# Design and Numerical Simulation of Heat Transfer Rate of Triple Concentric Copper Tube Heat Exchanger

**Gautam Yadav[1], Ravi Jatola[2], M. L. Jain[3], B. More[4]**

[1,2,3,4]*Department of Mechanical Engineering, S.G.S.I.T.S. Indore, M.P., India*

---***---

**Abstract -** *Enhancement of heat transfer rate leads to lower energy consumption rate which results improved efficiency and performance of heat exchanger and produces lower adverse effects effect on environment. Triple concentric pipe heat exchanger was modeled and analyzed its heat transfer rate, efficiency and performance as instead of conventional heat exchanger. The triple pipe heat exchanger is the improved and modified version of the conventional double pipe heat exchanger. The analytical analysis of the triple concentric tube heat exchanger for compact size of heat exchanger is compared to double pipe heat exchanger. In this research work, design of compact size length of triple concentric heat exchanger is calculated through the overall heat transfer coefficient and log mean temperature differences. The 1.2 meter length of heat exchanger was calculated through analytical analysis. This triple concentric tube heat exchanger theoretical analysis results show that better performance and increased heat transfer coefficient rate in compact size heat exchanger.*

***Key Words***: Triple concentric tube heat exchanger, Compact size, Overall heat transfer coefficient, Surface Roughness and LMTD.

## 1. INTRODUCTION

The heat exchanger is a device which transfers the heat energy of a hot fluid to the cold fluid. In heat exchanger transfer of thermal or heat energy between two or more fluids and fluids separated by solid surfaces at different temperature. The mostly used heat exchanger is double pipe heat exchanger. In this type of heat exchanger one pipe is placed concentrically inside a large diameter pipe with proper fitting and flow arrangements. [1,2]

In this research work triple pipe heat exchanger designed on the basis of double concentric pipe heat exchanger. A pipe is inserted at the mid of the double pipe heat exchanger and double pipe heat exchanger modified as the triple pipe heat exchanger. [3] Three pipes of different diameters were arranged concentrically and three fluids exchange heats between them, it was given better heat transfer rate as compare to double pipe heat exchanger. [4] Triple concentric pipe heat exchanger comprises of three pipes of various widths and three liquids trade warms between them. Subsequently for this situation, there are three segments: middle pipe, inward pipe and external pipe. In triple pipe heat exchangers, a heated liquid is gone through an middle pipe and cold liquid gone through the inner pipe and normal liquid flows through the external pipe. Triple concentric-pipe heat exchangers are utilized for sustenance preparing, purification of thick nourishment items (milk, cream, thick squeezed orange, apple crush), sanitization, refrigeration, cooling, energy transformation.[5]

The most well-known issues in heat exchanger design are evaluating (rating) and estimating (sizing).[6] The rating issue is worried with the determination of the heat exchange rate and the liquid outlet temperatures for recommended liquid stream rates, inlet temperature, and admissible pressure drop of a current heat exchanger. 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 & outlet temperatures and flow rates.[7]

The present research work is based on the enhanced heat transfer rate with compact size of the heat exchanger. In this, triple concentric pipe heat exchanger was designed and performance of heat exchanger were analyzed at various different temperature and mass flow rate of all three fluids to approach the maximum temperature drop of hot fluid as compare to double pipe heat exchanger.

### 1.1 Design and Theoretical Analysis of Heat Exchanger

Before you Considerations and assumptions made for sizing of triple concentric tube heat exchanger.

1. Two cold water streams enter the heat exchanger at same mass flow rates and same inlet temperatures. Heat transfer from hot water to cold water streams are assumed symmetrical.
2. Heat exchanger is made of three copper pipes of different diameters and has no deposit of dirt on the pipe because pipes are thin. Hot water temperature drop is considered as 40°C.
3. Calculate unknown outlet temperatures of cold water streams C1 and C2 from energy balance equation. ($Q_H=Q_{C1}+Q_{C2}$).
4. Determine the convective heat transfer coefficients for inner pipe, intermediate pipe and outer pipe from the physical properties of fluid.
5. Calculate two overall heat transfer coefficients, one based on outside area of inner tube and other based on inside area of intermediate tube & logarithmic

mean temperature differences from inlet and outlet temperatures of three fluids.

