Enhancement of Thermal Efficiency of Heat Exchanger using Titanium – Oxide nanofluid

R. B. Manoram, P. Sricharana, B. Abinesh, M. Vallarasu, C. Sivasakthi

Abstract – Improvement of heat removal rate in heat exchanger using passive techniques is considered to be one of the most challenging task for engineers and scientist. In this study efficiency of the heat exchangers has been studied with TiO_2/ water based nanofluid. The thermal properties, physical properties and heat removal efficiency of heat exchanger with nano-fluid as working fluid was investigated. Nanoparticle concentration of about 0.1 and 0.3 vol% was used. It was detected that the thermal conducting property and viscous property of the nanofluid increased proportionally with volume percentage. With the increased heat, the thermal conducting property increased while the viscous property of the nanofluid decreased. The heat removal rate on both shell outlet and tube outlet was estimated for different mass flow rate. The experiment results showed that with increased volume percentage and flow rate, the heat transfer performance improved. A maximum enhancement of 34% was observed at 0.3 vol% and 6l/min. Though there is increase in heat transfer rate the pressure dropped and pumping requirement increase with volume concentration and flow rate.

Index Terms: Heat Exchanger, Heat Transfer, Nanofluid, Thermal Conductivity.

I. INTRODUCTION

Energy saving is considered to be one of the vital issue in twenty first century and most significant challenge in near future. More investigators are continuously trying to report the issue of energy saving. Energy saving is done by converting and conserving the energy source. To conserve energy various types of heat exchangers are used in various industrial areas like power plants, process industry, food engineering etc., Different technologies have been implemented to advance the efficiency of the heat exchanger. Most frequently used passive method of heat removal enhancement is addition of fins. Though fins improve the heat removal rate, increased weight and size of the heat exchanger were considered to be the disadvantage of using this technology. Enhancing thermal conducting property of the fluid is another passive method used widely to improve the performance of the heat exchanger. The thermal conducting property of the working fluid is increased by suspending nano particles. The fluid that carry solid nanoparticle is nanofluid and the term nanofluid was coined and introduced by Choi [1].

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Several research have been presented to show the use of nanofluid in the application of heat exchanger. Numerous studies were performed to proliferate the heat removal rate using nanofluid as an alternate to water which is most commonly used working fluid. The heat transfer co-efficient improved with a small set back of pressure drop [2]. Yang et al [3] studied the influence of graphite nanofluid on the effectiveness on horizontal tube heat exchanger. The study concludes that with increased volume concentration convective heat transfer coefficient increased. The study was performed under laminar flow region. The performance improvement was identified at high Reynolds number. Pantzali et al [4] performed both experimental and numerical exploration on heat removal enhancement using Titanium Oxide/ Water based nanofluid and enhancement of about 18% was observed at 4 vol% compared to base fluid. Wen and Ding [5] explored the efficiency of Al_2O_3 nanofluid as working fluid and found that the heat removal rate enhanced with increased flow rate and nanoparticle volume fraction in the base fluid. While Hajmohammadi and Toghraei (6) optimized geometrical and physical parameter of Double layered micro channel heat sink in conjunction with Al_2O_3 nanofluid. The influence of Aluminium oxide and Titanium oxide nanofluids on the heat transfer improvement in a heat Exchanger was experimentally investigated by Farajollahi et al [7]. The authors reported a maximum improvement of around 56% for both Aluminium oxide/water and titanium oxide nanofluid at the 2 Vol%. Recently Ali Akbar Abbasian Arani [8] optimized the performance of shell and tube heat exchanger (STHE) using combining the baffle and circular & triangular rib longitudinally placed along the tube. A maximum performance criterion of around 39% was observed over conventional baffles. Said Z et al [9] studied the heat transfer enhancement and life cycle assessment of STHE with copper oxide nanofluid. Overall heat transfer coefficient and convective heat transfer increased by 7 and 11.39% respectively. Also 6.81% reduction in area was estimated while using copper oxide nanofluid as working fluid.

