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Experimental study of heat transfer enhancement using nanofluid in double tube heat exchanger

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Abstract

This study aims at experimentally investigating the effect of Al_2O_3 /water nanofluids on the heat transfer enhancement inside the double tube heat exchanger at variable inlet temperature. Al_2O_3 nanoparticle with concentration of 0.25% and 0.5% by volume concentration has been used at different inlet temperature. The experimental setup consisted of double tube heat exchanger with nanofluids on the cold side was used in turbulent regime with Reynolds number ranging from 20000 to 60000. Results from the study shows that the heat transfer increases with the increase in temperature and volume concentration of nano-particles. Significant improvement over the water is seen with maximum Nusselt number increase up to 24.5% at 50℃ inlet temperature.

Keywords: nanofluid; heat transfer enhancement; double tube heat exchanger; Nusselt number; volume concentration

1. Introduction

It is well known fact that solids have orders of magnitude higher thermal conductivity at room temperature than those of fluids. Thermal conductivity of copper is 700 times greater than that of water at room temperature. So it is well understood that by dispersing these solid particles in fluid thermal conductivity of fluid can be expected to increase significantly. Furthermore compared with microsize particles, nanoparticles have much larger surface area. The surface to volume ration is much higher thus enhances the thermal conductivity at much higher scale.

Measurement of thermal conductivity started with oxide nanoparticles (Masuda et al[1],a Lee [2]) but nanofluids did not gain much attention until Eastman et al [3]showed for the first time that the copper nanoparticles have more significant effect compared with oxide based nanofluids. Many different nanomaterial particles are used in making nanofluids such as Al_2O_3, CuO, TiO_2, Cu, Fe and now even carbon nanotubes and graphenes based structures.

Over the previous decade many experimental studied have been conducted to investigate the possible effect and underlying mechanism of increasing thermal conductivity in convective heat transfer due to the use of nanoparticles in different base fluids.

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Pak and Cho[4] investigated Al_2O_3 and TiO_2 nanoparticles having average size of 30nm in their studies to find out that Nu is 30% larger than base fluid and higher than predicted by Dittus Boelter equation. Li and Xuan [5] conducted there experiment using Cu nanoparticles with diameter less then 100nm to investigate the effect of nanoparticles in turbulent regime heat transfer. They showed that average increase of Nu is much larger than predicted by DB equation. Wen and Ding[6] used Al_2O_3 nanoparticles in laminar flow in a tube to study the effect of convective heat transfer with average particle size of 30 to 50 nm. They found out that Nu is greater than 4.36 for fully developed flow with constant wall heat flux. Ding [7] again in his study showed that using carbon nanotubes with rod like structure having average size greater than 100nm has a profound effect on convective heat transfer. Nu increase by more than 300% at Re =8000 that is in laminar flow regime. Heris et al[8] used 20nm size Al_2O_3 nanoparticles in water to experimentally investigate the convective heat transfer in laminar flow. His study showed that Nu measured is larger than that of pure water. Williams [9] experimentally studied the effect of increasing heat transfer due to use of Al_2O_3 and ZrO_2 nanoparticles of size 46nm and 60nm respectively. In his studies he found no significant improvement in heat transfer and concluded that any traditional correlation can predict nanofluids heat transfer. Kolade et al [10] used 40nm to 50nm Al_2O_3 nanoparticles in his studies to investigate the effect of heat transfer and found an apparent increase in Nu compared to basefluid. Duangthongsuk et al [11] using 21nnm size TiO_2 nanoparticles in turbulent regime showed that nanofluids have significant improvement in heat transfer than basefluid. Rea et al[12] conducted experiment using 50nm Al_2O_3 and ZrO_3 nanopaticles in water to show an increase of 27% compared to water. Jung et al [13] conducted experimental study in rectangular microchannel using Al_2O_3 nanoparticles of average diameter of 170nm. Results showed that with increasing Reynolds number Nu increases significantly by using nanofluids over basefluid. Haris et al[14] using spherical Al_2O_3 nanoparticles in laminar flow regime experimentally showed that Nu increases with increasing Peclet number and volume fraction. Use of nanofluids is still lacking in real life applications due to contradictory results amongst researchers and lack of theoretical understanding. There are few experimental studies about the effect of nanofluids in double tube heat exchanger at very low volume concentration and especially the effect at constant wall temperature which occurs during the condensation of steam. Even few researchers have mentioned the effect of variation in temperature on nanofluids heat transfer while conducting the experiment using double tube heat exchanger. In this paper, double tube heat exchanger are used to develop the experiment, including the setup of heat exchanger, preparation of measurement techniques, calibration of equipments and collection of data. Governing equations are discussed which are being used to calculate the data from experiment. All the results from the experiment are calculated and analyzed to show by using nanfluid how significant change in heat transfer can be achieved. Convective heat transfer coefficient and Nusselt number are used as main indicator to prove the results. The research method as well as the results provide significant references for the application of nanofluid in heat exchangers.

