Numerical Simulation and CFD Analysis of Double Tube Heat Exchanger with Different Tube Geometries on Same Cross Section Area

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Abstract— The heat exchanger plays a crucial role in various industries, to decrease the energy consumption rate by increasing heat transfer rate through heat exchanger. In industry, the tube in tube heat exchangers are used as condensers, vaporizers, sub-coolers, heat recovery exchangers, crystallizers etc. Much work has been done on tube with fins, corrugated tube, insertion in tubes baffle arrangement and nano fluid used, but the performance can also be increased by changing the tube geometry, which was designed to increase the performance of the heat exchanger. In this research work, a double tube heat exchanger of circular and elliptical tube is modeled and numerical simulation as well as CFD simulation have been done to enhance the performance of heat exchanger. Analytical result of Circular tube heat Exchanger validate by the CFD results and found that 0.059% variation in temp, which is acceptable. Comparission of CFD simulation done for Double tube heat Exchanger of Circular and Elliptical tube have been done and found that the elliptical tube geometry is better heat transfer than existing circular double tube heat exchanger.

Key words: Copper Tube, Double tube heat Exchanger, Circular Tube, Elliptical Tube, ANSYS Fluent, Heat Exchanger

I. INTRODUCTION

The energy conservation is one of the most vital issues in current century, and it will certainly be one of the most significant challenges in the near future. The advances made in heating or cooling in industrial devices cause energy saving and heat transfer improvement, and increase the operational life of the equipment. Energy savings can be performed by the efficient use of energy. Energy conversion, conservation and recovery are some routes for energy saving.

To above mentioned purpose, various types of heat exchangers are utilized in many industrial areas such as power plants, nuclear reactors, petrochemical industry, refrigeration, air-conditioning, process industry, solar water heater, food engineering, and chemical reactors. Heat Exchanger is a device which is used for effective Transfer of heat energy between two fluids with maximum rate and minimum operating cost.

Tubular heat exchangers is most popular types of heat exchanger used in industries. An heat exchanger, fluids flow inside the tube that is called tabular heat exchanger. It may be classified in following types: Double tube Heat Exchanger, Shell and tube heat exchanger (STHE), Coiled Tube Heat Exchanger. Double-pipe heat changers with U-bend design are known as hairpin heat exchangers.A double-pipe heat exchanger is compact size heat exchanger and it is used because of design is easy to service and requires low inventory of spares because of its standardization. The flow arrangement is pure counter flow. A number of double-pipe heat exchangers can be connected in series or parallel as necessary. The surface area ranges from 300 to 6000 ft^2 (finned tubes). They are suitable for high pressures and temperatures Design pressures and temperatures are similar to shell and tube heat exchangers.

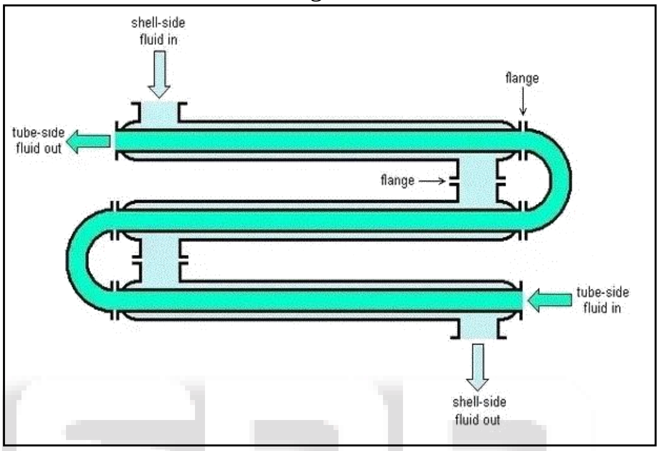

Fig. 1: Double Tube Heat Exchanger

II. LITERATURE REVIEW

Folaranmi Joshua [1] designed a concentric tube heat exchanger for counter flow arrangement to study the process of heat transfer between two fluids by Logarithmic Mean Temperature Difference (LMTD) method. Analytical results compared with experimental and analytical result, then found the heat exchanger was 73.4% efficient and has an overall coefficient of heat transfer of 711W/m^2K and 48^{0}C Log Mean Temperature Difference.