Above researchers have contributed to the application of nanofluid in the heat exchanging system. However heat removal enhancement, pressure drop characteristics of heat exchanger system using nanofluid as a working fluid in needs to be investigated further. The objective of this article is to estimate the physical property of Titanium oxide nanofluid and its influence on the efficiency of heat transfer in shell and tube heat exchanger.

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II. NANOFLUID PREPARATION AND STABILITY

Titanium oxide nanofluid is prepared in two different ratios by dispersing Titanium oxide of particle size 10nm and 99.5% purity in distilled water. Scanning Electron Microscope (SEM) image of TiO_2 nanoparticle is shown in figure (1). The main drawback in using nanofluid is its tendency to agglomerate. To reduce the agglomeration surfactant was added and pH values of the nanofluid solution was adjusted. Sodium dodecyl Benzene sulfonate (SDBS) is used as surfactant. The volume concentration was chosen as 0.1 and 0.3%. Using Eq. (1) the amount of nanoparticle required for the preparation of nanofluid of 0.1 vol % and 0.3 vol% is estimated.

$$\text{Volume Concentration, } Ø(\%) = \left[\frac{\frac{W_{TiO2}}{\rho_{TiO2}}}{\frac{W_{TiO2}}{\rho_{TiO2}}+\frac{W_{Water}}{\rho_{water}}}\right] \qquad (1)$$

Where Ø is the volume concentration, $\rho_{TiO2} = 4230$ kg/m^3, $\rho_{water} = 998.5$ kg/m^3, W_{water} = 10 litres and W_{TiO2} - weight of the nanoparticle. Nanofluid is prepared by dispersing the the required quantities of 63.51 g (0.1 vol %) and 190.54 g (0.3 vol %) of TiO_2 nanoparticle in 10 liters of distilled water (DW). The surfactant (SDBS) of about 10% of the weight of the nanoparticle (6.3g and 19.05g) was added and sonicated using an ultrasonicator for 1 hr.

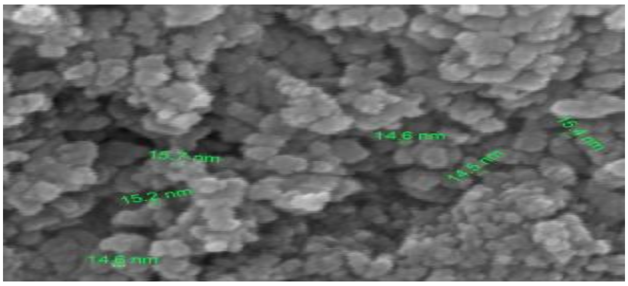

Fig 1 SEM picture of TiO_2nanoparticle

III. EXPERIMENTAL SET-UP

The studied experimental set-up is illustrated in figure 2 with details. The heated water is pumped inside the inner tube from hot water tank and nanofluid is pumped from nanofluid tank to the outer shell. Hot and nanofluid are kept constant at specified temperature by electric heater and cooling cycle respectively. Valves were used to control the flow while roto-meters were used to fix the flow rate at which water and nanofluid flow throughout the experiment. Thermocouples were fixed at the entry and departure of the test section to determine the fluid bulk temperature. The geometrical specification of the heat exchanger is provided in the table – 1

Factors	Details (in mm)
SHELL	
Outer dia	90
Thickness	10
Length	120
Material used	Stainless steel
TUBE	
Outer dia	13
Thickness	1
Material	Copper
Number of tubes	5

Table 1 Geometrical Description of Shell and Tube Heat Exchanger

IV. RESULTS AND DISCUSSION

A. Nanofluid Stability

Adding surfactant in the nanofluid is the widely used way to improve suspended particles' stability. Nano fluid's stability with and without the presence of surfactant was investigated. Surfactant was selected based on their ability to stablize the nanoparticle suspension without affecting the functionality of the nanofluid. SDBS was chosen as the surfactant. The results show that the performance of the nanofluid was better without the surfactant. The stability strength of the nanoparticle suspension in the base fluid is estimated with Zeta potential value with particle size. The zeta potential value with particle size is provide in the table 2.

