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Design and CFD analysis of concentric triple tube heat exchanger with circular fins

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Abstract

The triple tube heat exchanger design increases the heat transfer rate, effectiveness when compare to existing heat exchanger. The triple tube heat exchanger consists of three tubes in various diameters which are arranged in concentric method with circular fins. The circular fins are arranged in circumference of the outer tube with different distance. Mild steel material is used for manufacturing inner tube, outer and middle tubes .The circular fins are made up of mild steel .The hot fluid flows in inner and outer tubes in same direction. The cold fluidflows in middle tube in opposite direction to hot fluid. The flow of hot and cold fluids is maintained as laminar flow. The heat transfer coefficient, effectiveness and heat transfer of the triple pipe heat exchanger is investigated by counter flow method.

Keywords: Triple tube heat exchanger (TTHE), hot water, cold water, CFD simulation.

1. Introduction

A heat exchanger is a piece of equipment built for efficient heat transfer from one medium to another. The media may be separated by a solid wall to prevent mixing or they may be in director contact. They are largely used in refrigeration, air conditioning power plants, chemical plants, petrochemical plants, petroleum refineries, natural gas processing, and sewage treatment. In order to achieve optimum process operations, it is essential to use the right type of process equipment in any given process. Heat exchangers, widely used to transfer energy from one fluid to another, are no exception. In many heat exchangers, the fluids are separated by a heat transfer surface, and ideally they do not mix or leak. Such exchangers are referred to as direct transfer type, or simple re-cuperators, In contrast, exchangers in which there is intermittent heat exchange between the hot and cold fluids-via thermal energy storage and release through the exchanger surface or matrix are referred to as indirect transfer type, or simply regenerators. Examples of heat exchangers are shell and tube exchangers, automobile radiators, condensers, evaporators, air pre heaters, and cooling towers.

Triple concentric pipes heat exchanger consists of three pipes of different diameters and three fluids exchange heats between them. Thus in this case, there are three sections: central, middle and inner pipe. In triple pipe heat exchangers, a thermal fluid is passed through an inner annular space and heat transfer Triple concentric pipes heat exchanger consists of pipes of different diameters and fluids exchange heats between them. In this case, there are three sections: central pipe, inner pipe and outer pipe. In triple pipe heat exchangers, a thermal fluid is passed through an inner annular space and heat transfer Arrangement of fines over out tube of heat exchanger will play an important role. It we guide the flow of air over the outer tube & enhance the heat transfer rate.

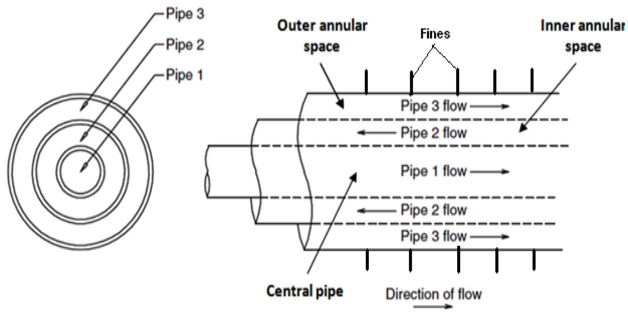


Fig.1: Triple Tube Heat Exchanger flow pattern [2]

