# Computational Fluid Dynamics & Numerical Simulation of Compact Size Triple Steel Concentric Tube Heat Exchanger

**Mohan Singh Mandloi[1] Devendra S. Sikarwar[2] Gajendra Das Kori[3]**
[1]PG Scholar [2,3]Assistant Professor
[1,2,3]Depatment of Mechanical Engineering
[1,2,3]Patel College of Engineering, Indore

*Abstract*— The heat exchanger plays a crucial role in various industries, to decrease the energy consumption rate by increased heat transfer rate through heat exchanger. Heat exchanger increases the efficiency and performance of system. In industry, the tube in tube heat exchangers are used as condensers, vaporizers, sub-coolers, heat recovery exchangers, crystallizers etc. In this research work, to enhance the efficiency and performance of heat exchanger, a triple tube heat exchanger was modeled and numerical simulation has been done for the analysis of performance and efficiency. This triple tube heat exchanger is an updated and modified variant of conventional modified double tube heat exchanger. The triple tube heat exchanger is made up of three different diameters of tubes and all three tubes are arranged in concentric way. In this, cold or normal water flows in most outer and inner tube while hot water is flowing through a middle pipe. The triple tube heat exchanger was analyzed at various different mass flow rate and temperature of hot water. The model of triple tube heat exchanger was prepared and analyzed in Ansys Fluent and numerical simulation was also done and verified the results. In this type of heat exchanger maximum area of middle hot water flowing pipe is in contact with both inner and outer normal water flowing pipe, it provides maximum area for transfer of heat and gives maximum heat transfer rate and performance instead of double pipe heat exchanger. The results of both numerical and software simulation of triple tube heat exchanger shows the increased rate of heat transfer coefficient in compact size of heat exchanger. The triple tube heat exchanger gives better performance as compare to convention double tube heat exchanger.

***Key words:*** Steel Tube, Concentric Tubes, C-H-N arrangement, Compact Size, Heat Transfer Rate Heat Exchanger

## I. Introduction

The heat exchanger is an apparatus which transfers the energy in the form of heat of a hot liquid to the cold or normal temperature liquid. [1]In heat exchanger transfer of thermal energy of hot liquid to the cold liquid and both liquids are separated by a solid body. The mostly widely used heat exchanger is double tube heat exchanger. [2] In double tube heat exchanger one tube is placed inside the another tube and either hot water flows inner and normal water flows outer tube or hot water flows outer and normal water inner.[3]

In this project work, a triple concentric tube heat exchanger was modeled in reference of double concentric tube heat exchanger. The triple concentric tube heat exchanger is the modified and updated form of double pipe heat exchanger. The three tubes of different diameters are concentrically arranged and hot and normal water exchanges heat energy between them. This heat exchanger gives greater heat transfer rate in comparison of double concentric heat exchanger. In this hot water flows inside the middle tube and normal or cold water flows inside the both inner and outer tubes. Hot water flows between both sides of normal or cold water. The three main part of the heat exchanger inner, middle and outer tube, they plays very important role to enhance heat transfer rate and performance of heat exchanger.

## II. Literature

The heat exchanger design is evaluating (rating) and estimating (sizing) are the most important problem.[4] The rating issue is worried with the determination of the heat exchange rate and the liquid outlet temperatures for recommended liquid flow rates, inlet temperature, and admissible pressure drop of a current heat exchanger[5]. Then again, the issue of the size of boiler is regarding the determination of measurement of heat exchanger, for selecting a suitable size of heat exchanger and deciding the size to meet the predetermined hot and cool liquid inlet and outlet temperatures and flow rates. [6] The triple concentric tube heat exchangers are used for refrigeration, cooling, energy transformation, purification of thick nourishment items (milk, cream, apple crush), sanitization, etc.[7]

Numerical Simulation of Triple Concentric Tube Heat Exchanger: Numerical simulation of triple concentric tube head exchanger for calculation of Co-efficient of heat transfer rate, Nusselt Number, friction factor and to decide the length of tube for velocity of 0.75 liter per second.