Sample	Particle size	Zeta Potential
0.1 % (Without surfactant)	120 nm	31.6
0.1% (With surfactant)	100 nm	36.2

Table 2 Zeta Potential value

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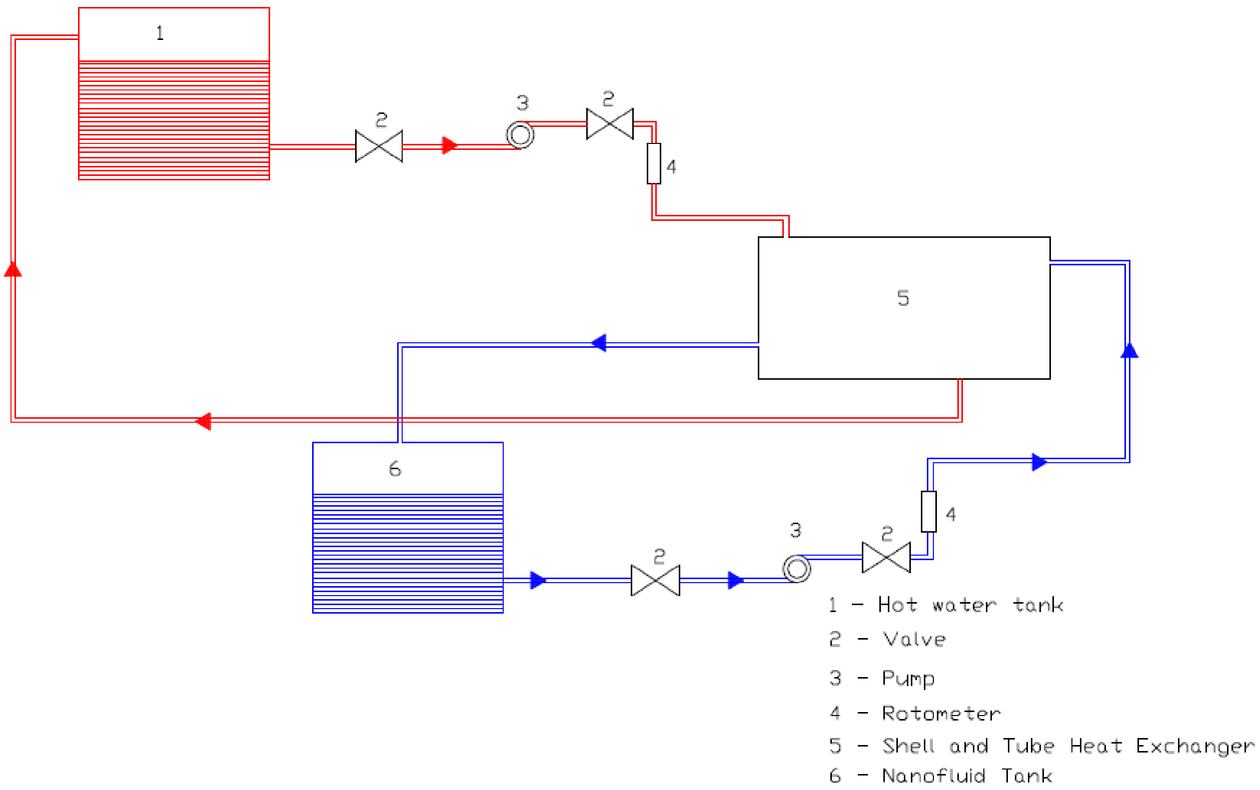

Fig 2 Schematic Diagram of the Experimental set - up

B. Physical property of the nanofluid

a. Thermal conductivity

Physical property parameter, mainly thermal conductivity and viscosity plays the pivotal role in the heat removal characteristics of the nanofluid. The thermal conducting property of TiO_2/DW nanofluid was measured at changed temperatures ranging from 25˚C to 60 ˚C. The influence of volume fraction on the thermal conducting property of the nanofluid is presented in fig 5. With the increase in volume percentage temperature conductivity of the nanofluid increased. At 55 ˚C conductivity improved by 10.83% for 0.1 vol% and 16.62 % for 0.3 vol% compared to that of DW.

