

Heat Transfer Enhancement Characteristics of Water Based Nanofluids in a Shell and Tube Heat Exchanger

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ABSTRACT: Over the past couple of years the use of Nanofluids to enhance the heat transfer has been reported by several researchers. This work deals with experimental investigation of the forced convection heat transfer of Shell and Tube heat exchangers using water based Nanofluid as a coolant. Steady, forced convection, turbulent flow conditions were maintained in this experiment. Flow rate was varied and heat flux was kept constant. The various heat transfer parameters considered for study are Nusselt number, heat transfer coefficient, heat transfer rate and Reynolds Number. From the obtained results, it can be concluded that heat transfer enhancement does occur in heat exchangers using Nanofluids. For all the investigated flow rates, it was observed that with increase in Reynolds number, both the Nusselt number and pressure drop increases which further lead to increase in the pumping power.

KEYWORDS: Shell and Tube heat exchanger, Forced convection, Nanofluid, turbulent flow.

I. INTRODUCTION

In chemical Industries, heat exchanger is one of the most important equipment related to energy and heat transfer. A lot of efforts has been done to augment the heat transfer, to reduce the area of the heat exchanger and finally to improve the efficiency of the exchanger. But the main problem in the improvement of these parameters is the thermal conductivity of the fluid which is very less as compared to solids. So solid nanoparticles are mixed with the fluids to improve the conductivity and other parameters. Many researchers have shown that with the use of nanofluids the increment in the heat transfer occurs. Farajollahi et al [1] carried out an experiment on shell and tube heat exchanger under turbulent flow condition using $\text{c-Al}_2\text{O}_3/\text{water}$ and $\text{TiO}_2/\text{water}$ nanofluids. They observed a significant increase in the heat transfer characteristics after adding the nanofluids. The increment was about 56% in total heat transfer coefficient for 0.5% volume concentration of nanofluids with a decrease in enhancement as particle concentration increases. A similar order of increment was seen by Zamzamian et al. [2] in their experiment with copper oxide–ethylene glycol nanofluid in a double pipe and plate heat exchanger for turbulent flow conditions. In an another experiment on plate type and Shell and tube heat exchanger Kanjirakat et al [3] used three different concentrations of silicon dioxide water ($\text{SiO}_2\text{–water}$) nanofluids. And observed that the enhancement or diminution of heat transfer depends on the flow rate and concentration of the nanofluid. Also they found an increase in pressure drop with the use of nanofluids. WeerapunDuangthongsuk and SomchaiWongwises[4] conducted an experiment to study the heat transfer and fluid flow characteristics of 0.2 vol.% TiO_2 nanofluids in a double pipe heat exchanger. They found an increment in the heat transfer coefficient with the increase in the mass flow rate of the nanofluids. They also find that the use of the nanofluid has a little penalty in pressure drop. Mare' et al. [5] conducted an experiment on plate type heat exchanger using two types of nanofluids namely alumina and CNT-water nanofluids. The experiment was conducted at low temperatures and the thermal performance of these fluids were studied. They reported an increment of 42% and 50%, in the heat transfer rates. An increase in the pressure drop for nanofluid flow was also reported by them.

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II. EXPERIMENTAL SETUP

The test section comprises of Shell and tube heat exchanger (Two tube pass, one shell pass type). For shell side stainless steel material with 25% cut baffles were used, whereas for tube side stainless steel with ID 13mm OD 16mm length 500 mm was used. For Water flow Measurement, a measuring cylinder and a stopwatch with two Rota meters (one each for cold and hot fluid) were used. The Hot water tank was made of stainless steel insulated with ceramic fiber wool. And for circulation of Hot water, Magnetic pump made of polypropylene was used. (Maximum working temperature maintained was 85° C). 2 kW Nichrome wire heater (2 nos.) were used for heating the water and nanofluids. The heat input to the heat exchanger can be varied by using dimmer start but in this experiment it was kept constant. The heat exchanger was further connected to inlet header for inflow flow of coolant and outlet header/plenum to discharge the coolant out of the heat exchanger. A pump along with control valve was used for continuous supply of coolant and for controlling the flow rate of coolant. The upper surface temperature of heat exchanger was measured using K-type thermocouples which were fixed at equal distance throughout the heat exchanger. While T-type thermocouples were attached to inlet and outlet of the heat exchanger to measure inlet & outlet temperature of the coolant. The whole assembly was mounted on an iron frame which holds the pump and reservoir at the lower sections of the framed table, heat exchanger test section was placed on the table. Coolant was first pumped from the reservoir tank to the test section. Inlet temperature were measured as soon as it gets into the inlet. Then the coolant flows in to the heat exchanger tubes with defined cross sections and gets heated up. After that it is passed through the heat exchanger to retain its inlet temperature value. Again it is transported to the reservoir and the procedure is repeated for different flow rates. The analysis was carried out for various discharges, keeping heat flux as constant. Steady state, forced convection, turbulent flow conditions were maintained throughout the experiment. For each flow rates, steady state temperature readings were recorded.



