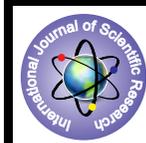


Heat Transfer Analysis of Shell and Tube Heat Exchanger Using Silicon Nitride-Water Nano Fluid



Engineering

KEYWORDS : Silicon nitride; Nano fluid; Transport properties; Thermal conductivity; Heat transfer coefficient.

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ABSTRACT

Heat transfer fluid have inherently low thermal conductivity that greatly limits the heat exchanger efficiency. Many research activities are carried out to the thermal transport properties of the fluid by adding more thermally conductive solid into liquid. Liquid dispersions of Nano particle, which has been termed "Nano fluid", exhibit substantially higher thermal conductivities than those of corresponding base fluid. In this work new Nano fluid system has been developed by using silicon nitride Nano particle to synthesize Nano fluid in a shell and tube heat exchanger. The thermal transport properties of Nano fluid, including thermal conductivity, viscosity, heat capacity and heat transfer coefficient in convective environment are characterized and modelled. Since heat capacity of heat transfer fluid is one of the major thermal transport properties, it is described with help of the Einstein-Bachelor model. The result shows that Nano fluid possess improved thermal transport properties and it has been experientially proved that Nano fluids have the potential to use as next generation advanced heat transfer fluid.

Introduction

Nano fluid are dilute liquid suspensions of nanoparticle with at least one of their principal dimensions smaller than 100 nm. From pervious investigation, Nano fluid have been found to possess enhanced thermo physical properties such as thermal conductivity, thermal diffusivity, viscosity and convective heat transfer co efficient compared to those of base fluid like oil or water.

It can be seen that Nano fluids clearly exhibit enhanced thermal conductivity, which goes up with increasing volumetric fraction of nanoparticle. Thermal conductivity effects some important factors such as a particle size and shapes, clustering of nanoparticle, temperature of fluid, and dissociation of surfactant on the effective thermal conductivity of Nano fluid have not been studied adequately. Recently most development models only include one or two postulated mechanisms of Nano fluids heat transfer. For instant, there has not been much fundamental work reported on the determination of the effective thermal diffusivity of Nano fluid nor heat transfer coefficient for Nano fluid in natural convection

Effects of some parameters on thermal conductivity of Nano fluids

Experimental studies show that thermal conductivity of Nano fluids depends on many factors such as particle volume fraction, particle material, particle size, particle shape, base fluid material and temperature. Amount and types of additives and the acidity of the Nano fluid were also shown to be effective in the thermal conductivity enhancement.

Particle Volume Fraction

Particle volume fraction is a parameter that is investigated in almost all of the experimental studies and the results are usually in agreement qualitatively. Most of the researchers report increasing thermal conductivity with increasing particle volume fraction and the relation found is usually linear. However, there are also some studies which indicate nonlinear behaviour. According to the same authors, such nonlinear relation is an indication of fraction is very small, nanotubes interact with each other due to the very high particle concentration (1011 particles/cm³).

Particle Material

Most of the studies show that the particle material is an important parameter that affects the thermal conductivity of Nano fluids. At first glance, it might be thought that the difference in the thermal conductivities of particle materials is the reason of this effect. However, studies show that particle type may affect the thermal conductivity of Nano fluids in other ways. For ex-

ample, Lee et al. considered the thermal conductivity of Nano fluids with Al₂O₃ and CuO nanoparticles and they found that Nano fluids with CuO nanoparticles showed better enhancement when compared to the Nano fluids prepared using Al₂O₃ nanoparticles. Therefore, thermal conductivity of particle material may not be dominant parameter that determines the thermal conductivity of the Nano fluid. Effect of particle materials is much more pronounced when carbon nanotubes are used for the preparation of Nano fluids. Some authors noted that such an anomalous enhancement might be due to the liquid Nano layers forming around the nanotubes. On the other hand, the fact that heat is transported ballistic ally inside the nanotubes improves the conduction of heat in the tubes, but the effect of this factor is not dominant according to the authors.