Nomenclature

Roman symbols

k	thermal conductivity ($Wm^{-1}K^{-1}$)
c_p	specific heat ($Jkg^{-1}K^{-1}$)
T	temperature (K)
Q	heat transfer rate(W/m^2)
D	diameter (m)
Re	Reynolds number
Pr	Prandtl number
A	area (m^2)
ΔT_{lm}	logarithmic mean temperature (K)
m	mass flow rate (kgs^{-1})
t	thickness (m)
l	length (m)

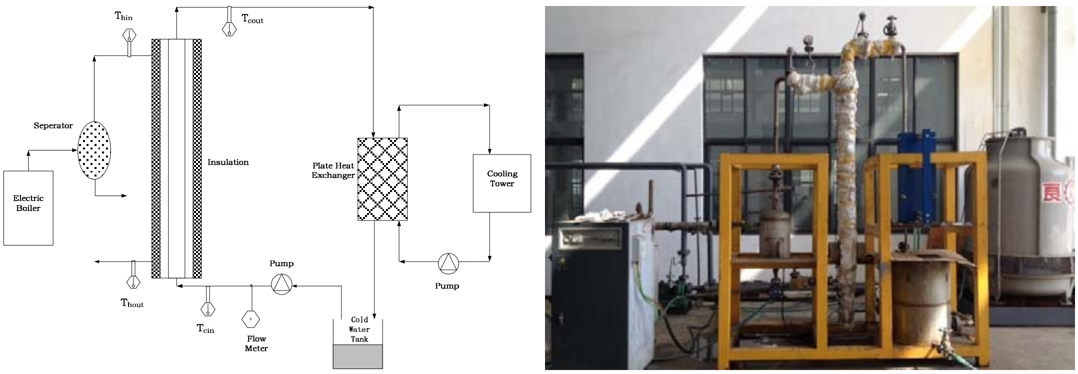
Greek letters

ρ	density (kgm^{-3})
μ	dynamics viscosity (Pa.s)
φ	volume concentration (%)

δ	difference
Subscripts	
f	fluid
nf	nanofluid
c	cold side
p	particle
w	wall
i	inlet
o	outlet
v	vapor

2. Description of the experimental system

The experimental subsystem consist of three subsystems: heating subsystem, double tube heat exchanger and cooling subsystem. Fig. 1 give schematics and actual experimental setup at sight respectively. Hot side system is to produce superheat steam that will be eventually separated from the condensate using separator. The steam is then passes through the outer tube of double tube heat exchanger. Cooling system which comprises of plate heat exchanger and cooling tower is then use to cool down hot water inside liquid which in this case is nanofluids to maintain it inlet temperature in the loop. Among them, the double tube heat exchangers core components of the system as a whole composed of 2100mm length, 100mm outside diameter tube and 38mm inner tube.



(a) Schematic (b) Experimental Setup

Fig. 1 Configurations of the experimental platform

3. **Governing Equations for Experiment**

Calculation of heat load Q. Cold side heat transfer rate can be obtained as:

$$Q = Gc_p(T_{co} - T_{ci}) \tag{1}$$

where G is the mass flow rate, cold side heat capacity at constant pressure c_p, cold side inlet temperature T_{ci}, cold sid e outlet temperature of T_{co}. Adoption of heat load calculation overall heat transfer coefficient K

$$K = \frac{1.03Q}{A\Delta T_m} = \frac{1.03Gc_p(T_{co} - T_{ci})}{A\Delta T_m} \tag{2}$$

$$A = \pi d_i l \tag{3}$$

where: d_i is the inside tube diameter, A the heat exchange area. The log mean temperature difference ΔT_m can be expressed as:

$$\Delta T_m = \frac{T_{\max} - T_{\min}}{\ln \dfrac{T_{\max}}{T_{\min}}} \tag{4}$$

$$T_{\max} = T_{hi} - T_{co}$$

$$T_{\min} = T_{ho} - T_{ci}$$

where hot side inlet temperature, outlet temperature are T_{hi}, T_{ho}, respectively. Convective heat transfer coefficient of steam h_V can be calculated as:

$$h_v = 1.13\left[\frac{g\rho^2\lambda^2 r}{\eta\left(t_s - t_w\right)l}\right]^{\frac{1}{4}} \tag{5}$$

$$r' = r + 0.68C_p\left(t_s - t_w\right) \tag{6}$$

Furthermore, cold side convective heat transfer coefficient of Nanofluid h_W, overall heat transfer coefficient of conv ective heat transfer coefficient, heat and fluid under the relationship between thermal conductivity and thickness can be expressed as:

$$K = \frac{1}{\dfrac{1}{h_w} + \dfrac{\delta_t}{\lambda_t}\cdot\dfrac{d_i}{d_m} + \dfrac{1}{h_v}\cdot\dfrac{d_i}{d_o}} \tag{7}$$

$$h_w = \frac{1}{\dfrac{1}{K} - \dfrac{\delta_t}{\lambda_t}\cdot\dfrac{d_i}{d_m} - \dfrac{1}{h_v}\cdot\dfrac{d_i}{d_o}} \tag{8}$$

$$Nu = \frac{h_w d}{\lambda} \tag{9}$$

where δ_t is the tube thickness, λ_t the heat conductivity, d_i, d_o and d_m inside, outside and mean diameter. Dittus-Boelte r correlation can be calculated by using Nusselt number Reynolds Number Re and Prandtl number Pr.

$$\mathrm{Re} = \frac{\rho u d}{\mu} \tag{10}$$

$$\mathrm{Pr} = \frac{\mu C_p}{\lambda} \tag{11}$$

$$Nu = 0.023\,\mathrm{Re}^{0.8}\,\mathrm{Pr}^{0.4} \tag{12}$$

4. Results and discussion

4.1. Case of distilled water

Initially experiment was conducted using distilled water as a working fluid on the cold side. This is to establish the accuracy of the measurement for comparison while using nanofluids in place of water. Fig. 2 shows the comparison between the established correlation given by Gnielinski [15] and experimental result. The maximum deviation found is to be 13 % which is in acceptable limits and shows that methodology used to calculate data from experiment can be used to calculate nanofluids heat transfer.

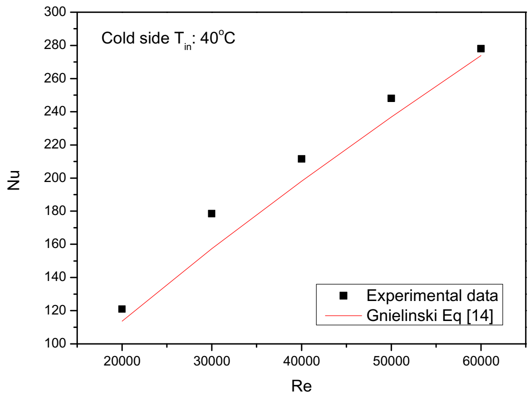
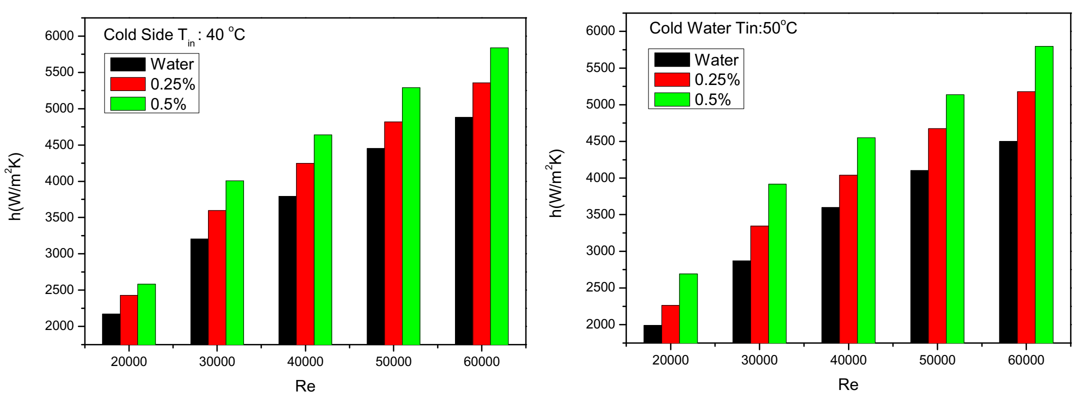


Fig 2. Comparison between experimental and numerical result from Gnielinski equation

4.2. Effect on Convective heat transfer coefficient

The present study was conducted using different concentration of Al_2O_3 that includes 0.25% and 0.5% by volume concentration with Reynolds numbers varying between 20000 and 60000. As shown in Fig. 4, heat transfer coefficient increases with the increasing Reynolds number because of turbulence flow breaking up the boundary layer resistance effect. It can be observed that with increasing concentration of nanoparticles in the base fluid, convective heat transfer coefficient is also increasing. Fig. 3(a) shows the comparative study of convective heat transfer between different concentrations of nanoparticles at inlet temperature of 40oC. At higher concentration convective heat transfer shows much significant enhancement compared with low concentration. Maximum increase in convective heat transfer coefficient has been calculated of about 9.7% and 19.6% for 0.25% and 0.5% of volume concentration respectively. This increased heat transfer effect can be explained by enhancement of thermal conductivity due to addition of nanoparticles.

