Experimental Study of Heat Transfer in Concentric Triple Pipe Heat Exchanger

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Abstract. Heat exchangers are devices which are used to transfer the thermal energy between two or more fluids. They are used in various industries for space heating, air conditioning and chemical processing. Some heat exchangers which are experienced in our daily lives include pasteurization, radiators and oil coolers in automobiles Heat exchangers have been divided in several ways, based on its flow direction which are parallel or counter flow, types of construction of the heat exchanger like tubular or plate heat exchanger, the ways of contact between the fluids i.e. direct or indirect.

The heat exchangers performance is usually depending upon the physical characteristics of the fluid and the material. When a concentric tube is added in the intermediate space of a double pipe heat exchanger, we obtain a triple pipe heat exchanger, we obtain a triple pipe heat exchanger. The performance of the triple is better than the double pipe, as it provides better heat transfer efficiencies. Basically, the additional pipe improves the heat transfer by providing an additional flow passage and a larger area for heat transfer area per unit length of the exchanger.

1. Introduction
A heat exchanger is device that manages thermal exchange between two or more fluids are used in both heating and cooling operations. Concentric heat pipe exchangers are the most common type of heat exchangers. Double pipe heat exchangers are the most common type of heat exchangers but the design of heat exchanger with high heat transfer efficiency is necessary in various industrial applications. For this a triple pipe heat exchanger setup is studied and compared with a double pipe heat exchanger along with possible counterflow and parallel flow setups. Numerical analysis using finite element method was conducted on a triple concentric pipe by G.A. Quadir et al [1]. Steady state conditions were observed and experiment was conducted with hot, cold and normal water for insulated as well as non-insulated heat exchanger. Correlation between numerical and experimental result of dimensionless temperature variation was established and design parametric study of the heat exchanger was performed. Tejas M Ghiwala [2] suggested a method to calculate heat transfer coefficient and also the length of the concentric pipe. Comparison between double and triple concentric pipe was also studied for both properties. Advantages of triple pipe heat exchanger over double
pipe concentric heat exchanger was shown conceptually. Studies conducted by Carlos A Zuritz [3] resulted in derivation of analytical equations in order to calculate the temperature at any instant inside the triple pipe heat exchanger. The equations stood true for any type of flow and also took heat losses into account. With mass flow rate, inlet temperature of the fluid and heat transfer coefficient as input, we were able to obtain total heat transfer rate. This resulted in accurate calculation of reduction effective length requirement for a triple pipe exchanger over double pipe. D.P. Sekulic et al [4] worked in generalising the thermal design theory to accommodate the triple pipe heat exchanger. The initial equation was limited to only one thermal communication which meant heat losses and effects of the environment were not taken into consideration. Problem of space constraints was also solved by generalising where more the three fluid interactions can be solved. Theoretical study was carried out on a triple concentric pipe heat exchanger where a mathematical model of the exchanger was constructed by Ahmet Unal [5]. Differential equation of parallel and counter flow arrangements was used in order to derive the model. The equations can be used to solve design and performance calculations. Determination of bulk temperature along the axis of the exchanger was also possible. Ahmet Unal [6] in his second part of the work has given the solutions for various important case studies based on the mathematical model derived from his previous work with focus on counter-flow arrangement. Efficiency of exchanger was found by varying tube length and exchanger length.

Relation for number of transfer units (NTU) was derived for both parallel and counter-flow arrangements in a triple pipe heat exchanger [7]. NTU is expressed against the newly introduced third flow of stream in the heat exchanger and the total efficiency. O Garcia Valladares [8] in his paper studied about the hydraulic and thermal behaviour of a triple pipe heat exchanger. He also numerically simulated his study using the derived equations. Previously derived methods by the researchers lacked validity due to usage of assumptions. Ediz Batmaz et al [9] derived at a more generic way to calculate heat transfer coefficient, temperature profile of the exchanger and also overall heat transfer. With more accuracy, distinct comparison was made against double pipe exchanger. G A Quadir et al [10] continued his study in triple pipe heat exchanger by conducting experimental studies to determine its efficiency under different conditions. These values are taken under steady conditions are used to validate numerical models.