1.1 Literature Review

A set of analytical equations for fluid temperatures at any axial location along the heat exchanger for parallel and counter flow configurations and conducted simulation of triple concentric pipe heat exchanger (C.A.Zuritz, et al, 1990).They offered in detail a review on thermal design theory of three fluid heat exchanger, where they have allowed for third fluid temperature to vary according to main thermal communication while neglecting interaction with ambient He used effectiveness- NTU (number of heat transfer units) approach and corresponding rating and sizing problems for the determination of the effectiveness or NTU for a three-fluid heat exchanger. (D.P. Sekulic, et al, 1995).His first part developed a mathematical model, consisting the derivation and possible solutions of the governing equations for both counter-flow and parallel-flow arrangements. The equations derived in this study can be used for both design calculations and performance calculations, besides they can be used for the determination of bulk temperature variation along the exchanger. (Ahmet Unal, et al, 2001). In the second part we conducted several case studies for counter-flow arrangement based on the solution obtained in the first part. It has been demonstrated that demonstrates that: 1) the relative sizes of the tubes (the tube radii) play a very important role on the exchanger performance and/or on the exchanger length. 2) Optimizing triple tube heat exchanger effectiveness provides a considerable amount of increase in the exchanger performance. They derived the effectiveness-NTU relation for triple concentric tube heat exchanger including both counter-flow and parallel flow arrangements. Some representative data are represented in graphical form. This graphs can be used for determining effectiveness of triple concentric pipe heat exchanger by using input parameters i.e. heat capacity ratio and number of transfer units. This developed numerical model for analyzing behavior of triple pipe heat exchanger. Model present was consider realistic situation such as transient effect, heat conduction within the tube wall and insulation, temperature dependent fluid property and the possibility of two phase flow condition so it different from simplified model. The result show the effectiveness of counter flow was 12% more than parallel flow and outlet temperature of hot fluid was 70C lower in counter flow arrangement. (O. García-Valladares, et al, 2004).Analyzed performance of heat exchanger for two flow arrangements, called N–H–C and C–H–N, and for insulated as well as non-insulated conditions of the heat exchanger. The three fluids are consider as hot water, cold water and the normal water. Under N–H–C arrangement, normal water flows in the innermost pipe, hot water flows in the inner annulus. (G.A. Quadir, et al, 2013).

Gap analysis of literature survey

Triple concentric tube heat exchanger consists of three tubes of different diameters connected concentrically. Triple concentric tube heat exchanger performs better than double concentric tube heat exchanger. Most of the previous studies used two fluids for different arrangement. Cold fluids flow from inner tube and outer annulus and hot fluid from inner annulus. Different parameters were found which affect performance of triple concentric tube heat exchanger. The present work involves sizing, testing &CFD analysis of triple concentric tube heat exchanger.

2. Methodology:

The proposed work has main objective is enhancement in performance evolution of TTHE by analytical method, CFD analysis & testing of Heat exchanger.

We will study counter flow TTHE analytic method derived by Ediz Batmaz. This will gives us the idea about heat transfer rate & effectiveness.

A) Overall heat transfer coefficients in a counter-current arrangement.

B) Axial temperature distribution of fluids in the counter-current arrangement.

We will use basic procedure for calculating overall heat transfer coefficients and length of triple concentric pipes heat exchanger. Length of triple pipe heat exchanger is computed for a required temperature drop of hot water with available dimensions of three pipes by LMTD method. LMTD method can be used to solve the sizing problem with the following steps:

A) Calculate unknown outlet temperatures of cold water streams C1 and C2 from energy balance equation.

B) Determine convective heat transfer coefficients for inner pipe, intermediate pipe and outer pipe from the physical properties of fluid.

C) Calculate two overall heat transfer coefficients, one based on outside area of inner tube and other based on inside area of intermediate tube.

D) Calculate logarithmic mean temperature differences from inlet and outlet temperatures of three fluids.

E) Calculate length of heat exchanger by using equation.

We will conduct CFD analysis for two different cases Case 1- process fluid at 40°C and Case 2-process fluid at 50. For both case cooling fluid temperature will be 27°C we will study below parameters from CFD

A) Pressure drop across Heat Exchanger

B) Velocity contours and velocity vector to analyze flow profile.

C) Temperature contour to study thermal variation across heat exchanger

D) Outlet temperature of both process fluid and cooling water.

We will conduct test on TTHE to measure flowing parameters two different cases Case 1- process fluid at 40and Case 2-process fluid at 50for both case cooling fluid temperature will be 27.

E) Temperature drop in heat exchanger.