Particle Size

Particle size is another important parameter of thermal conductivity of Nano fluids. It is possible to produce nanoparticles of various sizes, generally ranging between 5 and 100nm. Eastman et al. concluded that the size of the nanoparticles is an important factor that affects the thermal conductivity enhancement, which is contrary to the predictions of conventional models such as Hamilton and Crosser model, which does not take the effect of particle size on thermal conductivity into account.

The general trend in experimental data is that the thermal conductivity of Nano fluids increases with decreasing particle size. The trend is theoretically supported by two mechanisms of thermal conductivity enhancement; Brownian motion of nanoparticles and liquid layering around nanoparticles. However, there is also a significant amount of contradictory data in the literature that indicate decreasing thermal conductivity with decreasing particle size. In fact, for the case of Nano fluids with Al₂O₃ Nano particles, such results are more common than the results showing increasing thermal conductivity with decreasing particle size.

Particle shape

There are mainly two particle shapes used in Nano fluid research; spherical and cylindrical. Cylindrical particles are usually have a large length-to-diameter ratio. Two types of nanoparticles were used by Xie et al., for the preparation of Nano fluids; spherical particles with 26nm average diameter and cylindrical with 600nm average diameter. It was found that 4.2 vol. % water based Nano fluid with spherical particles had a thermal conductivity enhancement of 15.8%, whereas 4 vol. % Nano fluid with cylindrical particles had a thermal conductivity enhancement of 22.9%. In addition to these experimental results, the fact the Nano fluids with carbon nanotubes (which are cylindrical in shape) generally show greater thermal conductivity enhancement than Nano fluids with spherical particles provide higher

thermal conductivity enhancement than spherical particles. One of the possible reasons of this is the rapid heat transport along relatively larger distances in cylindrical particles since they have lengths on the order of micrometres.

However, it should be noted that Nano fluids with cylindrical particles usually have much larger viscosities than those with spherical nanoparticles. As a result, the associated increase in pumping power is large and this reduces the feasibility of usage of Nano fluids with cylindrical particles.

Particle material and Base fluid

Many different particle materials are used for Nano fluid preparation Al_2O_3 , CuO, TiO_2 , SiC, TiC, Ag, Au, Cu and Fe nanoparticles are frequently used in Nano fluid research. Carbon nanotubes are also utilized due to their extremely high thermal conductivity in the longitudinal (axial) direction.

Base fluids mostly used in the preparation of Nano fluids are the common working fluids of heat transfer applications; such as, water, ethylene glycol and engine oil. According to the conventional thermal conductivity models such as the Maxwell model, as the base fluid thermal conductivity of a mixture decreases, the thermal conductivity ratio (thermal conductivity of Nano fluid) divided by the thermal conductivity of base fluid. It is seen that poor conductive fluid serve best then highly conductive ones. Hence water is generally is avoided. When it comes to Nano fluids, the situation is even more complicated due to the fact that the viscosity of the base fluid affects the Brownian motion of nanoparticles and that in turn affects the thermal conductivity of the Nano fluid.

Temperature

In conventional suspensions of solid particles (with sizes on the order of millimetres or micrometres) in liquids, thermal conductivity of the mixture depends on temperature only due to the dependence of thermal conductivity of base liquid and solid particles on temperature. However, in case of Nano fluids, change of temperature affects the Brownian motion of nanoparticles and clustering of nanoparticles, which results in dramatic changes of thermal conductivity of Nano fluids with temperature.

Effect of Acidity (pH)

The number of studies regarding the pH value on the effect of fluid acidity on the thermal conductivity enhancement of Nano fluids is limited when compared to the studies regarding the other parameters. A significant decrease in thermal conductivity ratio with increasing pH values as report literature. It was also observed that the rate of change of thermal conductivity with particle volume fraction was dependent on pH value. Thermal conductivity enhancement of 5 vol % Al_2O_3 /water Nano fluid was 23% when pH is equal to 2.0 and it became 19% when pH is equal to 11.5. The authors related the dependence of thermal conductivity on pH to the fact that as the difference between the electric points is Al_2O_3 nanoparticles and pH value of the solution increases, mobility of nanoparticles, which improve the micro-convection effect. It is obtained optimum values of pH (approximately 8.0 for Al_2O_3 / water and 9.5 for CuO/water Nano fluids) for maximum thermal conductivity enhancement. At the optimum value of pH, surface charge of nanoparticle increases, which creates repulsive forces between nanoparticles. As a result of this effect, severe clustering of nanoparticles is prevented (excessive clustering may result in sedimentation, which decreases thermal conductivity enhancement).