Fig. 1 Experimental set up

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NOMENCLATURE

Q	=	Heat transfer rate in the direction from point 1 to 2.
U	=	Average overall coefficient of heat transfer ($\text{W/m}^2 \text{ C}$) ---- [5]
A	=	Area of surface through which heat is transferred (m^2)
f	=	Correlation factor
ΔT_{lm}	=	Logarithmic mean temperature difference: counter flow
T_{hi}	=	Hot water inlet, (T_1)
T_{ho}	=	Hot water outlet, (T_2)
T_{ci}	=	Cold water inlet, (T_3)
T_{co}	=	Cold water outlet (counter), (T_4)
Q_c	=	Heat transfer rate for cold stream
Q_h	=	Heat transfer rate for hot stream
U_{ri}	=	Overall heat transfer coefficient based upon A_i ($\pi d_i L$)
U_{ro}	=	Overall heat transfer coefficient based upon A_o ($\pi d_o L$)
A_i	=	Area of surface based on inner diameter of tube.
A_o	=	Area of surface based on outer diameter of tube.
d_i	=	Inner diameter of tube.
d_o	=	Outer diameter of tube

III.RESULTS AND DISCUSSION

In this work, an experimental study which comprises the heat transfer analysis of shell and tube heat exchanger cooled with water based coolants (Alumina nanofluids) is carried out. The study was conducted under turbulent, steady and forced flow condition. The important parameters of interest like log mean temperature difference, heat transfer rate, and effectiveness were calculated and compared using graphical representation.

1.Effect of flow rate on heat transfer rate

The variation of heat transfer rate for different flow rates as shown in the figure 2 below. It can be seen that as flow rate increases, heat transfer rate also increases. This may be due to the fact that as flow rate increases the convection rate from the coolant also increase, which intern increases the flow rate. It can also be observed that the rate of increase of heat transfer rate decreases as flow rate increases and finally becomes negligibly small. So it can be concluded that there is an upper limit for the flow rate above which the heat transfer rate will not increase. The heat transfer rate was more for nanofluids (red line) as compared to water (7, 8, 9, and 10).

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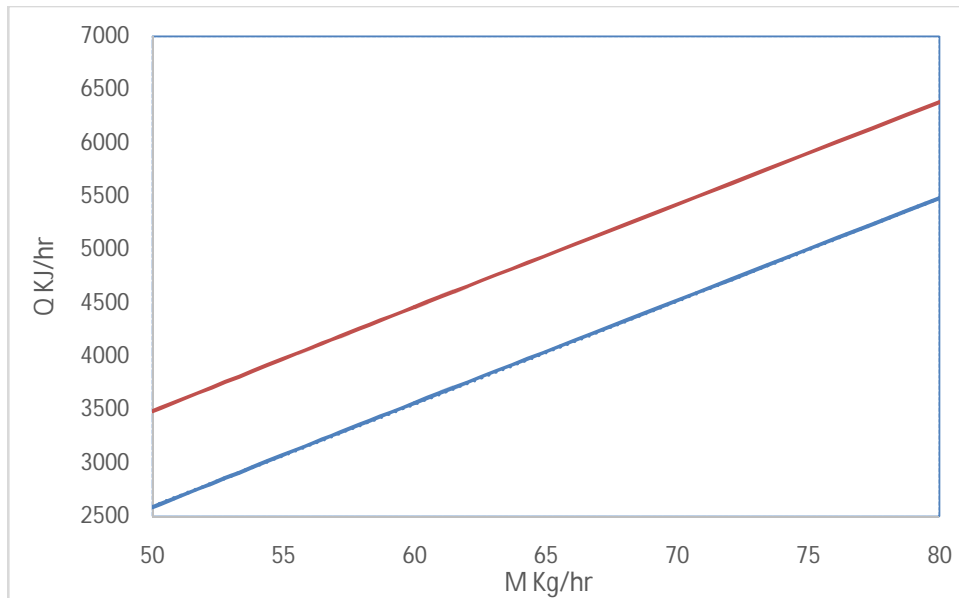


Fig. 2 Effect of flow rate on heat transfer rate

2. Effect of Mass Flow rate on Effectiveness of the exchanger

Figure 3 below shows variation of mass flow rate with Effectiveness of the exchanger. It can be seen that as flow rate increases, the effectiveness also increases. Viscosity and specific heat of the nanofluids may be the causes for these phenomena. For the shell side coolant, as the viscosity does not increase and specific heat is also higher, effectiveness increases with the increase of the shell side mass flow rate [11].