3. Numerical analysis

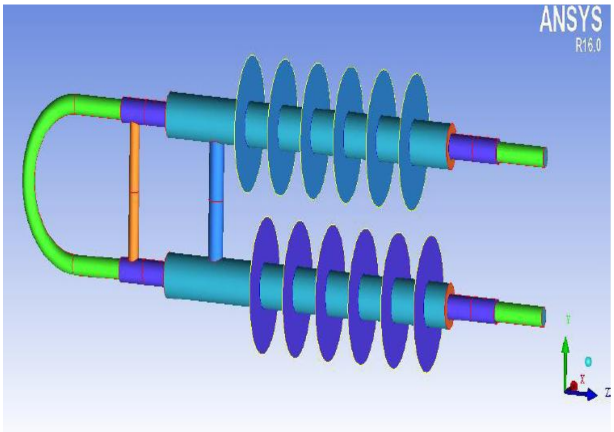


Fig.2: ISO View

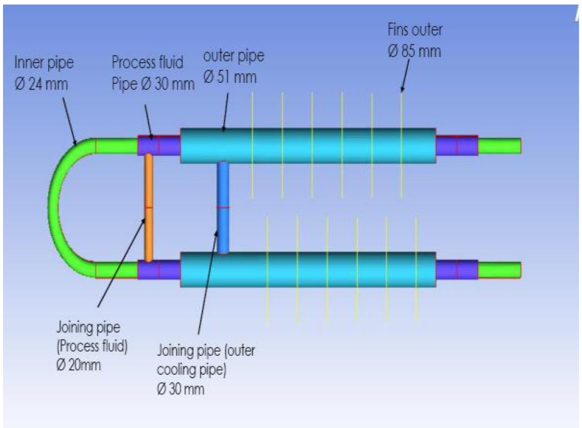


Fig.3: Dimension Details

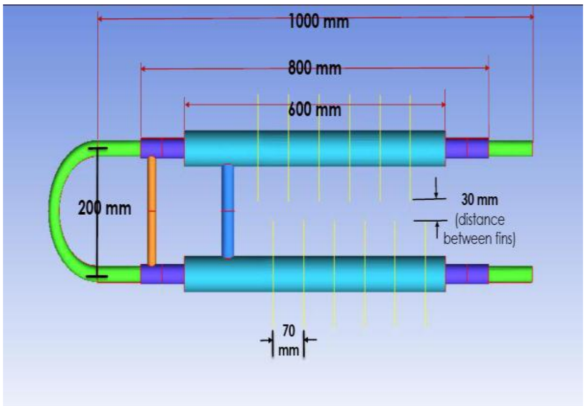


Fig.4: Dimension Details

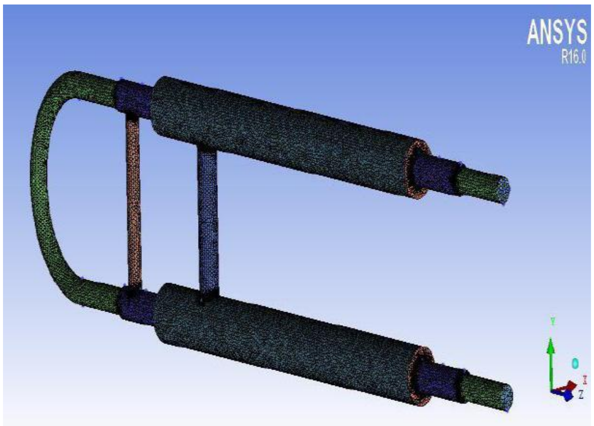
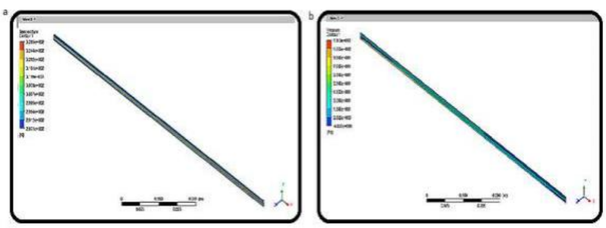


Fig.5: Meshing (Unstructured)



Counter of a) Temperature distribution b) Pressure distribution

4. Sample calculation:

Length of triple concentric pipe heat exchanger:

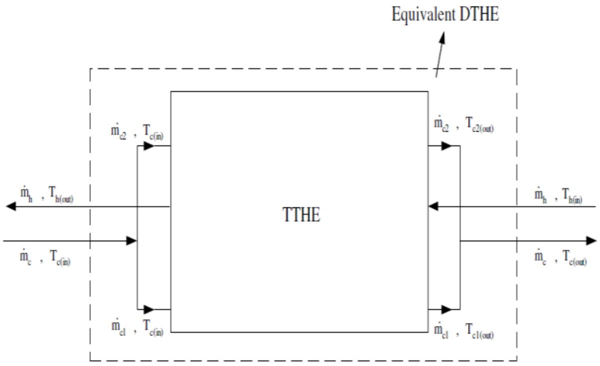
The heat exchanger length can be calculated from the heat balance equation, which is given below:

$$mH \times CpH \times (THi-THe) = U01\ A01\ \Delta T\ lm1 + Ui2\ Ai2\ \Delta T\ lm2$$

$$mH \times CpH \times (THi-THe) = U01\ \pi\ d01\ L\ \Delta T\ lm1 + Ui2\ \pi\ d02\ L\ \Delta T\ lm2$$