Paisarn Naphon [2] studied of the heat transfer enhancement techniques to improve the performance of heat exchangers. He used the passive technique in which Curved tubes have been used. The study describe on heat transfer and flow characteristics of single-phase and two-phase flow in curved tubes and also describe the use of three main categories of curved tubes; helically coiled tubes, spirally coiled tubes, and other coiled tubes.

Yang Xia [3] experimental studied, the performance of the shell and tube heat exchanger by the enhancement of convection heat transfer by the electro hydrodynamics (EHD) effect. The results show that for work medium of water, the maximal enhancement coefficient θ is 1.224 when the flow rate of 0.1m^3/h at tube-side inlet. The convective heat transfer can be enhanced by applying high electric field.

Cavallini et al. [4] proposed a new method to calculate the condensation heat transfer coefficient of fluid and used the two equations related respectively to ∇T –

independence and to ∇T–dependence. The comparison was conducted on different fluids like HCFCs, HFCs, HCs, CO_2, Ammonia and water. The result obtained by this method compare with Experimental data, which show that average deviation e_R= +2%, Absolute mean deviation e_{AB}= 14% and standard deviation σ_N = 19% for the total no of 5478 data points.

Mr. B. Vijayaragavan [5] used the passive method to increase the heat transfer rate in double tube heat exchanger. In this research work, performance of heat exchanger with dimples of various shapes is used and investigated by CFD as well as experimentally. Result found that the hemispherical dimpled tube with a pitch of 150 mm arrangement is provide most efficient heat transfer. CFD result compared with experimental method and validate with CFD result

R. Hosseini et al. [6] used the experimental setup of shell and tube exchanger for calculating heat transfer coefficient and pressure drop on the shell side of a shell-and-tube heat exchanger by three different types of copper tubes (smooth, corrugated and with micro-fins) and result compared with theoretical data collected and the compared result showed that, i. for Reynolds number below 400 the Performance of heat exchanger for Corrugated and micro-fin tubes showed degraded and micro-finned tubes heat exchanger best performance compared to other in higher Reynolds number.

L. J. Brognaux et al. [7] experimental studied done heat transfer and friction characteristics for single-phase flow in the single-grooved and crossed grooved micro-fin tubes. Main aim of this study was to determine the effect of prandtl number in surface geometry. And result found that, as compare to single-grooved tube, the cross-grooved tube provides higher performance.

Y.S. Chen et. al. [8] experimentally evaluated heat transfer performance in the concentric tube heat exchanger, in which heat exchanger transversely grooved tube Experimental results showed that transversely grooved tube provided significantly enhance the heat transfer performance of molten salt and meanwhile decrease the critical Reynolds numbers of the transition from laminar flow to turbulent flow.

Smith Eiamsaard [9] experimentally investigates of double pipe heat exchanger fitted with regularly spaced twisted tape elements. Twisted tube was inserted in two different case which was (1) full-length typical twisted tape at different twisted ratios (y =6.0 and 8.0), and (2) twisted tape with various free space ratios (S=1.0, 2.0, and 3.0). The result compare with exchanger without twisted tape, the results found that the heat transfer coefficient increased with twist ratio (y). The heat transfer coefficient and friction factor both improve with the increase in the free space ratio (S). Also results from each case were correlated for Nusselt number and friction factor.

Deepali Gaikwad et. al. [10] experimental study of plain tube and plain tube with twisted wire brush inserts in double pipe heat exchanger device. The twisted wire brush inserts are fabricated by winding a 0.2 mm diameter of the copper wires over a 2 mm diameter two twisted iron core-rods. The inner convective heat transfer coefficient, friction factor are determined on the basis of tube geometry and hot air Reynolds number. Convective heat transfer coefficient and other data is calculated for laminar flow under various operating conditions.