2. Methods & Methodology

2.1 Working Principle

The second law of thermodynamics states that the total entropy of an isolated system can only increase over time. It can remain constant in ideal cases where the system is in a steady state (equilibrium) or undergoing a reversible process. The increase in entropy accounts for the irreversibility of natural processes, and the asymmetry between future and past.

2.2 Orthographic Drawing

2.2.1 Triple Pipe

![Orthographic Representation](image)
2.2.2 Experimental Setup

Figure 2 Triple Pipe Counter Flow.

Figure 3 Triple Pipe Parallel Flow.

Figure 4 Setup of Triple Pipe Heat Exchanger.
2.3 Construction

2.3.1 Double Pipe Heat Exchanger

Cold water is supplied through pipe lines and hoses to a geyser inlet and outer GI pipe. The inlet of cold-water line is connected through shut off valve so that water can be supplied either parallelly or counter to it. Thermocouples are mounted in-between the inlet & outlet of both hot water line and cold-water line to measure the temperature in the required area. All the five thermocouples are connected with electric supply and a channel indicator.

2.3.2 Triple Pipe Heat Exchanger

The construction of a triple pipe heat exchanger is similar to the double pipe heat exchanger except a separate input facilitated to supply cold water to the inner most copper tube. The discharge of cold water is done via separate outlets. The inlet valve is connected to a shut off valve which can be used to modify the type of flow-parallel or counter. This type of heat exchanger houses 6 thermocouples in order to measure the required temperatures.

2.4 Specification

2.4.1 Heat Exchanger

We made corrugation in high thermal conductive material such as COPPER.

| Inner Tube (Copper): | Inner Diameter (di)₁ = 7mm |
| Outer Diameter (do)₁ = 9mm |
| Middle Tube (Copper): | Inner Diameter (Di) = 18mm |
| Outer Diameter (Do) = 20mm |
| Outer tube (GI): | Inner Diameter (di)₂ = 27mm |
| Outer Diameter (do)₂ = 29mm |

Length of Heat Exchanger (L) = 1m

2.4.2 Water heating element

3 KW Heat Input, 1 Liter Capacity.

2.4.3 Thermocouple

RTD Thermocouple, Range (-50 to 199°C).

2.5 Test Procedure

Turn on the electric power supply and check for any standard error. Make sure the equipment is independent of environmental stimulus like climate, humidity, temperature. Open the water supply and make sure the water flows through the pipe without any obstruction. Turn on the geyser and shut off the flow through counter pipe heat exchanger. This allows the water to flow parallelly. After checking if both inner and outer pipe have water flow, start taking the temperature readings. Now shut off the supply to parallel supply and do the same procedure for counter flow heat exchanger. Repeat the same experiment for triple heat exchanger also. Use the readings obtained to make calculations.
### 3. Observation & Calculation

**Table 1** Parallel flow Double Pipe Readings

| HOT WATER | COLD WATER |
|-----------|------------|
| **Time taken for collecting 1L of water**<br>\((t_h)\) | **Hot water inlet temperature; °C**\((T_{hi})\) | **Hot water outlet temperature; °C**\((T_{ho})\) | **Time taken for collecting 1L of water**<br>\((t_c)\) | **Cold water inlet temperature; °C**\((T_{ci})\) | **Cold water outlet temperature; °C**\((T_{co})\) |
| 37.78 | 55 | 48 | 22.42 | 30 | 33 |
| 57.74 | 62 | 54 | 33.63 | 30 | 34 |
| 35.26 | 54 | 48 | 53.48 | 30 | 35 |
| 41.27 | 58 | 52 | 37.76 | 31 | 35 |

**Table 2** Counter flow Double pipe readings.

| HOT WATER | COLD WATER |
|-----------|------------|
| **Time taken for collecting 1L of water**<br>\((t_h)\) | **Hot water inlet temperature; °C**\((T_{hi})\) | **Hot water outlet temperature; °C**\((T_{ho})\) | **Time taken for collecting 1L of water**<br>\((t_c)\) | **Cold water inlet temperature; °C**\((T_{ci})\) | **Cold water outlet temperature; °C**\((T_{co})\) |
| 26.77 | 48 | 43 | 28.80 | 29 | 31 |
| 32.35 | 53 | 49 | 52.33 | 31 | 35 |
| 25.96 | 49 | 45 | 24.46 | 31 | 34 |
| 35.70 | 56 | 50 | 59.33 | 31 | 36 |
### Table 3 Triple Pipe Parallel Flow Hot Water Readings