- Flow Rate = $Q_{C1}$= 0.00075 $m^3$/sec
- Diameter of inner pipe = $D_i$ = 0.060 meter
- Area of inner pipe = $A_i = (\pi/4)\times D_i^2$
- $A_i = (\pi/4) \times (0.060)^2$
- $A_i = 0.002826\ m^2$
- $Q_C = A_i \times V_C$
- $V_C$ = 0.26539 meter/sec
- Mass flow rate = $m_{C1} = \rho_{C1} \times A_i \times V_{C1}$
- $m_C$ = 0.758 Kg/sec
- Mass flow rate of cold water in inner tube $m_C$ = 0.758 kg/sec
- Mass flow rate of hot water in middle tube $m_H$ = 0.743 kg/sec
- Mass flow rate of normal water in outer tube $m_N$ = 0.727 kg/sec

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

$$Q_H = Q_C + Q_N$$

$$m_H C_{P,H} (T_{Hi} - T_{Ho}) = m_C C_{P,C} (T_{Co} - T_{Ci}) + m_N C_{P,N} (T_{No} - T_{Ni})$$

$$T_{Co} = 24.68\ ^oC;\ T_{No} = 49.37\ ^oC$$

 

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

Bulk mean temperature of cold water: $T_{b1} = (T_{C\,in} + T_{C\,o})/2$

Linear velocity of cold water: $W_C = (m_C \times 4)/(\rho_C \times \pi \times d^2_{in1})$

$W_C = 0.2683$ meter/sec

Calculation for Reynolds number: $Re_C = (\rho_C \times W_C \times d_{in})/(\mu_{b1})$

$Re_C = 157953.98$

| Properties | | $T_{b1} = 18.34^oC$ | $T_{b2} = 36.37^oC$ | $T_{b2} = 80^oC$ |
|---|---|---|---|---|
| Density, Kg/m$^3$ | P | 9.9814E+2 | 9.9307+2 | 9.7121E+2 |
| Dynamic Viscosity, Kg/ms | μ | 1.0179E-3 | 6.7992E-4 | 3.4599E-4 |
| Kinematic Viscosity, m$^2$/Sec | υ | 1.0198E-6 | 6.8466E-7 | 3.5625E-7 |
| Specific Heat, J.Kg/K | C | 4.0780E+3 | 4.0681E+3 | 4.0696E+3 |
| Conductivity, W/mK | K | 0.60215 | 0.62808 | 0.67002 |
| Prandtl Number, | Pr | 6.8940 | 4.4039 | 4.0864 |
| Thermal Diffusivity, m$^2$/Sec | A | 1.4896E-7 | 1.5360E-7 | 1.6952E-7 |
| Thermal Expansion Coefficient,1/k | αv | 3.4306E-3 | 3.2804E-31 | 2.8317E-3 |

Table 6.1: Thermo physical properties water at various temperatures

1) *Calculations for Convective Heat transfer:*

To calculate the convective heat transfer coefficient flowing fluid this circulates through the pipe $f_C = 0.016$

$Nu_C = 1684.73$

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

$\alpha = (Nu\,K)/d_{in}$

$\alpha_C = 16907.67$

2) *Calculation for Normal water (N) flowing in outer tube:*

The outlet temperature of Normal water stream (N) flowing in outer tube is calculated by steady state energy balance equation are following:

$T_{No}=49.37\,^oC$; $T_{Ni}=24\,^oC$

3) *Bulk mean temperature:*

$T_{b2}=36.37^oC = 309.52$ K

4) *Hydraulic diameter:*

$D_{hydro\ outer} = D_N = d_{outer} - d_{middle} = (0.084-0.074) = 0.010$ *meter*