Mechanism of heat transfer improvement.

Apart from the basic reason of improvement in thermal conductivity in Nano fluids, the suspension of Nano particles alters the flow behaviours in general. Following section describes several of the proposed mechanisms

Enhancement of heat transfer by improvement of thermal conductivity.

Liquid molecules close to a solid surface are known to form layered structure. The layered molecules are in an intermedi-

ate physical state between a solid and bulk liquid. With these solid like liquid layer, the Nano fluid structure consist of a solid Nano particle, solid-like liquid layer, and bulk liquid so it key to enhancing thermal conductivity.

Microscopically, the forced heat transfer coefficient, h with representing local thickness of thermal boundary layer and k_f the local effective thermal conductivity of Nano fluids adjacent to wall surface. The simple expression indicate that either an increasing in k_f and decrease both, can result in an increase of conductivity of heat transfer coefficient. As Nano fluids have a higher thermal conductivity in compare in base fluid, simple expression is partially explain the enhanced convective heat transfer coefficient. The expression however, cannot provide an adequate explanation of experimental observation that, in some cases the convective heat transfer coefficient enhancement is much higher than the thermal conductivity enhancements, while in other cases, there is no convective heat transfer enhancement despite considerable thermal conduction enhancement. Effect of Brownian motion:

It is a seemingly random movement of particles suspended in a liquid or gas and to collisions with base fluid molecules, which makes the particles under goes random-walk motion. Thus, the Brownian motion intensified with an increasing in temperature as per the kinetic theory of particles.

Some researchers, have suggested that potential mechanism for enhancement of thermal conductivity is the transfer of energy due to the collision of higher temperature particles with lower one. Effectiveness of Brownian motion decreases with an increases in the bulk viscosity.

Thermophoresis:

Thermophoresis or the sort effect is a phenomenon observed when a mixture of two or more type of motile particle is subjected to the force of temperature gradient. The phenomenon is most significant in a natural convection process, where the flow is driven by buoyancy and temperature. The particle travels in the direction of decreasing temperature and the process of heat transfer increase with a decreases in the bulk density.

Intensification of turbulence

Xuan and li proposed that the enhancement could also come from intensification of turbulence due to the presence of the nanoparticle. However, pressure drop measurements by xuan and Li, pak and choi clearly shows that turbulent friction factor in their Nano fluid can be very well predicted by the traditional friction factor correlation for pure fluid, if the measured Nano fluid viscosity is used. This suggest that beyond the obvious viscosity effect, turbulence is not affected by a compression of the time and length scales for the nanoparticle and the turbulent eddies.

Clustering of Nano particles:

Nano particle are known to form cluster. These cluster can be handled by using fractal theory. This phenomenon is illustrate schematically in below.

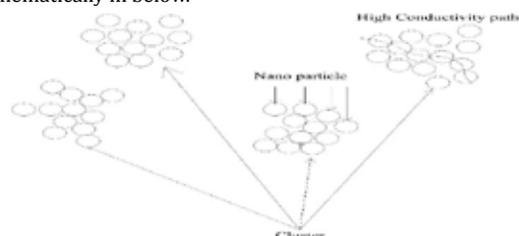


Figure 1: cluster of nanoparticle

It was shown that the effective thermal conductivity increases with increases the clusters size. However, as particle volume of fraction increased, the Nano fluid with cluster showed relatively smaller thermal conductivity enhancement. When it's come interfacial resistance, it was found that interfacial resistance decreases the enhancement of thermal conductivity, but this decreases dissimilar for Nano fluid for large cluster.

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Liquid layering around nanoparticle

A recent study shows that liquid molecules form layered structure around the solid surface and it is expected that those Nano layer having large efficient thermal conductivity than the liquid matrix. As a result of this observation the layered structure that form around nanoparticle are proposed to be responsible for the thermal conductivity enhancement of Nano fluid. This phenomenon is illustrated schematically.