| Time taken for collecting 1L of water (th) | Hot water inlet temperature; °C (Thi) | Hot water outlet temperature; °C (Tho) |
|------------------------------------------|--------------------------------------|---------------------------------------|
| 28.78                                    | 49                                   | 44                                   |
| 35.09                                    | 53                                   | 45                                   |
| 37.66                                    | 55                                   | 46                                   |
| 38.28                                    | 55                                   | 46                                   |
| 42.06                                    | 58                                   | 47                                   |
| 51.63                                    | 63                                   | 49                                   |
| 63.64                                    | 73                                   | 51                                   |

### Table 4 Triple Pipe Parallel Flow Cold Water Readings

| Time taken for collecting 1L of water (tc1) | Cold water inlet temperature; °C (Tc1i) | Cold water outlet temperature; °C (Tc1o) |
|-------------------------------------------|----------------------------------------|----------------------------------------|
| 60.38                                     | 31                                     | 38                                     |
| 60.38                                     | 32                                     | 39                                     |
| 60.38                                     | 32                                     | 40                                     |
| 60.38                                     | 32                                     | 40                                     |
| 60.38                                     | 32                                     | 40                                     |
| 60.38                                     | 32                                     | 42                                     |
| 60.38                                     | 32                                     | 43                                     |
Table 5 Triple Pipe Parallel Flow Outer Pipe Readings

| Time taken for collecting 1L of water (t_c2) | Cold water inlet temperature; °C (T_c2i) | Cold water outlet temperature; °C (T_c2o) |
|---------------------------------------------|------------------------------------------|------------------------------------------|
| 57.78                                       | 31                                       | 36                                       |
| 41.34                                       | 31                                       | 35                                       |
| 39                                          | 32                                       | 36                                       |
| 34.04                                       | 32                                       | 35                                       |
| 48.53                                       | 32                                       | 37                                       |
| 54.47                                       | 32                                       | 38                                       |
| 59.06                                       | 32                                       | 39                                       |

Table 6 Counter Flow Hot water reading outer pipe

| Time taken for collecting 1L of water (t_h)  | Hot water inlet temperature; °C (T_hi) | Hot water outlet temperature; °C (T_ho) |
|---------------------------------------------|----------------------------------------|----------------------------------------|
| 30.25                                       | 51                                     | 44                                     |
| 37.12                                       | 55                                     | 45                                     |
| 44.39                                       | 62                                     | 48                                     |
| 40.03                                       | 58                                     | 46                                     |
| 49.56                                       | 63                                     | 48                                     |
| 53.93                                       | 67                                     | 49                                     |
| 64.10                                       | 73                                     | 51                                     |
### Table 7 Counter Flow Cold water central pipe readings

| Time taken for collecting 1L of water (t<sub>c1</sub>) | Cold water inlet temperature; °C (T<sub>c1i</sub>) | Cold water outlet temperature; °C (T<sub>c1o</sub>) |
|------------------------------------------------------|-----------------------------------------------|-----------------------------------------------|
| 60.38                                                | 32                                           | 38                                           |
| 60.38                                                | 31                                           | 39                                           |
| 60.38                                                | 32                                           | 40                                           |
| 60.38                                                | 32                                           | 39                                           |
| 60.38                                                | 32                                           | 41                                           |
| 60.38                                                | 32                                           | 42                                           |
| 60.38                                                | 32                                           | 43                                           |

### Table 8 Counter Flow Cold Water Outer pipe readings

| Time taken for collecting 1L of water (t<sub>c2</sub>) | Cold water inlet temperature; °C (T<sub>c2i</sub>) | Cold water outlet temperature; °C (T<sub>c2o</sub>) |
|------------------------------------------------------|-----------------------------------------------|-----------------------------------------------|
| 16.35                                                | 32                                           | 34                                           |
| 19.10                                                | 31                                           | 34                                           |
| 22.90                                                | 32                                           | 36                                           |
| 19.53                                                | 32                                           | 35                                           |
| 25.81                                                | 32                                           | 36                                           |
| 25.38                                                | 32                                           | 37                                           |
| 18.97                                                | 32                                           | 36                                           |
4. Results and Discussion