C.Y. Zhao [11] studied forced convection heat transfer characteristics in high porosity open-cell metal-foam filled tube heat exchangers. The Brinkman-extended Darcy momentum model and two-equation heat transfer model for porous media was used for the analysis of the heat transfer performance. The study found that the thermal performance of a metal-foam heat exchanger can be superior to that of conventional finned tube heat exchangers.

III. Methodology

The modeling in numerical simulation and CFD simulation of circular tube double tube heat exchanger with is done for the performance analysis of double tube heat exchanger, compare with elliptical tube double tube heat exchanger.

Heat exchanger geometry is built in the ANSYS workbench design module. Geometry is designed for both types of heat exchangers. The diamentions are as follows:

S. No.	Pipe	Circular Tube	Elliptical tube		Length (Thickness 2 mm)
		Diameter	Major Axis	Manor Axis	
1	Inner	25.8 mm	36.48 mm	18.24 mm	1756 mm
2	Outer	50.6 mm	71.48 mm	35.24 mm	1756 mm

Table 1: Geometry of Double Heat Exchanger of Circular and Elliptical Tube [10]

Meshing is done to discretization of the domain into small volumes where the equations are solved by the help of iterative methods and apply the boundary condition the analysis is performed on different flow rate and temp. Variation thus obtained result is compared between both the types of heat exchanger.

S. No.	Particulars	Symbols	Value
1	Hot water inlet temperature, °C	T_{Hi}	87
2	Hot water outlet temperature, °C	T_{Ho}	79
3	Cold water inlet temperature, °C	T_{Ci}	27
4	Thickness of each pipe, mm	t	2
5	Volumetric flow rate hot water, ltr/sec	V_H	0.125,0.1, 0.075, and 0.050
6	Volumetric flow rate cold water, ltr/sec	V_C	0.125, 0.1, 0.075, and 0.050
7	Specific heat of water, J/Kg K	C_{pH}	4.0764E+3
8	Thermal conductivity of Copper W/mk	K_{copper}	387.5

Table 2: Input Parameter

A. Results of Numerical Simulation of Double Tube Heat Exchanger:

Numerical simulation of Double tube head exchanger for calculation of Co-efficient of heat transfer rate, Nusselt Number and to decide the length of tube for Velocity flow rate of 0.1 liter per second in both Fluids.

Flow Rate in hot Fluid = Q_{h1}= 0.0001 m^3/sec
Diameter of inner pipe = d_i = 0.0258 meter
Area of inner pipe = $A_i = (\pi/4)\times D_i^2$
A_i = 0.0005225 m^2

$$Q_h = A_i \times V_h$$

V_h = 0.1913 meter/sec
Mass flow rate = $m_h = \rho_{h1} \times A_i \times V_h$= 0.096 Kg/sec
Diameter of outer pipe = D_o = 0.0506 meter
Area of outer pipe $A_m= (\pi/4)\times(D_o^2-D_{io}^2)$= 0.001312 m^2

$$Q_c = A_O \times V_c$$

V_c= 0.07617 meter/sec
Mass flow rate = $m_c= \rho_c \times A_m \times V_c$= 0.09957Kg/sec

The outlet temperatures of cold water streams (C) is calculated by steady state energy balance equation are following:

$$Q_H = Q_C$$

$$m_H C_{P,H} (T_{Hi}- T_{Ho}) = m_C C_{P,C} (T_{Co}- T_{Ci})$$

$$T_{Co} = 34.78\ ^oC$$

Calculation for heat transfer coefficient of hot water flow in Inner pipe.