For a given diameters d01=0.024 and di2=0.030 heat exchanger length L calculated by heat balance equation is **LTTHE 2.25m.**

Equivalent double pipe heat exchanger:



Logarithmic mean area of Double pipe heat exchanger is equal to sum of the two logarithmic mean area of triple pipe heat exchanger.

$$Alm1 = \pi \times \frac{dout1 - din1}{\ln (dout1/ din1)} \times L = 0.04475\ m^2$$

$$Alm2 = \pi \times \frac{dout2 - din2}{\ln (dout2/ din2)} \times L = 0.09309\ m^2$$

$$Alm = Alm1 + Alm2 = 0.13784\ m^2$$

Mass flow rate of cold water in equivalent double pipe heat exchanger is equal to sum of mass flow rates of two cold water streams C1 and C2

$$mc = mc1 + mc2 = 0.06048\ kg/s$$

For the same temperature drop of hot water (10°C), the outlet temperature of cold water is obtained by the energy balance equation,

Tce=31 °C

And the logarithmic mean temperature difference is:

$$\Delta T\ lm = \frac{(THi - Tce) - (THe - Tci)}{\ln (THi - Tce\ /\ THe - Tci)} = 18\ °C$$

$$Q = mH \times CpH \times (THi-THe) = 1380\ W$$

To calculate overall heat transfer coefficient in equivalent double pipe heat exchanger, we use equation

$$U = \frac{Q}{Alm\ \ \Delta Tlm} = 556.81\ W/m^2K$$

The U value calculated for this equivalent DPHE combines the effect of the overall heat transfer coefficients U01 and Ui2 . Thus, we refer to this value as the effective overall heat transfer coefficient (Ue). We can then use this value to compare a TPHE to a DPHE and make the choice of one over the other, depending on the process parameters.

Length of double pipe heat exchanger is given simply as, Alm= π x din x LDTHE
Where,
din = inside diameter of inner pipe
LDTHE = length of double pipe heat exchanger
LDTHE = 5.13 m

Efficiency of fin on tube heat exchanger:
Transverse fins are used in our heat exchangers
Assumptions:
i) Insulated tip- As tip area is negligible as compared to the total fin area.
ii) Finite heat dissipation from the tip.
iii) Fin of infinite length -As no heat dissipation from its tip

$\eta_{fIn} = \tanh(mL) / mL$ Where,
$m = (hC/KA)^{(1/2)}$
h= film heat transfer coefficient from the fin surface
C= circumference of the fin [m]
K= thermal conductivity of fin material (Kcal /hr m $^\circ$C)
A= cross-sectional area of fin (m^2)

From the above equation, it can be seen that the fin efficiency is a function of mL, and as the value of mL increases, the fin efficiency decreases. A reasonable value of fin efficiency will be around 50 to 75% for which mL should have a value between 1 and 2. If the fin height L should be sufficient (of the order of 5 to 8 cm), then it can be seen that the value of h should be around 10 to 20 which can be given by air in natural convection. Forced convection will be much higher than 20. Thus, the given set-up is used for heat transfer to air in natural convection region.

