Experimental Analysis Of Triple Tube Heat Exchanger With TiO_2 Nanofluid

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Abstract— This article reports an experimental study of triple tube heat exchanger (TCTHE). The triple concentric tube heat exchanger is made with three stainless steel tubes. the diameters and lengths are 16mm, 32mm, 44mm and 850mm, 750mm, 650mm respectively. The thickness of all the three tubes are 1mm. The purpose of the experiment is to decrease the length, cost of the material and to raise the heat transfer area, by providing the intermediate tube and also TiO_2 nano particles were used for increasing the heat transfer of the triple concentric tube heat exchanger. The performance of the heat Exchanger at various volumetric concentrations of nanofluid are analyzed. The experimental data indicate that the heat transfer of triple tube heat exchanger was raise with the use of TiO_2 and for the same heat transfer area, the length of the heat exchanger is reduced compared to double concentric tube heat exchanger.

Index Terms— Heat exchanger, Triple tube heat exchanger, TiO_2 nanofluid, Over all heat transfer coefficient, logarithmic mean temperature difference(IMTD)
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1 INTRODUCTION

Heat exchangers are mainly used to transfer the heat from one fluid to another fluid. Heat exchangers are widely used in industrial applications. The challenging task to the engineers is improving the thermal characteristics of Heat Exchanger, this reflects on the plant output. So, the engineers fallow different techniques to achieve this.

The basic heat exchanger is double tube heat exchanger in which one fluid passing through one tube and other fluid flowing in another tube. In simple heat exchanger the hot and cold fluids flows in same or opposite direction, In parallel flow heat exchanger the cold fluid and hot fluid flows in same direction where as in counter flow heat exchanger the cold and hot fluids flows parallel but opposite direction, Many researchers have been performed experiments and concluded that counter flow heat exchangers gives good performance. In the triple tube heat exchanger, there are three cocentric sections:

central tube
inner annular space and
outer annular space.

Three different fluids are passed through the inner tube and outer annular spaces and a thermal fluid is passed through an inner annular space. In recent days triple tube heat exchangers are becoming popular because of more surface area. Heat transfer fluids plays a major role in heat exchangers because, based on the thermal conductivity of the fluid the amount of heat transfer depends. So many researchers are working on this. In this article, TiO_2 nano particles are used in fluids to improve thermal conductivity, the main reasons for selecting titanium dioxide

(1) because of low cost
(2) it is a safe material (normally used in cosmetic products and water treatment)
(3) it has great chemical and physical stability even without an additional stabilizer.

2 EXPERIMENTAL SETUP

2.1 Materials

The system consists of a stainless tube that have diameters of 16mm, 32mm, and 44mm and the lengths are 850mm, 750mm, and 650mm respectively, a hot water tank(15L), cooling system, storage tank(15L) are arranged for nanofluid and pump,
thermocouples are used for circulating the nanofluid and to take the temperature readings. TiO_2 nano powder is used for making nanofluid.

2.2 Sample Preparation

Nanofluid, it is just not intend of mixture of fluid and nano particles. In order to mix the nanoparticles in a fluid, it is required to mix and stabilize properly. Usually, the following are the three techniques employed to overcome the sedimentation problem, the following are the three techniques:

(1) maintaining the suspension's ph value.
(2) by using the surface activators and
(3) using high vibration

The above methods try at modifying the properties of the suspended particles and reduces the formation of the clusters, and to get stable suspensions. In this experiment, stirrers were used for producing the vibrations. 21 nm sized nanoparticles were used.