4.1 Analytical Result

4.1.1 Heat Transfer Rate ($q_{avg}$)

Table 9 Analytical results for Heat Transfer Rate.

| Trial | Double pipe Parallel | Counter | Triple pipe Parallel | Counter |
|-------|----------------------|---------|----------------------|---------|
| 1     | 661.1896457          | 530.6683292 | 570.4009612          | 707.0965892 |
| 2     | 533.7441046          | 414.7453448 | 693.3638234          | 857.5469576 |
| 3     | 546.0227488          | 573.8815336 | 739.4048371          | 970.8262175 |
| 4     | 520.7607881          | 522.8777705 | 716.3658414          | 899.4410646 |

Figure 5 Graphical representation for heat transfer rate parallel flow.

Figure 6 Graphical representation for heat transfer rate counter flow.

The heat transfer rate in the double pipe heat exchanger is gradually increasing when compared to triple pipe heat exchanger. In parallel flow, the heat transfer rate is less in the first trial in triple pipe when compared to double pipe because of higher temperature in triple pipe heat exchanger. The difference of change of heat transfer rate between double pipe and triple pipe heat exchanger is 119.2 Watts.
4.1.2 Mass Flow Rate ($m_{avg}$)

Table 10 Analytical results for Mass flow rate.

| Trial | Double pipe | Triple pipe |
|-------|-------------|-------------|
|       | Parallel 1  | Counter 1  | Parallel 2  | Counter 2  |
|       | 0.035299236| 0.035773056| 0.025645743| 0.035517279|
| 2     | 0.023371365| 0.024806245| 0.024266382| 0.030468531|
| 3     | 0.023322491| 0.039419845| 0.023664898| 0.026125704|
| 4     | 0.025163049| 0.022248511| 0.024382914| 0.029214398|

Figure 7 Graphical representation of Mass flow rate in parallel flow.

Figure 8 Graphical representation of Mass Flow Rate in counter flow.

In parallel flow, mass flow rate of double pipe heat exchanger is coming in the range of 0.23 to 0.35 kg/s whereas in triple pipe heat exchanger it is a constant graph. In counter flow the mass flow rate of double pipe is varying variably whereas in triple pipe it is gradually decreasing then it increasing in last trail.
4.1.3 Effectiveness ($\varepsilon$)

Table 11 Analytical result for Effectiveness.

| Trial | Double pipe Parallel | Counter | Triple pipe Parallel | Counter |
|-------|----------------------|---------|----------------------|---------|
| 1     | 0.241968043          | 0.193145943 | 0.459688969          | 0.53995917 |
| 2     | 0.233222215          | 0.236882572 | 0.478958872          | 0.518456118 |
| 3     | 0.194263776          | 0.187253409 | 0.466348721          | 0.46955  |
| 4     | 0.192760926          | 0.29796006  | 0.451817837          | 0.5019549 |

Figure 9 Graphical representation of Effectiveness in parallel flow.

Figure 10 Graphical representation of Effectiveness in counter flow.

The effectiveness of triple pipe heat exchanger has been increased as compared to double pipe heat exchanger which was one of our project objectives. The increase in effectiveness is roughly around 25%. The one of the reasons of it is because of the increasing surface area of contact in triple pipe as compared to double pipe.
4.1.4 Logarithmic Mean Temperature Difference (LMTD)

Table 12 Analytical results for LMTD.

| Trial | Double pipe Parallel | Double pipe Counter | Triple pipe Parallel | Triple pipe Counter |
|-------|-----------------------|----------------------|----------------------|---------------------|
| 1     | 19.57615189           | 15.23287819          | 20.00565101          | 18.62652114         |
| 2     | 25.53171774           | 17.69969758          | 26.95200701          | 20.34253148         |
| 3     | 17.94147733           | 14.21387663          | 18.44255644          | 18.23047519         |
| 4     | 21.61584858           | 18.97145415          | 22.94149834          | 24.33461848         |

**Figure 11** Graphical Representation for LMTD (Parallel flow).

**Figure 12** Graphical representation for LMTD (Counter flow).

In LMTD the graphical representation of parallel flow is nearly same for both double pipe and triple pipe heat exchanger with a difference in both being 0.5°C. Whereas in counter flow the difference of double pipe and triple pipe varying an amount of 5°C.
4.1.5 Overall Heat Transfer Coefficient (U)