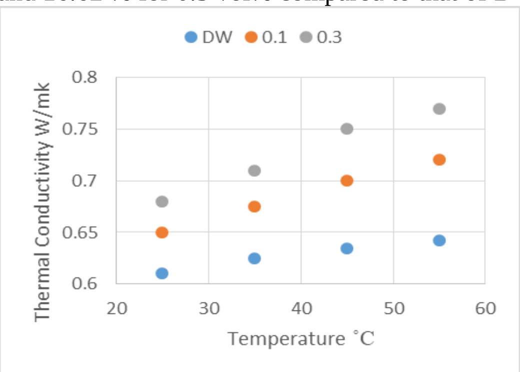

Fig 5 Thermal Conductivity of Nanofluid of Different Concentration

b. Viscosity

Viscosity of TiO_2/DW based nanofluid for two different volume fraction was estimated at changed temperatures. Figure 6 shows the viscous property of the distilled water and nanofluid for 0.1 and 0.3 vol% for different temperatures. The results shows that with increased volume fraction the viscous property of the nanofluid increased. At 25 ˚C viscosity of nanofluid of 0.1 & 0.3 vol% increased 8.3 % & 18% respectively compared to that of distilled water. At 60 ˚C viscosity increased by 21.31 % and 11.11% for 0.1 & 0.3 vol% respectively. Results also showed that increasing temperature decreased the viscosity of the nanofluid. For 0.3 vol% viscosity decreased by 43% when the temperature reduced.

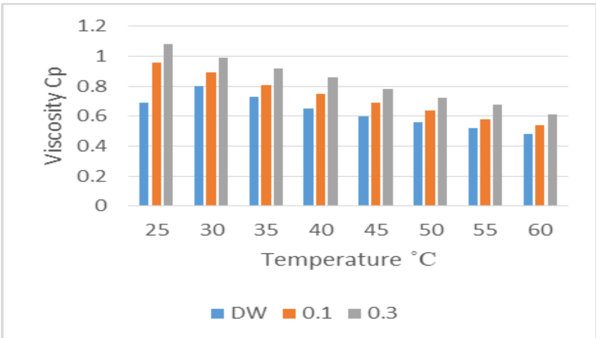

Fig 6 Viscosity of Nanofluid (0.1 and 0.3 vol% for different temperature

C. Influence of Nanoparticle

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concentration on thermal performance

The study result shows that heat removal coefficient increases proportionally with volume fraction as shown in figure 7. This is attributed to the improved conductivity with higher volume fraction. The mass flow rate of the hot water was kept constant at 6 l/min. About 16% and 34.4% enhancement was found for 0.1 and 0.3 vol% respectively. Therefore heat exchanger area reduction shall be achieved with 0.3 vol%. Similarly maximum heat transfer enhancement of about 6 % was observed at 0.3 Vol%. Fig 8 shows the heat transfer enhancement for different volume fraction.