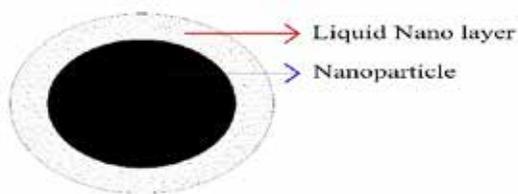


Figure 2: liquid layering of nanoparticle

The fact that there is no experimental data regarding the thickness and thermal conductivity of these Nano layer is an important drawback of the proposed mechanism. Some researcher developed a theoretical model by considering liquid layering around the nanoparticle and illustrate the prediction of their model by just assuming some value for thermal conductivity and thickness of the Nano layer.

Ballistic phonon transport in nanoparticle:

In a particle with a diameter smaller than 35nm heat transport is not diffusive, but heat transported ballistically. Although this fact prevent the application of conventional theories for the modelling of thermal conductivity of Nano fluid noted that ballistic heat transport still not explain the anomalous thermal conductivity enhancement, because temperature inside the nanoparticle near constant and this fact does not depend on whether heat is transported by diffusion. Therefore the boundary consideration for the base fluid are the same in both cases, and this result is identical thermal conductivity value for the Nano fluid. In other hand indicated that ballistic heat transport can create a significant effect on thermal conductivity of Nano fluid if it enables efficient heat transport between nanoparticles.

Near field radiation:

The effect of near field of radiation on heat transport between two nanoparticles. Problems created by utilization molecule dynamic simulation and found when distance between the nanoparticles is smaller than the diameter of the particles, the heat conductance is two or three order of magnitudes higher than the heat conductance between two particles that are in contact. This finding can be considered as a heat transfer enhancement mechanism for Nano fluid since the separation between nanoparticles can be very small in Nano fluid with nanoparticle smaller than 10 nm. Furthermore, Brownian motion of nanoparticles can also improve that mechanism since the distance between nanoparticle changer rapidly due to the random motion.

EXPERIMENTAL SETUP:

TABLE-0 Silicon Nitride Nanoparticle Properties

Appearance	white powder
Purity	99%
Average particle	size <50 nm
Crystal phase	Amorphous

Specific Surface Area	75m2/g
Bulk density	0.05g/cm3
Hardness	9-9.5
Melting point	1900 °C (under pressure)
thermal conductivity	30 W / (m · K)
Solubility	Dissolve in water, while is soluble in hydrofluoric acid

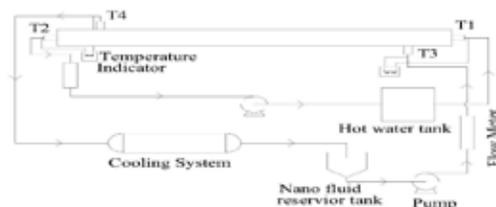


Fig. 3 Experimental setup

TABLE: 1 HEAT EXCHANGER DETAILS:

Type of heat exchanger	1-1 pass shell and tube heat exchanger	Tube clearance	0.01 m
Shell diameter	0.088m	Equivalent diameter	0.03189 m
Shell length	0.61m	Tube diameter ratio	1.08 m
Shell thickness	0.003m	Pitch ratio	1.76 m
Tube diameter	0.013m	Number of tube required	13 tubes
Tube length	0.61m	Number of baffle required	25 baffles
Tube thickness	0.001 m	Baffle spacing	0.023 m
Tube pitch type	Triangular pitch	Tube clearance	0.01 m

EXPERIMENTAL OBSERVATION:

Table 2- Experimental Data for Water As Cooling Fluid

Time taken for one litter water collection (Litre/sec)	Hot water inlet (°C)	Hot water outlet (°C)	Cold water inlet (°C)	Cold water outlet (°C)
37	90	65	28	38
40	80	60	28	36
42	70	55	28	35
43	60	52	28	34
44	50	46	28	32

Table 3- Water as a Working Fluid Numerical Data

Temperature (°C)	Mass flow rate (Lit/sec)	Heat transfer Rate (W/m ²)	LMDT (°C)	Overall heat transfer coefficient (W/m ² °C)	NTU	Effectiveness (%)
90	0.0270	2.8	42.10	0.3972	0.5936	40.31
80	0.025	2.087	36.14	0.3461	0.553	37.64
70	0.0238	1.491	29.65	0.2982	0.5078	35.8
60	0.0232	0.775	24.33	0.1877	0.3264	25.44
50	0.022	0.3794	17.69	0.1272	0.2274	18.25