Table 1 : Properties of Water and TiO_2 Nano Particles

Property	Water	Tio2
ρ [kg/m3]	998.2	3980
Cp [j/kgK]	4182	690
k [W/mK]	0.6	10.2

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2.3 Figures

Figure 1: Nano Powder Box

Figure 2: TiO_2 Nano Powder

Figure 3: Concentric Triple Tube Heat exchanger

Figure 4: Experimental Setup

Exchanger

Table 2 Know input parameter

parameters	values
Inlet temperature of hot water (T_{hi})	59°C
Inlet temperature of cold water (T_{c2i})	32°C
Nanofluid inlet temperature (T_{c1i})	32°C
Hot water mass flow (m_h)	2.5lit/min
Cold water mass flow rate (m_{c2})	5lit/min
Nanofluid mass flow rate (m_{c1})	1.5lit/min
Central tube diameter (d_{it})	16mm
Middle tube diameter (d_{mt})	32mm
Outer tube diameter (d_{ot})	44mm
Thermal conductivity of ss (k_{steel})	17w/m-k

3.4 Procedure

For the counterflow the cold water, nanofluid and hot water are passed in opposite direction, the hot water is passed through the inner annular space, cold water is passed through the out annular space and nanofluid is passed through an inner tube. Temperatures of the fluids at inlet and exit are noted with the help of thermocouples and temperature indicators the temperature of hot water is maintained with the help of geyser as shown in Figure 4. The readings are taken with different volumetric concentrations of nano fluid and valves are used to maintain the uniform flowrate

3 Mathematical Model of the Triple Concentric-Tube Heat Exchanger

The following are the assumptions made while performing the experiment:

- The flow in the heat exchanger is steady state;
- Lumped parameters system is used;
- Tube wall conduction resistance is neglected in the thin tube;
- Incompressible fluids were used;
- Properties of fluid are constant;
- No phase change take place;
- Insulation is made around the heat exchange.

Steady state energy balance equation:

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

Bulk mean temperature of fluids:

$$T_{b1} = T_{c1i} + T_{ce2}$$

$$T_{b2} = T_{H1i} + T_{He2}$$

$$T_{b3} = T_{c2i} + T_{ce2}$$

Linear velocity of water:

$$V_{c1} = \frac{\dot{m}_{c1} \times 4}{\rho_{c1} \times \pi \times {d_{in1}}^2}$$

$$V_{c2} = \frac{\dot{m}_{c2} \times 4}{\rho_{c21} \times \pi \times {d_{in1}}^2 - {d_{out2}}^2}$$

$$V_H = \frac{\dot{m}_H \times 4}{\rho_H \times \pi \times {d_{in2}}^2 - {d_{out1}}^2}$$

Hydraulic diameter of water

$$d_{h2} = d_{in2} - d_{out1}$$

$$d_{h3} = d_{in3} - d_{out2}$$

Reynolds number

$$Re_{c1} = \frac{\rho_{c1} \times W_{c1} \times d_{in1}}{\mu_{c1}}$$

$$Re_{c1} = \frac{\rho_{c2} \times W_{c2} \times d_{h3}}{\mu_{c2}}$$

$$Re_H = \frac{\rho_h \times W_h \times d_{h2}}{\mu_H}$$

Nusselt number:

Nusselt number can be calculated for different flows, Like

Laminar flow whose Re< 2300

$$Nu_c = 0.51 \times {Re_c}^{0.5} \times Pr_c^{\frac{1}{3}} \times \left(\frac{Pr_c}{Pr_w}\right)^{0.25}$$

where $\left(\frac{Pr_c}{Pr_w}\right)^{0.25}$ is 1 for the same fluid flow.

Transition flow, Re value is between 2300 to 4000

$$Nu_H = 2.718 \times {Re_H}^{0.597} \times Pr_H^{\frac{1}{3}} \times \left(\frac{d_{h2}}{1.193}\right)^{\frac{1}{3}}$$

Turbulence flow, Re values is between 3000 and $5\times10^{6.}$

Table 3: 0 gm TiO2 Nano powder +10 L water

T_{hi}		T_{ci}	T_{co}	T_{ni}	T_{no}
59.8^{0}C	50.3^{0}C	32.5^{0}C	35.5^{0}C	32.5^{0}C	37^{0}C

