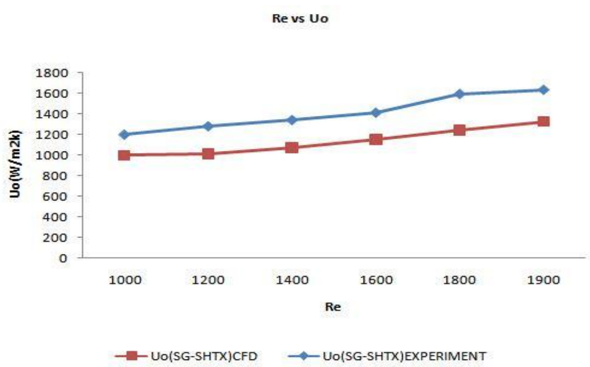

Fig -12: Comparison of Uo with Reynolds number of SG-STHX at tube side velocity is 0.89 m/s

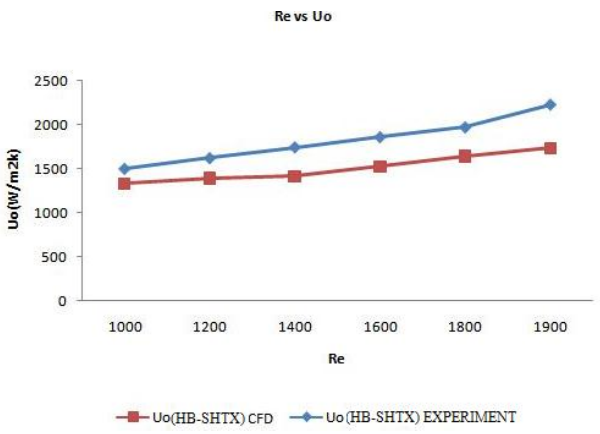

Fig-13: Comparison of Uo with Reynolds number of HB STHXs at tube side velocity is 0.89 m/s

Fig. 12 and Fig. 13 shows the **Uo** overall heat transfer coefficient comparison between two STHXs at tube side velocity is 0.89m/s. Graph is plotted Re (reynolds number) vs overall heat transfer coefficient. From graph we can conclude that overall heat transfer coefficient in HB-STHX is more compare to SG-STHX. It increases up 25-32%.

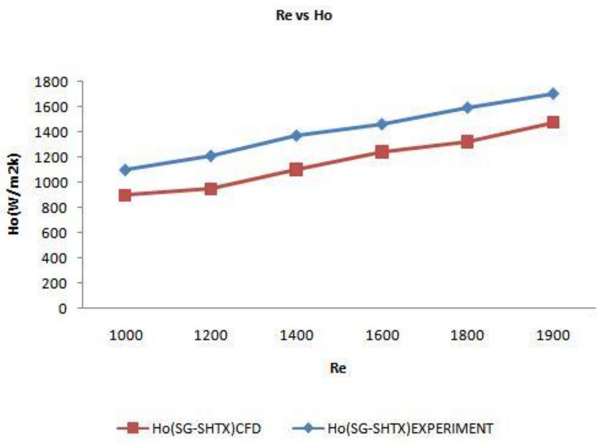

Fig-14: Comparison of ho with Reynolds number of HB-STHXs at tube side velocity is 0.89 m/s

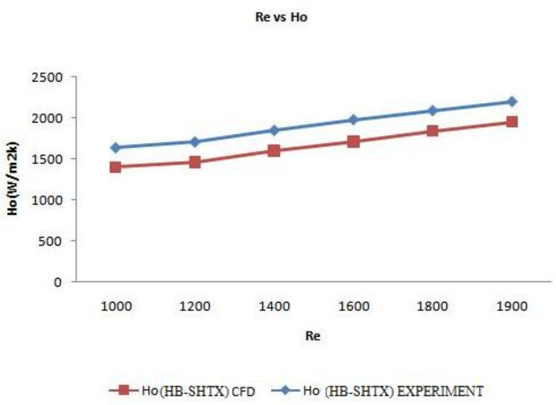

Fig-15: Comparison of ho with Reynolds of SG-STHX at tube side velocity is 0.89 m/s