Bulk mean temperature of hot water: $T_{b1}= (T_{h\ in}+ T_{ho})/2$

$$T_{b1}=83^0C$$

Linear velocity of hot water: $W_h = (m_h\times 4)/(\rho_h\times\pi\times d_i^2)$
W_h = 0.189 meter/sec
Reynolds number for hot water is calculated by,

$$Re_h = (\rho_h\times W_h \times d_i)/(\mu_{b1})=13870.51$$

Properties		Properties of Hot Water at T_{b1} = 83 *°C* Temp	Properties of Cold Water at T_{b2} = 30.89 *°C*
Density Kg/m^3	P	9.70E+02	9.95E+02
Dynamic Viscosity Kg/ms	μ	3.42E-04	7.84E-04
Kinematic Viscosity m^2/Sec	υ	3.53E-07	7.87E-07
Specific Heat J.Kg/K	C_p	4.20E+03	4.18E+03
Conductivity W/mK K	K	6.69E-01	6.16E-01
Prandtl Number Pr	Pr	2.15E+00	5.31E+00
Thermal Diffusivity m^2/Sec A	A	1.64E-07	1.48E-07
Thermal Expansion Coefficient αV 1/k	α_V	6.64E-04	3.14E-04

Table 3: Thermo physical properties of Hot and Cold water

To calculate the convective heat transfer coefficient flowing fluid this circulates through the pipe $f_h= (0.079/Re_h^{1/4})$ for Re_h varying from 4000 to 10^6

$$Nu_h = 66.64$$

From the value of Nusselt number, we can determine convective heat transfer coefficient from following equation:

$$\alpha= (NuK)/d$$

$$\alpha_h= 1727.12\ W/m^2k$$

Calculation for Cold water (C) flowing in outer tube:
The outlet temperature of Cold water stream (C) flowing in outer tube is calculated by steady state energy balance equation are following:

T_{co}= 30.89 *°C*
Bulk mean temperature of cold Fluid:
$T_{b2}= (T_{C\ in}+ T_{C\ o})/2$
T_{b2}=30.89 *°C* =307.78 *K*
Hydraulic diameter:
$D_{hydroouter} = Dc = (d_o^2– d_{io}^2)/ d_{io}$= 0.0561 *meter*
Linear velocity:
W_c = 0.076 *meter/sec*
Reynolds number:
Rec = 5430.035
Calculations for Convective Heat transfer:
Friction factor:
f_c= 0.00920
Nusselt number:
Nu_c = 39.22
Convective heat transfer coefficient:
α_c= 430.73 W/m^2k
Calculated value of Overall heat transfer coefficients:
Overall heat transfer coefficient based on outside area of central pipe
$1/U = (d_{in}/d_{out}\alpha_c) + d_{in}\ln (d_{out}/d_{in})/ 2k_{copper}+1/\alpha_H$
U_O = 378.39 W/m^2 °C
Calculations for Logarithmic mean temperature difference for Counter Flow:
$\Delta T_{lm\ 1} = \{(T_{Hi} – T_{Co}) – (T_{Ho}– T_{Ci})\}/ [\ln\{(T_{Hi} – T_{Co}) – (T_{Ho}– T_{Ci})\}]$
$\Delta T_{lm\ 1}$ = 52.108 °C
Calculations for Heat transfer rates:
Heat flow rate of hot water through middle pipe:
$Q_H = m_H C_{P,H}(T_{Hi}-T_{Ho})$
Q_H = 3239.00 W
Calculation for Length of double tube heat exchanger
The length of heat exchanger calculated from the heat balance equation, are the following.
$m_H C_{P,H} (T_{Hi}-T_{Ho}) = U_{o1}\times A_{o1}\times \Delta T_{lm}$
$m_H C_{P,H} (T_{Hi}-T_{Ho}) = U_{o1}\times\pi d_{o1} L\times \Delta T_{lm}$
L=1.756 meter

Calculated length of tube 1756 mm for velocity 0.1 ltr/ Sec.

B. Results of Computational Fluid Dynamic Analysis and Discussion:

In this research work, double concentric copper tube heat exchanger is modeled and analyzed. Its heat transfer rate at different flow rates in different tube geometry and compares the result. The Computational fluid dynamics analysis of heat exchanger is done on the Ansys 16 Fulent software. On the basis of model an observation about that effect of flow velocity. In this research work, design and modeled a Double concentric tube heat exchanger with circular and elliptical tube for compact size and maximum heat transfer coefficient and performance. Numerical simulation Results of the heat exchanger with circular tube are found for flow rate 0.10 liter per second. Heat exchanger designed for the dimensions length of 1756 mm and CFD analysis of double tube heat exchanger with circular and elliptical tube at velocity flow rate 0.1, 0.075 and 0.050 ltr/s has done and compare the result.