Table 4: 5gm TiO_2 nano powder + 10L water

T_{hi}	T_{he}	T_{ci}	T_{co}	T_{ni}	T_{no}
59.8^{0}C	48.4^{0}C	32.5^{0}C	36^{0}C	32.5^{0}C	38.5^{0}C

Table 5: 10gm TiO_2 nano powder + 10L water

T_{hi}	T_{he}	T_{ci}	T_{co}	T_{ni}	T_{no}
59.8^{0}C	46.2^{0}C	32.5^{0}C	36.8^{0}C	32.5^{0}C	41.0^{0}C

$$Nu_{c1} = \frac{\left(\frac{f}{2} \times (Re_{c1} - 1000) \times Pr_{c1}\right)}{\left(1 + 12.7\left(\frac{f}{2}\right)\right) \times 0.5 \times \left(Pr_{c1}^{\frac{2}{3}} - 1\right)}$$

where f is the Darcy friction factor:

$$f = \left(1.58 \times ln(Re_{c1}) - 3.28)\right)$$

Convective heat transfer coefficient :

$$\alpha_{c1} = \frac{(Nu_{c1} \times k_{c1})}{d_{in1}}$$

$$\alpha_H = \frac{(Nu_H \times k_H)}{d_{h2}}$$

$$\alpha_{c2} = \frac{(Nu_{c2} \times k_{c2})}{d_{h3}}$$

Overall Heat Transfer Co-Efficient:

Actually, there are 2 overall heat transfers coefficient in TCTHE and one overall heat transfer coefficient is for inner annular space and another overall heat transfer coefficient is for outer annular space.

$$\frac{1}{U_{o1}} = \left(\frac{d_{out1}}{d_{in1} \times \alpha_{c1}}\right) + \left(\frac{d_{out} \times ln\left(\frac{d_{out1}}{d_{in1}}\right)}{2k_{steel}}\right) + \left(\frac{1}{\alpha_H}\right)$$

$$\frac{1}{U_{i2}} = \left(\frac{d_{in2}}{d_{out2} \times \alpha_{c2}}\right) + \left(\frac{d_{in2} \times ln\left(\frac{d_{out2}}{d_{in2}}\right)}{2k_{steel}}\right) + \left(\frac{1}{\alpha_H}\right)$$

The LMTD:

$$\Delta T_{lm1} = \frac{(T_{Hi} - T_{c1e}) - (T_{He} - T_{c1i})}{ln\left(\frac{T_{Hi} - T_{C1e}}{T_{He} - T_{c1i}}\right)}$$

$$\Delta T_{lm2} = \frac{(T_{Hi} - T_{c2e}) - (T_{He} - T_{c2i})}{ln\left(\frac{T_{Hi} - T_{C2e}}{T_{He} - T_{c2i}}\right)}$$

Heat Transfer Rates

For hot water :

$$Q_H = m_H \times C_{pH} \times (T_{Hi} - T_{He})$$

For cold water *C1*:

$$Q_{c1} = m_{c1} \times C_{p1} \times (T_{c1e} - T_{c1i})$$

For cold water $C\,2$:

$$Q_{c2} = m_{c2} \times C_{pc2} \times (T_{c2e} - T_{c2i})$$

4 EXPERIMENTAL STUDY

Initially the tests are conducted with out using nano fluid and Temperature readings are noted. Later by using the nanofluids of different volume concentrations the inlet and exit temperatures of all the three fluids are noted. For each test three readings are taken and their average values are noted in the below tables