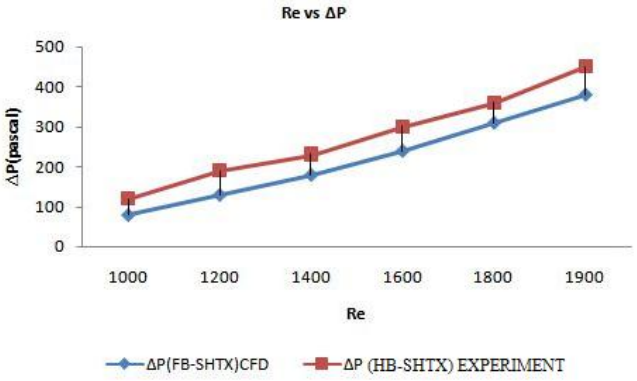

Fig-16: Comparison of Pressure drop with Reynolds number of HB-STHX at tube side velocity is 0.89 m/s

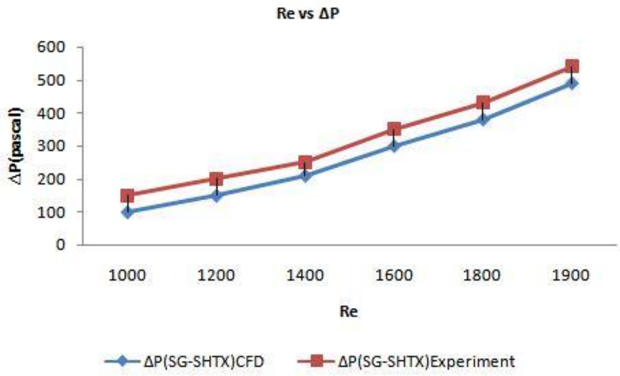

Fig-17: Comparison of Pressure drop with Reynolds number of SG-STHX at tube side velocity is 0.89 m/s

Fig 5.16 and Fig 5.17 shows the **ΔP** (pressure drop) comparison between SG-SHTX and HB-STHX. From fig we can conclude that pressure drop in HB-STHX is less than SG-STHX. It decreases up to 25-30%. Therefore, HB-STHX is more efficient than SG-STHX.

7. CONCLUSIONS

In the present investigation, a CFD model was created for the shell-side stream and heat transfer of shell-and-tube heat exchangers (STHXS), precision is shown by the correlation with test information. The shapes of the speed and temperature fields, together with the distribution of heat transfer coefficient on the shell side, were gotten for the heat exchangers with segmental and baffles.

1) At tube side speed of 0.89 m/s. heat transfer coefficient in HB-STHX increments up to 35-46% than SG-STHX at same Reynolds number.

2) At tube side speed of 0.89 m/s. Pressure drop in HB-STHX is not as much as SG-STHX. Pressure drop reduces up to 20-28%. at on same Reynolds number.

3) Overall heat transfer coefficient in HB-STHX increments up to 25-32% than SG-STHX at same working conditions i.e. same Reynolds number and at tube side speed of 0.89 m/s.

It is observed that with the establishment of helical baffles, the liquid speed greatness and heat transfer coefficient change occasionally in the centre portion of the HB-STHX. With respect to the researched HB-STHX, the heat transfer rate is adequately improved on the shell side. Also, an examination of shapes between HB-STHX and SG-STHX was performed. It is discovered that they have different flow designs, and the HB-STHX has a superior overall thermal hydraulic performance than the SG-STHX.

On comparing CFD generated results with experimental data, it had been found that software results have less magnitude than experimental results and there is constant difference between these two values, which justifies our work. The CFD generated results shows that HB-SHTX have more efficiency than SG-SHTX and experimental results also shows that baffle have more efficiency than segmental baffle.