In this model of heat exchanger, hot and cold water is flowing in inner and outer tube respectively.

The CFD calculation is done on Two Cases:
1) For Same Flow Rate on both Fluid

2) For Different Flow rate on both Fluid
   a) Cold Fluid Flow rate higher
   b) Hot Fluid Flow rate higher

CFD result for above cases are shows in table 4 as well as refer fig. 1-9 which is available in page 6 :

Case	Fluid	Flow Rate		Circular Tube	Elliptical Tube
			Initial	Final	Final
1	Hot (Inner Pipe)	0.1 ltr/s	360 K	352.21K	351.13 K
	Cold (Outer Pipe)		300 K	308.26 K	308.41 K
2	Hot (Inner Pipe)	0.75 ltr/s	360 K	350.86 K	349.06 K
	Cold (Outer Pipe)		300 K	309.42K	310.61 K
3	Hot (Inner Pipe)	0.05 ltr/s	360 K	348.44 K	345.71 K
	Cold (Outer Pipe)		300 K	312.03 K	314.09 K
1	Hot (Inner Pipe)	0.10 ltr/s	360 K	351.66 K	350.82 K
	Cold (Outer Pipe)	0.125 ltr/s	300 K	307.11 K	306.95 K
2	Hot (Inner Pipe)	0.75 ltr/s	360 K	350.52 K	348.69 K
	Cold (Outer Pipe)	0.10 ltr/s	300 K	307.71 K	308.33 K
3	Hot (Inner Pipe)	0.05 ltr/s	360 K	347.95 K	344.86 K
	Cold (Outer Pipe)	0.75 ltr/s	300 K	308.62 K	310.11 K
1	Hot (Inner Pipe)	0.125 ltr/s	360 K	353.59 K	352.77 K
	Cold (Outer Pipe)	0.10 ltr/s	300 K	308.94 K	308.67 K
2	Hot (Inner Pipe)	0.75 ltr/s	360 K	351.48 K	349.95 K
	Cold (Outer Pipe)	0.05 ltr/s	300 K	313.97 K	315.01 K
3	Hot (Inner Pipe)	0.10 ltr/s	360 K	352.78 K	351.66 K
	Cold (Outer Pipe)	0.75 ltr/s	300 K	310.72 K	310.91 K

Table 4: CFD results

IV. Conclusion

In this project work, double tube heat exchanger is modeled and both numerical and computational fluid dynamics analysis is done to enhance of heat transfer rate. The double tube heat exchanger were modeled and analysed to calculate heat transfer rate for various tube geometry at various different flow rate of water in Ansys 16. At 0.10 ltr/s flow rate, length of tube is calculated and found compact size 1756 mm length. For computational fluid dynamics analysis, 1756 mm length of tube was used and analysis was done for all three 0.050, 0.75 and 1.00 ltr/s. Numerical simulation for 0.1 ltr/s flow rate for circular tube DTHE is done. The numerical simulation result is compare with CFD simulation and found that 0.059% variation in temp., which is acceptable. The heat exchanger for circular and elliptical tube were modeled and CFD simulation has been done and result found that maximum heat transfer rate provide at 0.5 ltr/s. The following are the conclusion for this work:

1) Elliptical tube double tube heat Exchanger (ETDTHE) provides the better performance compare to Circular tube Double tube heat Exchanger (CTDTHE).
2) For Same flow rate, low velocity flow rate (0.05 ltr/s) provide the best heat transfer rate compare to CTDTHE.
3) For Different flow rate, low velocity flow rate (0.05 ltr/s) provide the best heat transfer rate compare to CTDTHE.

A. Future Scope:

Present work shows that the heat transfer rate of elliptical tube is better then circular tube heat exchanger. We can be fabricated and experimental investigation can be done on fabricated model and verify the results with CFD simulation results. One more option to go ahead this research work by using different material can be select for the tubes of double tube heat exchanger.

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