In Fig. 3(b) the results are given of experiment when cold side inlet temperature increased to 50℃. With the increase in inlet temperature thermally conductivity of nanoparticles increased thus compared to 40℃ inlet temperature, heat transfer coefficient shows significant improvement at higher inlet temperature. The maximum rise can be seen of about 15% and 29% for 0.25% and 0.5% respectively. An important characteristic of nanofluids is its strong dependency of thermal conductivity on temperature as shown by study of Das et el [16].Comparing the results from Fig 4a and 4b it can be estimated that overall maximum change in heat transfer due to change in temperature was increased by 5.3% and 9.4% for 0.25% and 0.5% by volume concentration respectively. Due to the increase in inlet temperature the convective heat transfer showed marked increase which can also be seen in previous studies as by Reza et al [17] which shows the same trend in increases of nanofluids heat transfer capability with increasing temperature while the nanoparticle concentration remain constant.



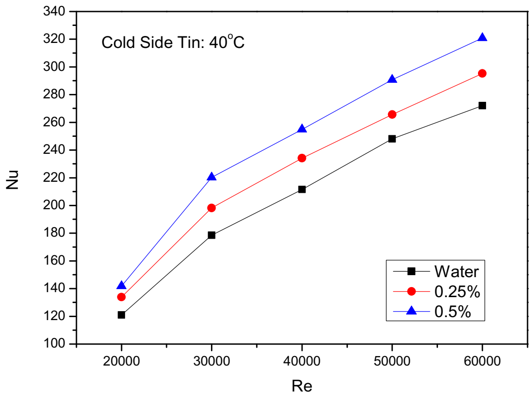
(a) (b)

Fig 3. Convective heat transfer coefficient a)at 40℃ b) at 50℃

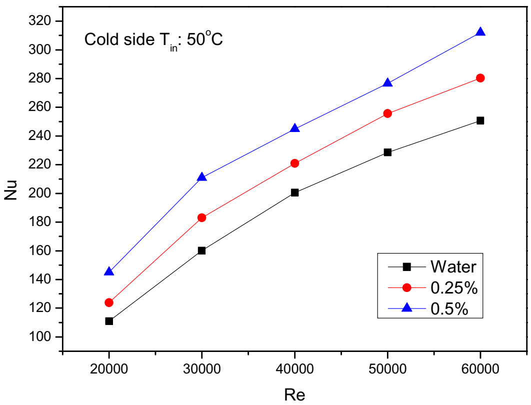
4.3. Effect on Nusselt Number

Fig. 4(a) shows experimental results of Nusselt number at inlet temperature of 40℃. It can be seen that with the increase in concentration of nanofluids the Nusselt number increases as well. Higher Reynolds number shows much prominent effect on heat transfer than low Reynolds number. At the highest Reynolds number of 6000 maximum increase in Nusselt number was observed of 8.5% and 17% for 0.25% and 0.5% of volume fraction respectively.

Fig. 4(b)shows the results of experiment as the inlet temperature of cold water is changed to 50℃. It can be seen that Nusselt number of water is decreased compared to that at 40℃. This effect can be explained by change in thermophysical properties of water as the temperature increases. When nanoparticles are added to cold side the heat transfer characteristics of water increased. It is observed that with addition of same volume concentration as at 40℃ the heat transfer shows much higher enhancement at higher temperature of 50℃ than at lower temperature. Nusselt number increases with the increase in Reynolds number with highest heat transfer and so the Nusselt number is observed to be 11.7% and 24.5% at 0.25% and 0.5% volume fraction respectively. Number of factors purposed by different researcher can explain this enhancement. The possible mechanism that aids the unusual thermal conductivity increase includes particle particle collision, Brownian motion, ballistic nature of heat conduction at nanoscale and nanoparticle clustering. Heat transfer at boundary layer increase significantly with the addition of nanoparticles as constant bombarding of nanosize particle transfer much of the heat from the boundary to the main stream fluid thus increasing heat transfer effect and Nusselt number.



(a)



(b)

Fig. 4 Nusselt number change a) at 40℃ b) at 50 ℃

5. Summary

In this paper, nanofluid is used to achieve the heat transfer enhancement in the double tube heat exchanger. The experiment was run using distilled water to establish the accuracy of the experiment. Results from the water as a coolant has been validated by established Dittus and Boelter equation. Once it has been checked that the data accuracy is within the limited error range nanofluid is added as a coolant on the coldside. The concentration of nanofluids was varied at 0.25% and 0.5% by volume fraction at variable inlet temperature. Results from the experiment show significant improvement over the water where maximum Nusselt number rising up to 24.5%. Furthermore it was seen that by increasing inlet temperature heat transfer of nanofluids increases which shows nanofluids dependency on temperature.

Acknowledgements

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