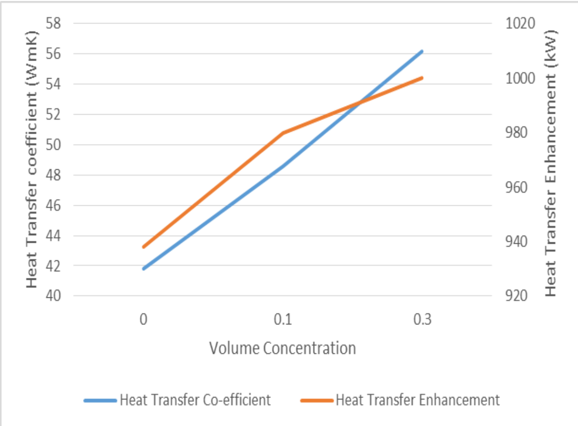

Fig 7. Thermal Performance at different volume fraction

D. Influence of mass flow rate on the thermal performance

The study revealed that with increasing flow rate, the performance of the heat exchanger increases (Fig 8). This is attributed to the higher number of random and bulk motion of the nanofluid molecule. An enhancement of about 16.9% and 12.4 % was observed for heat removal coefficient and heat removal enhancement respectively when the flow rate increased.

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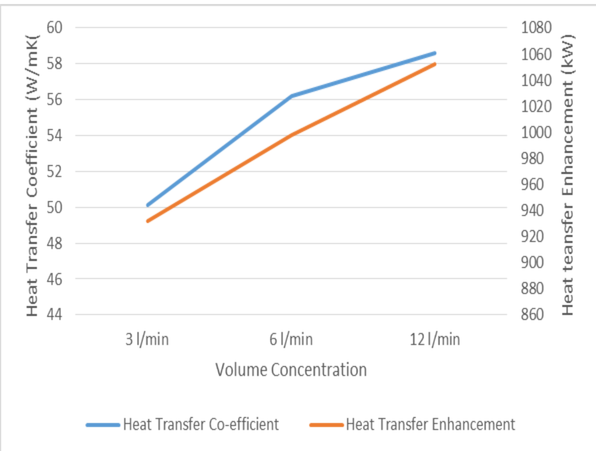

Fig 8. Thermal performance at different mass flow rate

E. Influence of flow rate on the fluid flow characteristics

Pressure drop characteristics were considered to be one of the influential parameter in heat exchangers. Fig. 9 shows the pressure drop characteristics for heat exchanger at various flow rate keeping the volume fraction as constant (0.3%). It is to be noted that pumping power and pressure drop increases proportionally with flow rate. The random motion of fluid molecules creates the pressure drop and hence the power required to pump the fluid goes higher. The pressure drop increased by 9.8 % from 3 l/min to 12 l/min while the corresponding pumping power increased by 4.4%.

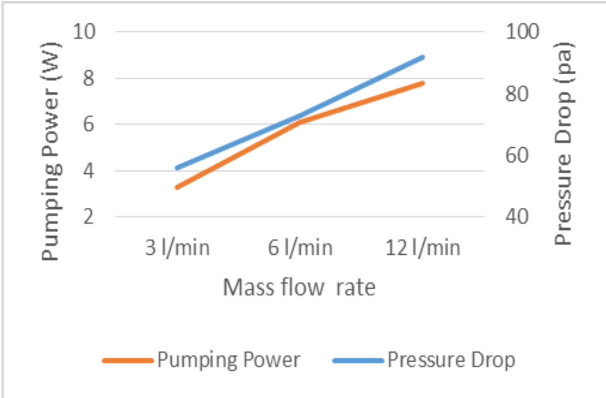

Fig 9. Fluid Flow Characteristics at different mass flow rate

I. CONCLUSION:

- SDBS surfactant was used to stabilize the nanoparticle suspension. Though the surfactant improved the stability it decreased the physical properties of the fluid.
- Thermal conducting property of the nanofluid increased proportionally with vol % and temperature.
- Viscous property of the nanofluid increased proportionally with vol % and decreased disproportionately with temperature.
- Maximum heat removal enhancement of about 6% was observed with 0. 3Vol % of TiO_2 / water based nanofluid at 6 l/min
- Though the pressure drop is higher, better heat removal enhancement of TiO_2 / water based nanofluid makes it a better choice as a working fluid.
- Thus the experimental results conclude that titanium oxide can be used as working fluid which could result in size and area reduction of heat exchanger.

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