6. The diameters of three pipes are prescribed and determine the length of heat exchanger.

Table-1: Heat exchanger input parameter for calculation of length of heat exchanger

| Particular | Notations | Value |
|---|---|---|
| Diameter of Inner Pipe | $D_1$ | 62 mm |
| Diameter of Middle Pipe | $D_2$ | 84mm |
| Diameter of Outer Pipe | $D_3$ | 106 mm |
| Thickness of Pipe | t | 1.5 mm |
| Inlet Temp of Cold Water in Inner Pipe $T_{C1}$ | $T_{C1i}$ | 09 °C |
| Inlet Temp of Hot Water in Middle Pipe $T_{H2}$ | $T_{H2i}$ | 100 °C |
| Inlet Temp of Cold Water in Outer Pipe | $T_{C3i}$ | 25 °C |
| Outlet Temp of Hot Water in Middle Pipe $T_{H2O}$ | $T_{H2O}$ | 60 °C |
| Specific Heat of Water | $C_p$ | 4182 J/Kg K |
| Thermal Conductivity of Copper | $K_C$ | 401 W/mK |
| Thermal Conductivity of Water | $K_W$ | 0.618W/mK |
| Dynamic Viscosity of Water | μ | 0.0008kg/ms |

Table 2: Properties of flowing water at different temperatures

| Properties | Temperature | | | |
|---|---|---|---|---|
| | 25°C | 100 °C | 60 °C | 9 °C |
| Density (Kg/m³) | 9.9658E+2 | 9.5709E+2 | 9.5709E+2 | 9.9970E+2 |
| Dynamic Viscosity (Kg/ms) | 8.6840E-4 | 2.7475E-4 | 2.7475E-4 | 1.3020E-3 |
| Kinematic Viscosity (m²/Sec) | 8.7137E-7 | 2.8706E-7 | 2.8706E-7 | 1.3024E-6 |
| Specific Heat (J.Kg/K) | 4.0727E+3 | 4.0822E+3 | 4.0822E+3 | 4.0917E+3 |
| Conductivity (W/mK) | 0.61229 | 0.68087 | 0.68087 | 0.58665 |
| Prandtl Number | 5.7763 | 1.6473 | 1.6473 | 9.0809 |

Calculation for mass flow rate of Inner, Middle and Outer tube

$Q_H = Q_{C1} + Q_{C2}$

Sample Calculation for mass flow rate of cold water at 9°C in Inner Tube

Flow Rate = $Q_{C1}$ = 0.00025 m³/sec

Diameter of inner pipe = $D_1 = D_i$ = 0.062 meter

Area of inner pipe= $A_1 = A_i = (\pi/4)\times D_i^2$

$A_i = (\pi/4) \times (0.062)^2$

$A_i = 3.01 \times 10^{-3}$ m²

$Q_{C1} = A_i \times V_{C1}$

$V_{C1}$ = 0.083 meter/sec

Mass flow rate = $m_{C1} = \rho_{C1} \times A_i \times V_{C1}$

$m_{C1}$ = 0.249 Kg/sec

Calculation for Mass flow rate of Hot water in middle tube and Cold water in outer tube were has been done by above sample method and the mass flow rates are following:

Mass flow rate of hot water in middle tube $m_H$ = 0.256 kg/sec

Mass flow rate of cold water in outer tube $m_{C2}$ = 0.249 kg/sec

The outlet temperatures of cold water streams (C1 & C2) are calculated by steady state energy balance equation are following:

$Q_H = Q_{C1} + Q_{C2}$

$m_H C_{P,H} (T_{Hi} + T_{Ho}) = m_{C1} C_{P,C1} (T_{C1o} + T_{C1i}) + m_{C2} C_{PC2}(T_{C2o} + T_{C2i})$