5. Experimental set up

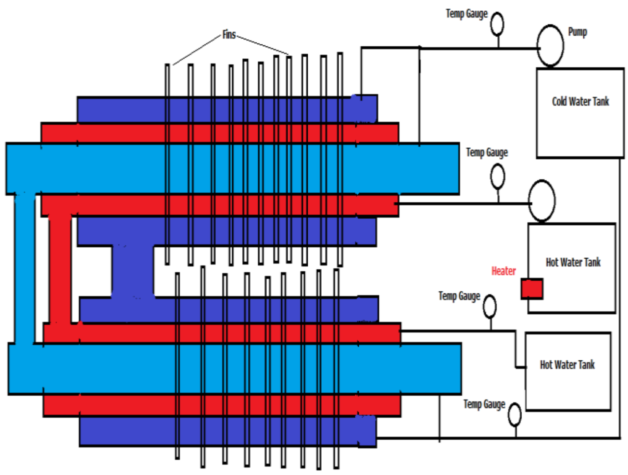
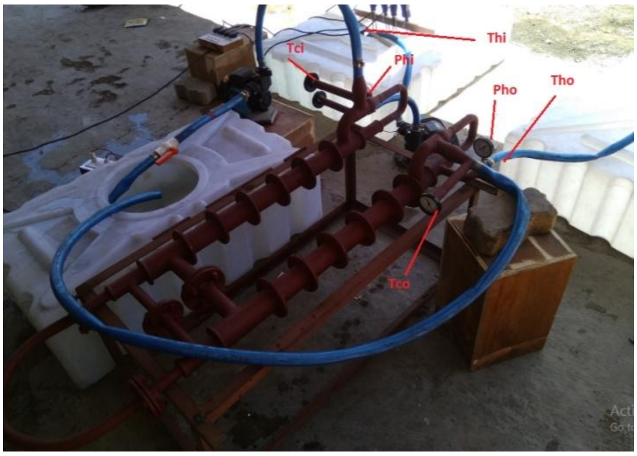


Fig.6: Block diagram of experimental set up

Triple concentric pipes heat exchanger it consists of three different diameters of the pipes and three fluids used in exchange heats between them. Thus in this case, there are three sections: central pipe, inner annular space and outer annular space. In triple pipe heat exchangers, a thermal fluid is passed through an inner annular space and heat transfer Triple concentric pipes heat exchanger consists of three pipes of different diameters and three fluids exchange heats between them. Thus in this case, there are three sections: central pipe, inner annular space and outer annular space. In triple pipe heat exchangers, a thermal fluid is passed through an inner annular pipe and heat transfer. Arrangement of fines over out tube of heat exchanger will play an important role. It we guide the flow of air over the outer tube & enhance the heat transfer rate.

Parts will be used for this set up:
1) Hot Water Pump
2) Cold Water Pump
3) Hot Water Inlet Tank
4) Cold Water Inlet/Outlet tank
5) Hot Water outlet Tank
6) Cold water inlet temperature gauge
7) Cold water outlet temperature gauge
8) Hot water inlet temperature gauge
9) Hot water outlet temperature gauge
10) Triple Tube Heat Exchanger with fines

6. Result and Discussion:
Test Setup:



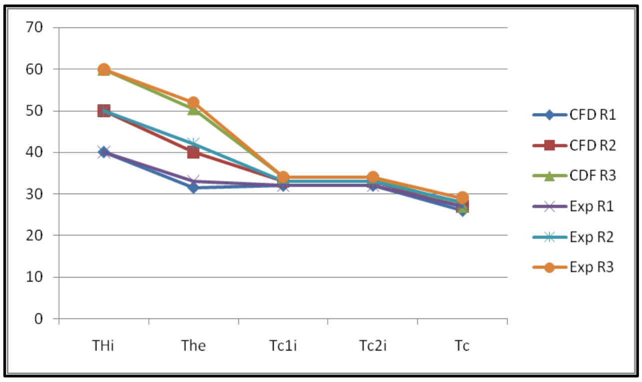
Reading & observations:

Parameters Temperature °C	Nom	Reading 1	Reading 2	Reading 3
Hot water inlet	Thi	40	50	60
Hot water outlet	The	33	42	52
Cold water (C_1) inlet	Tc_1i	32	33	34
Cold water (C_2) inlet	Tc_2i	32	33	34
Cold water (C) Outlet	Tc	27	28	29

Validation:

Three different reading is taken in CFD for comparison with actual experimental results. By putting these values under graph we can able to validate the results.

The CFD shows satisfactory results with comparison with experimental results. Slight variations in reading can be due to tolerance made at the time of experiments.



Conclusions

1. Most of the previous studies used two fluids for different arrangement. Cold fluids flow from inner tube and outer annulus and hot fluid from inner annulus.
2. The Triple tube heat exchanger achieves the maximum heat transfer rate compare the conventional double tube model.
3. Main advantage for reduce compact size and high heat transfer rate. Recommend for the very useful one of the thermal field within minimum size.
4. The present work involves sizing, testing &CFD analysis of triple concentric tube heat exchanger by using previous researches mathematical model, experimental model and correlation.
5. The comparison is carried out between CFD result and literature result. Effectiveness of heat exchanger increases with increased inner tube diameter, using counter flow.

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