5) *Linear velocity: $W_N = 0.092$ meter/sec*
6) *Reynolds number: $Re_N = 13610.19$*
7) *Calculations for Convective Heat transfer:*
8) *Friction factor: $f_N = 0.0284$*
9) *Nusselt number: $Nu_N = 330.464$*
10) *Convective heat transfer coefficient: $\alpha_N = 2077.69$ W/m$^2$k*
11) *Calculation for Hot water H flowing in middle tube:*

The inlet and outlet temperature of hot water stream (H) is following:

$T_{Hi} = 100\,^oC$ and $T_{Ho} = 60\,^oC$

12) *Hydraulic diameter:*

$D_{hydro\ middle} = D_{Hot\ water} = d_{middle} - d_{inner} = (0.072 - 0.062) = 0.010$ *meter*

13) *Linear velocity: $W_H = 0.954$ meter/sec*
14) *Reynolds number: $Re_H = 274800.3121$*
15) *Calculations for Convective Heat transfer:*
16) *Friction factor: $f_H = 0.0006$*
17) *Nusselt number: $Nu_H = 72.09$*
18) *Convective heat transfer coefficient: $\alpha_H = 4830$ W/m$^2$k*
19) *Calculated value of Overall heat transfer coefficients:*

Overall heat transfer coefficient based on outside area of central pipe

$1/U_{O1} = (d_{out}/d_{in}\ \alpha_c) + d_{out} \ln (d_{out}/d_{in})/\ 2k_{steel} + 1/\alpha_H$

$U_{O1} = 2816.28$

Overall heat transfer coefficient based on inside area of intermediate pipe

$1/U_{i2} = (d_{in}/d_{out}\ \alpha_c) + d_{in} \ln (d_{out}/d_{in})/\ 2k_{steel} + 1/\alpha_H$

$U_{i2} = 2100.24\ ^oC$

20) *Calculations for Logarithmic mean temperature difference:*

$\Delta T_{lm\,1} = \{(T_{Hi} - T_{C1o}) - (T_{Ho} - T_{Ci})\}/\ [\ln\{(T_{Hi} - T_{Co}) - (T_{Ho} - T_{Ci})\}]$

$\Delta T_{lm\,1} = 8.2597$

$\Delta T_{lm\,2} = \{(T_{Hi} - T_{No}) - (T_{Ho} - T_{Ni})\}/\ [\ln\{(T_{Hi} - T_{No}) - (T_{Ho} - T_{Ni})\}]$

$\Delta T_{lm\,2} = 5.539^oC$

21) *Calculations for Heat transfer rates:*

Heat flow rate of hot water through middle pipe:

$Q_H = m_H C_{P,H} (T_{Hi} - T_{Ho})$

$Q_H = 181.39$

22) *Calculation for Length of triple concentric pipe heat exchanger*

The length of heat exchanger calculated from the heat balance equation, are the following.

$m_H C_{P,H} (T_{Hi} - T_{Ho}) = U_{o1} \times A_{o1} \times \Delta T_{lm\,1} + U_{i2} \times A_{i2} \times \Delta T_{lm\,2}$

$m_H C_{P,H} (T_{Hi} - T_{Ho}) = U_{o1} \times \pi d_{o1} L \times \Delta T_{lm\,1} + U_{i2} \times \pi d_{i2} L \times \Delta T_{lm\,2}$

23) *L=1.084 meter*

Calculated length of tube 1084 mm for velocity 0.75 liter/Sec.

## III. RESULTS OF COMPUTATIONAL FLUID DYNAMIC ANALYSIS

In this research work, triple concentric steel tube heat exchanger is modeled and analyzed its heat transfer rate at different velocities. The numerical and Computational fluid dynamics analysis of heat exchanger is done on the Ansys 16.2 Fulent software. Numerical simulation for velocity of flow 0.50, 0.75 and 1.00 liter/second is done. The calculation gives an observation about that effect of flow velocity and length of tubes. In this research work, design and modeled a triple concentric tube heat exchanger for compact size and maximum heat transfer coefficient and performance. Results of the compact size of heat exchanger are found minimum for velocity flow rate 0.50 liter per second. Heat exchanger designed for the dimensions length of 1000 mm and analysis of heat exchanger at velocity of flow 0.75 liter/second has done.