$T_{C1o} = 26\ ^oC$

$T_{C2o} = 42\ ^oC$

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

Bulk mean temperature of cold water: $T_{b1} = (T_{C1o} + T_{C1o})/2$

Table 3: Thermo physical properties of various calculated bulk mean temperature

| Properties | Bulk mean temperature | | |
|---|---|---|---|
| | 33.5 °C | 40 °C | 17.5 °C |
| Density (Kg/m³) | 9.9409E+2 | 9.9180E+2 | 9.9831E+2 |
| Dynamic Viscosity (Kg/ms) | 7.2227E-4 | 6.3544E-4 | 1.0396E-3 |
| Kinematic Viscosity (m²/Sec) | 7.2657E-7 | 6.4069E-7 | 1.0413E-6 |
| Specific Heat (J.Kg/K) | 4.0689E+3 | 4.0673E+3 | 4.0789E+3 |
| Conductivity (W/mK) | 0.62416 | 0.63247 | 0.60082 |
| Prandtl Number | 4.7085 | 4.0864 | 7.0574 |

Linear velocity of cold water:

$W_{C1} = (m_{C1}\times 4)/(\rho_{C1}\times\pi\times d^2_{in1})$

$W_{C1}$ = 0.0826 meter/sec

Calculation for Reynolds number: Reynolds number for cold water is calculated by,

$Re_{C1} = (\rho_{C1} \times W_{C1} \times d_{in})/(\mu_{C1})$

$Re_{C1}$ = 304.98=3049.8

**Calculations for Convective Heat transfer:**

For a transition regime, Reynolds values ranges between 2300 and $10^3$

$Nu_C = ((f/2)(Re_c - 1000)\ Pr_c)/(1+12.7(f/2)^{1/2}(Pr_c^{2/3}-1)$

Where $f = (1.58 \ln Re - 3.28)^{-2}$

Friction factor $f_{C1} = 0.01132$

Nusselt number $Nu_{C1} = 23.055$

From the value of Nusselt number, determine convective heat transfer coefficient from following equation: $\alpha = (Nu\, K)/d_{in1}$

Convective heat transfer coefficient $\alpha_{C1} = 223.422\ W/m^2k$

To obtain Reynolds number of hot water, hydraulic diameter is required.

Hydraulic diameter:

$D_m = D_2 = d_{in2} - d_{in1}$

Calculations for Overall heat transfer coefficients:

There are two Overall heat transfer coefficients in triple concentric tube heat exchanger and they are defined as:

Overall heat transfer coefficient based on outside area of central pipe

$1/U_{O1} = (d_{out\,1}/d_{in\,1}\,\alpha_c) + d_{out1} \ln (d_{out1}/d_{in\,1})/\ 2k_{copper} + 1/\alpha_H$

Overall heat transfer coefficient based on inside area of intermediate pipe

$1/U_{i2} = (d_{in2}/d_{out2}\,\alpha_c) + d_{in1} \ln (d_{out2}/d_{in2})/\ 2k_{copper} + 1/\alpha_H$

Calculations for Logarithmic mean temperature difference

$\Delta T_{lm\,1} = \{(T_{Hi} - T_{C1o}) - (T_{Ho} - T_{C1i})\}/\ [\ln\{(T_{Hi} - T_{C1o}) - (T_{Ho} - T_{C1i})\}]$

$\Delta T_{lm\,2} = \{(T_{Hi} - T_{C2o}) - (T_{Ho} - T_{C2i})\}/\ [\ln\{(T_{Hi} - T_{C2o}) - (T_{Ho} - T_{C2i})\}]$

**Calculations for Heat transfer rates:**

The heat flow for all the three fluids is calculated using the following calorimeter equations:

Heat flow rate of hot water through middle pipe:

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

Heat flow rate of cold water through inner pipe

$Q_{C1} = m_{C1}\, C_{P,C1}\ (T_{C1o} + T_{C1i})$

Heat flow rate of cold through outer pipe

$Q_{C2} = m_{C2}\, C_{PC2}\ (T_{C2o} + T_{C2i})$

Calculation for Length of triple concentric pipe heat exchanger

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

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

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

For a given diameters $d_{o1}$ and $d_{i2}$, heat exchanger length L calculated by heat balance equation.