**Table 13** Analytical results for Overall Heat Transfer Coefficient.

| Trial | Double pipe Parallel | Double pipe Counter | Triple pipe Parallel | Triple pipe Counter |
|-------|----------------------|---------------------|----------------------|---------------------|
| 1     | 597.5807028          | 616.3665288         | 518.7740102          | 691.6649262         |
| 2     | 369.8715296          | 414.5849389         | 566.1154638          | 583.3323162         |
| 3     | 538.4562015          | 714.3442537         | 593.7466055          | 629.6291423         |
| 4     | 426.2494513          | 487.6378468         | 564.4446247          | 724.8421625         |

**Figure 13** Graphical representation of overall heat transfer coefficient in parallel flow.

**Figure 14** Graphical representation of overall heat transfer coefficient in counter flow.

The overall heat transfer coefficient in parallel flow for double pipe the graph is in the variable state and being less as compared to a constant increasing graph of triple pipe parallel flow. When it is compared to counter flow the graph of triple pipe is gradually increasing compared to double pipe heat exchanger.
4.1.6 Volumetric Flow $Q_{\text{avg}}$ ($m^3/s$)

Table 14 Analytical results for volumetric flow.

| Trial | Double pipe Parallel | Double pipe Counter | Triple pipe Parallel | Triple pipe Counter |
|-------|-----------------------|---------------------|----------------------|---------------------|
| 1     | 3.5536E-05           | 3.6038E-05          | 2.5840E-05           | 3.5793E-05          |
| 2     | 2.3527E-05           | 2.5011E-05          | 2.4437E-05           | 3.0699E-05          |
| 3     | 2.3529E-05           | 2.9701E-05          | 2.3827E-05           | 2.6321E-05          |
| 4     | 2.5356E-05           | 2.24E-05            | 2.4546E-05           | 2.9431E-05          |

Figure 15 Graphical Representation of Volumetric Flow rate ($Q_{\text{avg}}$) in parallel flow.

Figure 16 Graphical Representation for Volumetric Flow ($Q_{\text{avg}}$) in counter flow.

The volumetric flow rate in parallel flow from graph we can conclude that it is nearly same for both double pipe as well as triple pipe but it is increasing in the counter flow for the triple pipe heat exchanger for the same area of cross section of pipe.
4.2 Result

4.2.1 Double Pipe Heat Exchanger

Table 15 Experimental Result Double Pipe.

| DESCRIPTION                                      | PARALLEL  | COUNTER  |
|--------------------------------------------------|-----------|----------|
| Heat transfer rate(q) [Watts]                    | 520.76    | 522.87   |
| LMTD [°C]                                        | 17.94     | 14.21    |
| Overall heat transfer coefficient (U) [W/m²K]     | 426.24    | 487.63   |
| Effectiveness [%]                                | 19.27     | 29.79    |

4.2.2 Triple Pipe Heat Exchanger

Table 16 Experimental Result Triple Pipe.

| DESCRIPTION                                      | PARALLEL  | COUNTER  |
|--------------------------------------------------|-----------|----------|
| Heat transfer rate(q) [Watts]                    | 639.96    | 970.86   |
| LMTD [°C]                                        | 18.44     | 18.23    |
| Overall heat transfer coefficient (U) [W/m²K]     | 566.15    | 629.62   |
| Effectiveness [%]                                | 47.89     | 46.96    |

5. Conclusion

Heat transfer enhancement in a concentric triple pipe heat exchanger was reported in this paper. The main scope of the present study was to compare the double pipe heat exchanger with a triple pipe heat exchanger. The result of this study compares heat transfer rate, LMTD, overall heat transfer coefficient and effectiveness between the two type of exchangers. Finding indicated that the use of triple pipe heat exchanger, where

(i) Performance of heat exchanger enhanced by 119.2 Watts.
(ii) LMTD increased by 0.5°C.
(iii) Over all heat transfer coefficient was boosted by 139.91 W/m²K.
(iv) Total effectiveness increased by 28.62%.

The Volumetric Flow ($Q_{avg}$) and Mass Flow Rate ($m_{avg}$) for the double and triple pipe heat exchanger is almost identical regardless of the type of flow.
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