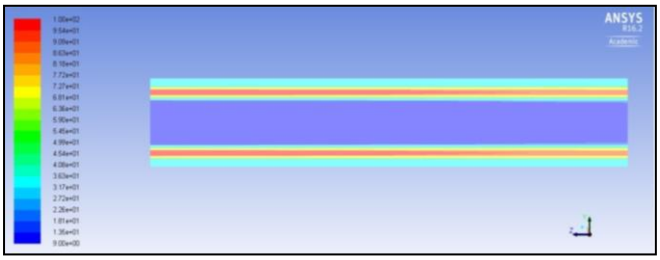


Fig. 1: Heat transfer (Counter Flow)

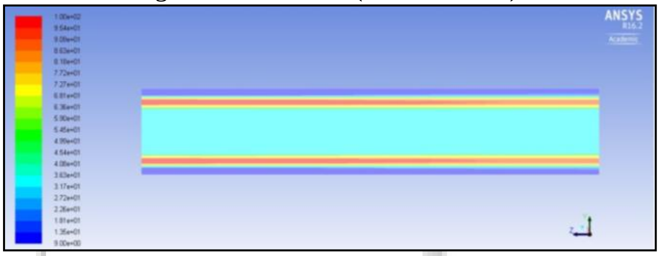


Fig. 2: Heat transfer (Co-Counter Flow)

The results for counter flow of computational fluid dynamics analysis of coefficient of heat transfer of velocity 0.75 liter/Sec flow of hot and normal water. In this analysis boundary condition was consider that hot water flow in middle tube and in this normal water is flowing outer and inner tube of heat exchanger.

| S. No. | Fluid | Temperature | | | |
|---|---|---|---|---|---|
| | | Counter Flow | | Co-counter Flow | |
| | | Initial | Final | Initial | Final |
| 1 | Cold | 12 ºC | 32.28 ºC | 12 ºC | 35.35 |
| 2 | Hot | 100 ºC | 63.96 ºC | 100 ºC | 61.31ºC |
| 3 | Normal | 12 ºC | 45.29 ºC | 12 ºC | 47.63ºC |

Table 2: Result of Heat transfer at 0.75 liter/second

The results for Co- counter flow of heat transfer coefficient for TTHE at 0.75 liter/Second velocity of flow of cold, hot and normal water. In this analysis, boundary conditions were selected for co-counter flow of fluid through the tubes. In this both the inner and outer tube water is flowing in opposite direction as the direction of flow of water in middle tube.

## IV. CONCLUSION

In this project work, triple steel concentric tube heat exchanger is modeled and both numerical and computational fluid dynamics analysis of heat exchanger. The triple concentric steel tube heat exchanger were modeled and analysed for coefficient of heat transfer rate and friction factor at various different flow rate of water in Ansys 16.2. At the velocity of flow 0.75 liter/second, length of tube was 1023 mm calculated. For computational fluid dynamics analysis, 1084 mm length of tube was decided and analysis was done for all three 0.50, 0.75 and 1.00 liter/second. The heat exchanger was modeled and analysed for size of 1000 mm length of all three tubes.

The numerical and computational fluid dynamics simulation result were showed maximum heat transfer rate at 0.75 liter/second for both boundary condition when normal water flows inner & outer tube respectively and normal water flows outer and inner tube and Heated hot water was middle tube. Hot water is cooled at 61.31 ºC in heat exchanger at velocity 0.75 liter/ sec and friction factor of inner tube 0.016, middle tube 0.006 and outer tube 0.0284.

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