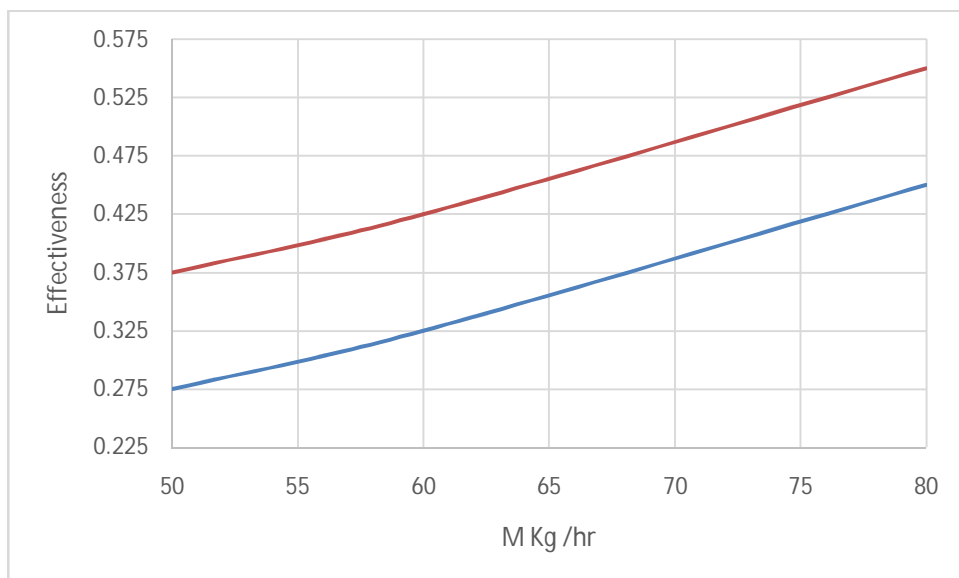


Fig. 3 Effect of mass Flow rate on Effectiveness of the exchanger

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4. Effect of Mass flow rate on LMTD for Water and Nanofluids

The below figure 4 shows the impact of Mass flow rate on Log mean temperature difference of the heat exchanger using both water and nanofluid as the coolants. It is very much clear, from this figure that as Mass flow rate increases, the Log mean temperature difference also increases which is quite obvious. The reason being increase in velocity of flowing fluid, which causes turbulence & increases the Log mean temperature difference.

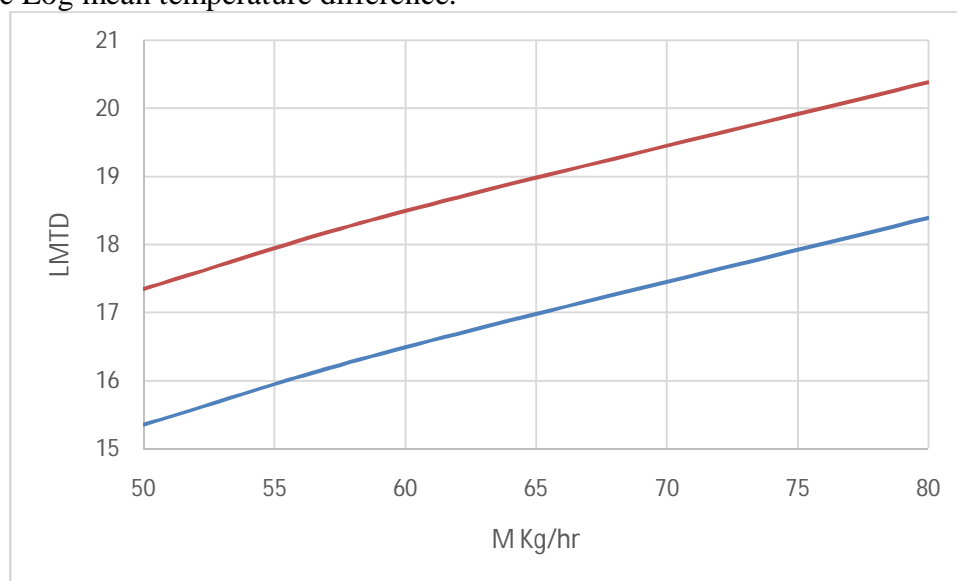


Fig. 4 Effect of Mass flow rate on LMTD for Water and Nanofluids

IV. CONCLUSION

An analysis was carried out in shell and tube heat exchanger using nanofluid and water as the coolants. Heat flux was kept constant, flow rate was varied. The experiment was conducted under steady state forced convection, turbulent flow conditions.

The following conclusion were drawn from the analysis

1. Heat transfer rate increases as flow rate in the heat exchanger increases for both the coolants used. But the heat transfer rate was more for nanofluids as compared to water. So it can be concluded that heat transfer rate does occur with the use of nanofluids.
2. It was also observed that, with the increase in the flow rate, an increase in effectiveness occurs for both the coolants. But the effectiveness had a slightly higher value for nanofluids as compared to water as a coolant.
3. With increase in mass flow rate, log mean temperature difference also increases. Again the increment is more for nanofluids as compared to water.

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