Table 6: 15gm TiO_2 nano powder + 15L water

T_{hi}	T_{he}	T_{ci}	T_{co}	T_{ni}	T_{no}
59.8⁰C	44.9⁰C	32.5⁰C	37⁰C	32.5⁰C	43⁰C

5 RESULTS AND DISCUSSION

The graphs are drawn based on the above readings

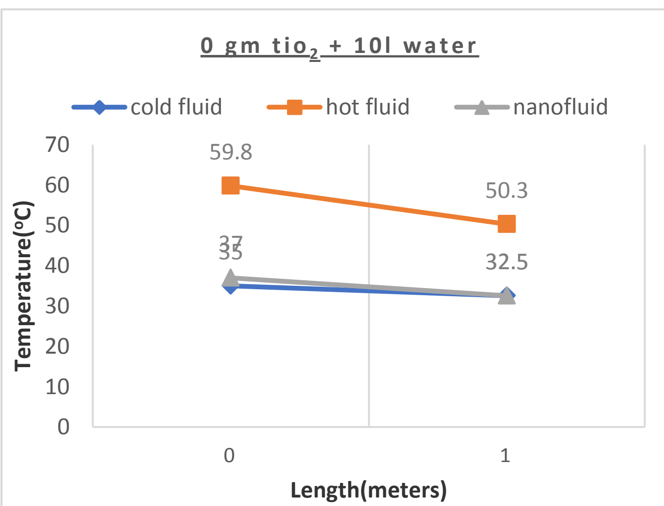

Figure 5: Temperature Distribution of TCTHE at 0gm Nano Powder

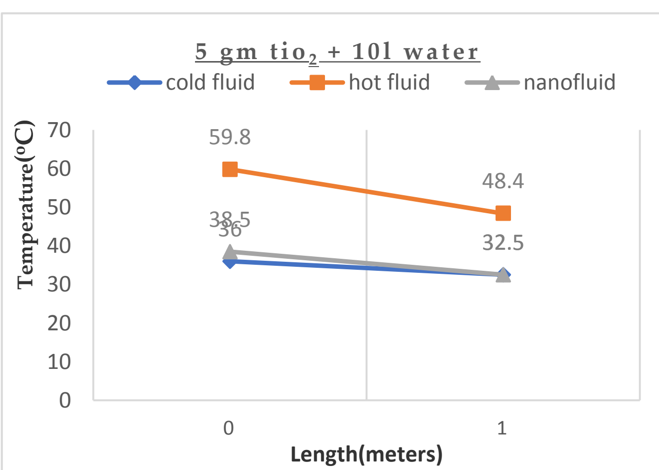

Figure 6: Temperature Distribution of TCTHE at 5gm Nano Powder

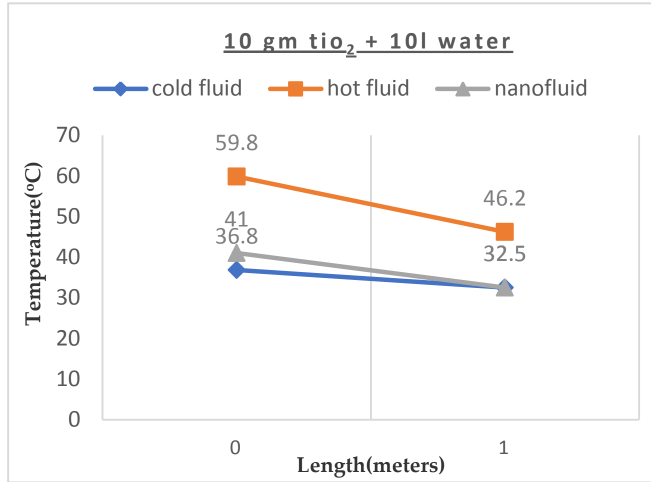

Figure 7: Temperature Distribution of TCTHE at 10gm Nano Powder

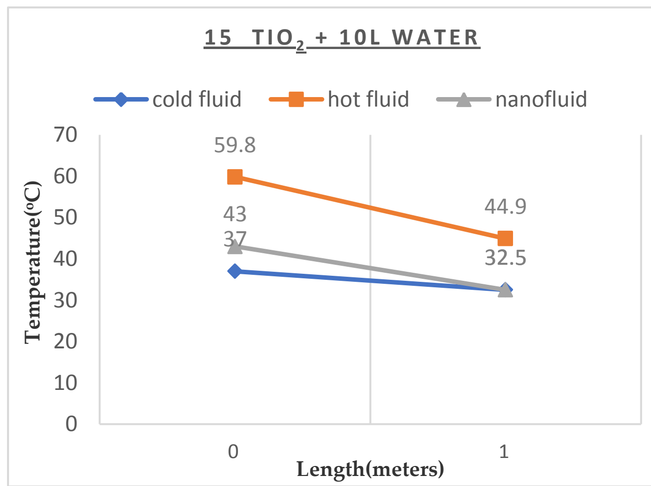

Figure 8: Temperature Distribution of TCTHE at 15gm Nano Powder

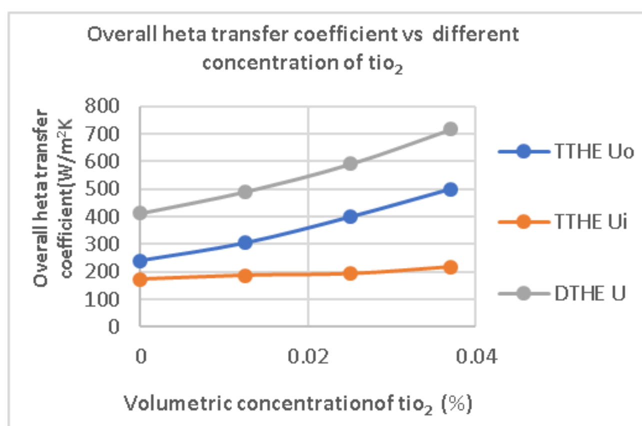

Figure 9: Overall heat transfer coefficient of TTHE and DTHE

The above graphs represents the variation of temperatures at the inlet and exits of heat exchanger for counter flow arrangement at different concentrations of nanofluid and theoretically, as the volumetric concentrations of nanofluid raises the heat transfer rate also increases and also for same heat transfer rate the triple tube heat exchanger length is 850mm while double tube heat exchanger length is almost 3000mm which is greater than 50% as compared to the triple tube heat exchangers length. As the concentration of nanofluid increases the overall heat transfer coefficient also increases and also it is greater than double concentric tube heat exchanger.

Table 7:comparision of readings between TTHE and DTHE