REFERENCES

[1] Aly, Wael I. A. "Computational Fluid Dynamics and Optimization of Flow and Heat Transfer in Coiled Tube-in-Tube Heat Exchangers under Turbulent Flow Conditions", Journal of Thermal Science and Engineering Applications, 2014. FLUENT. (2015). FLUENT User's Guide, Release 15. ANSYS, Inc. Certified ISO 9001:2008.

[2] Ferng, Y.M.. "Numerically investigated effects of different Dean number and pitch size on flow and heat transfer characteristics in a helically coil-tube heat exchanger", Applied Thermal Engineering, 201-204 J.S. Jayakumar, S.M. Mahajania, J.C. Mandala,P.K. Vijayanb, Rohidas Bhoia Experimental and CFD estimation of heat transfer in helically coiled heat exchangers chemical engineering research and design 8 6 (2008) 221–232.

[3] J.S. Jayakumar, S.M. Mahajania, J.C. Mandala,P.K. Vijayanb, Rohidas Bhoia Experimental and CFD estimation of heat transfer in helically coiled heat exchangers chemical engineering research and design 8 6 (2008) 221–232.

[4] Pawar, S.S., and Vivek K. Sunnapwar. "Experimental studies on heat transfer to Newtonian and non-Newtonian fluids in helical coils with laminar and turbulent flow", Experimental Thermal and Fluid Science, 2013. Rennie, T.J., Raghavan, V. G S, 2006a, Numerical studies of a double-pipe helical heat exchanger, Applied Thermal Engineering, 26, 1266-1273.

[5] Rahul Kharat, Nitin Bhardwaj, R.S. Jha, Development of heat transfer coefficient correlation for concentric helical coil heat exchanger, International Journal of Thermal Sciences 48 (2009) 2300–2308.

[6] Somchai Wongwises, Paisarn Naphon, Heat transfer characteristics and performance of a spirally coiled heat exchanger under sensible cooling conditions, JSME International Journal Series B 48 (4) (2005).

[7] Vimal Kumar, Burhanuddin Faizee, Monisha Mridha, K.D.P. Nigam Numerical studies of a tube-in-tube helically coiled heat exchanger science direct Chemical Engineering and Processing 47 (2008) 2287–2295.

[8] Mukharji R. (1988). Effective design of shell and tube heat exchanger, American Institute of Chemical Engineering, Vol. 3, No. 11, pp. 17200-17204. DOI: 10.15680/IJIRSET.2014.0311016 382.

[9] Serna M., Jimenez A. (2005). A compact formulation of the Bell Delaware method for Heat Exchanger design and optimization, Chemical Engineering Research and Design, Vol. 83, No. A5, pp. 539-550.DOI: 10.1205/cherd.03192.

[10] Lei G.Y., He Y.L., Li R. Gao Y.F. (2008). Effects ofbaffle inclination angle on flow and heat transfer of a heat exchanger with helical baffles, Science Direct-Chemical Engineering and Processing, pp. 1-10. DOI:10.1016/j.ijheat mass transfer.

[11] Lutcha J., Nemcansky J. (1990). Performance improvement of tubular heat exchangers by helicalbaffles, Chemical Engineering Research and Design, Vol. 68, pp. 263-270. DOI: 10.1155/2011/839468.

[12] Kumar P., Kumar V., Nain S. (2014). Experimental study on heat enhancement of helix changer with grooved tubes, IJLTET, Vol. 3, No. 4.

[13] Shinde S., Pancha M.H. (2012). Comparative thermal performance analysis of segmental baffle heat exchanger with continuous helical baffle heat exchanger using kern method, IJERA, Vol. 2, No. 4,pp. 2264-2271.

[14] Andrews Malcolm, Master Bashir (2005), Three Dimensional Modeling of Helix changer heat exchanger using CFD, Heat Transfer engineering, vol.26.no.6. pp.22-31.

[15] Mukherjee.R, (1998), Effective Design of Shell and Tube Heat Exchanger, Chemical Engineering Progress, pp.1-8.