**Calculation for Cold water C2 flowing in outer tube:**

The outlet temperature of cold water stream (C2) flowing in outer tube is calculated by steady state energy balance equation are following:

$T_{C2o} = 42\ ^oC$

$T_{C2i} = 25\ ^oC$

Bulk mean temperature: $T_{b2} = 33.5^oC = 306.65\ K$

Hydraulic diameter $D_{hydro\ outer}$ = (0.106-0.0855) = 0.0205 *meter*

Linear velocity $W_{C2} = 0.0638$ *meter/sec*

Reynolds number $Re_{C2} = 1800.29$

Friction factor $f_{C2} = 7.133 \times 10^{-3}$

Nusselt number $Nu_{C2} = 36.266$

Convective heat transfer coefficient $\alpha_{C2} = 1104.187\ W/m^2k$

**Calculation for Hot water H flowing in outer tube:**

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

$T_{Hi} = 100\ ^oC$

$T_{Ho} = 60\ ^oC$

Hydraulic diameter $D_{hydro\ outer}$ = (0.084 - 0.0635) = 0.0205 *meter*

Linear velocity $W_H = 0.0854$ *meter/sec*

Reynolds number $Re_H = 2719.708$

Friction factor $f_H = 0.02527$

Nusselt number $Nu_H = 27.52$

Convective heat transfer coefficient $\alpha_H = 849.288\ W/m^2k$

**Calculated value of Overall heat transfer coefficients:**

Overall heat transfer coefficient based on outside area of central pipe $U_{O1} = 114.23$

Overall heat transfer coefficient based on inside area of intermediate pipe $U_{i2} = 133.49$

Calculations for Logarithmic mean temperature difference:

$\Delta T_{lm\,1} = 61.79\ ^oC$

$\Delta T_{lm\,2} = 45.535\ ^oC$

Calculated Heat transfer rates:

$Q_H$ = 41.80

$Q_{C1}$ =17.31

$Q_{C2}$ = 17.23

**Calculation for Length of triple concentric pipe heat exchanger:**

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

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

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

L=1.201 meter

## 3. CONCLUSIONS

In this research work, triple tube heat exchanger is designed and analyzed heat transfer coefficient at 0.25 liter/second flow rate by theoretical analysis. At velocity of flow 0.25 liter/second, length of tube is calculated and found compact size 1200 mm length as compare to any double pipe heat exchanger. The theoretical analysis of triple concentric copper tube heat exchanger results showed maximum heat transfer rate at 0.25 liter/second for boundary condition when cold and normal water flows inner and outer tube. This compact size of heat exchanger have maximum heat transfer coefficient in comparison of any other heat exchanger of same size. Results show that temperature of hot water drops from 100°C to 60°C, when water flows from 1.2 meter long triple concentric tube heat exchanger which provides better heat transfer efficiencies and large heat transfer area per unit heat exchanger length.

## REFERENCES

[1] F.P. Incropera, D.P. Dewitt, Fundamentals of Heat and Mass Transfer, third Edn., Wiley, New York, 1990.

[2] G.A.Quadir, Saqab.S.Jarallah, N.J.Salman Ahmed, Irfan Anjum Badruddin, "Experimental investigation of the performance of a triple concentric pipe heat exchanger", International Journal of Heat and Mass Transfer, 2013, 62, 562–566.

[3] O.Garcia-valladares, "Numerical simulation of triple concentric pipe heat exchangers", International Journal of Thermal sciences, 2004, 43, 979-991.

[4] Ediz Batmaz, K.P.Sandeep, "Calculation of overall heat transfer coefficients in a triple tube heat exchangers", Heat Mass Transfer, 2005, 41, 271-279.

[5] Ahmet Unal, "Theoretical analysis of triple concentric-tube heat exchanger Part-1 Mathematical modeling", International Communication Heat Mass Transfer, 1998, 25, 949-958.

[6] Ahmet Unal, "Theoretical analysis of triple concentric-tube heat exchanger Part-2 Case studies", International Communication Heat Mass Transfer, 2001, 28, 243-256.

[7] Tejas M. Ghiwala, Dr. V.K. Matawala, " Sizing of triple concentric pipe heat exchanger", International Journal of Engineering Development and Research,2014, 1683-1692, Volume 2, Issue 2, ISSN: 2321-9939

[8] D. Kornack and P. Rakic, "Cell Proliferation without Neurogenesis in Adult Primate Neocortex," Science, vol. 294, Dec. 2001, pp. 2127-2130, doi:10.1126/science.1065467.

[9] M. Young, The Technical Writer's Handbook. Mill Valley, CA: University Science, 1989.