Amount of nano powder added in 10L of water(gm)	Length of TTHE	Length of DTHE	Overall heat transfer coefficient of TTHE Uo	Ui	Overall heat transfer coefficient of DTHE
0	1.062	3.2	239.5	172.4	411.93
5	1.068	3.4	303.8	186.4	490.2
10	1.069	3.3	398.4	192.2	590.6
15	1.072	3.2	499.84	216.8	716.16

7 CONCLUSION

From the experiment results it was found that the overall heat transfer coefficient and heat transfer rate is more in Triple tube heat exchanger compare to the double concentric tube heat exchanger. With Triple tube heat exchanger, even we can save space and material with the triple tube heat exchanger compared to double concentric tube heat exchanger, also found that by increasing the volumetric concentration of nanofluid the heat transfer rate increases.

NOMENCLATURE

A	Heat Transfer Area
C_p	Specific Heat
D	Diameter
K	Thermal Conductivity
$\dot{M}$	Mass Flow Rate
Pr	Prandtl Number
$\dot{Q}$	Heat Flow R
Re	Reynold Number
T	Temperature
U	Overall L Heat Transfer Coefficient
U_{o1}	Overall Heat Transfer Coefficient Based on Outside Area of Central Tube
Ui2	Overall Heat Transfer Coefficient Based on Inside Area of Central Tube
$\dot{N}$	Volumetric Flow Rate
V	Linear Velocity
P	Density
µ	Dynamic Viscosity
A	Coefficient of Heat Transfer
Δ	Difference

SUBSCRIPTS

1	Inner tube
2	Inner annular space
3	Outer annular space
b	Bulk mean
h	Hot fluid
c_1	Nanofluid
c_2	Cold fluid

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