Table 4-Water as a Working Fluid Numerical Data

Temperature (°C)	Reynolds number (tube)	Reynolds number (shell)	Friction Factor (tube)	Friction Factor (shell)	Pressure Drop (tube) (N/m ²)	Pressure Drop (shell) (N/m ²)
90	4027	1484	0.0108	0.444	125.52	2.05
80	3728	1365	0.0109	0.451	106.5	1.67
70	3549	1119	0.011	0.468	97.38	1.179
60	3460	680	0.013	0.515	91.99	0.515
50	3385	497	0.0115	0.546	89.04	0.27

Table 5- Experimental Data for Nano fluid as A Cooling Fluid (0.1%Vol Si₃N₄)

Time taken for one litter collection of hot water(Litre/sec)	Hot water inlet (°C)	Hot water outlet (°C)	Cold water inlet (°C)	Cold water outlet (°C)
38	90	58	28	40
41	80	57	28	38
44	70	51	28	37
45	60	47	28	36
46	50	44	28	35

Table 6- Nano fluid as a Working Fluid Numerical Data

Temperature (°C)	Mass flow rate (Lit/sec)	Heat transfer Rate (W/m ²)	LMDT (°C)	Overall heat transfer coefficient (W/m ² °C)	NTU	Effectiveness (%)
90	0.0263	3.51	35.57	0.5864	0.899	51.6
80	0.0243	2.33	32.77	0.4217	0.7019	44.2
70	0.0227	1.74	26.69	0.387	0.69	42.3
60	0.0222	1.20	20.08	0.2374	0.66	39.2
50	0.0217	0.54	14.54	0.222	0.4819	31.86

Table 7- Nano fluid as a Working Fluid Numerical Data

Temperature (°C)	Reynolds number (tube)	Reynolds number (shell)	Friction Factor (tube)	Friction Factor (shell)	Pressure Drop (tube) (N/m ²)	Pressure Drop (shell) (N/m ²)
90	4027	1484	0.0108	0.444	125.52	2.05
80	3728	1365	0.0109	0.451	106.5	1.67
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60	3460	680	0.013	0.515	91.99	0.515
50	3385	497	0.0115	0.546	89.04	0.27

RESULT AND DISCUSSION:

Nano fluid has the composition of (water+0.1%of silicon nitride)

Temperature vs. Mass Flow Rate

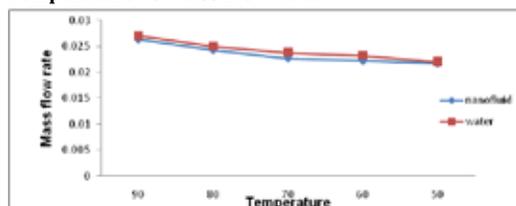


Figure 4: variation of mass flow rate with different temperatures (water and Nano fluid as working fluid).

Mass flow rate is decreasing with decrease in the temperature because the viscosity of fluids. Nano fluid having low mass flow rate compared with water, because Nano fluid having nanometre sized metal particle so increased the viscosity of base fluid, therefore having low the mass flow rate.

Temperature vs. Effectiveness

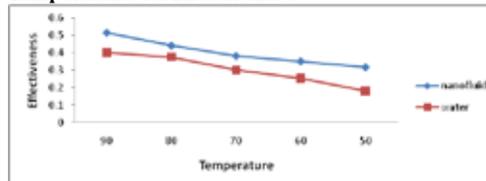


Figure 5: variation of effectiveness with different temperature (water and Nano fluid as a working fluids).

Effectiveness is decreased with decreasing temperature, but Nano fluid having effectiveness compared with water. Because Heat transfer rate of Nano fluid is high, because metal particle added into the base fluid, and so increasing the heat absorbing

rate of Nano fluid and increased the effectiveness. Silicon nitride nanoparticle withstand up to 1200K, hence increasing temperature and the effectiveness of Nano fluid will be increased.

Temperature vs Overall Heat Transfer Coefficient

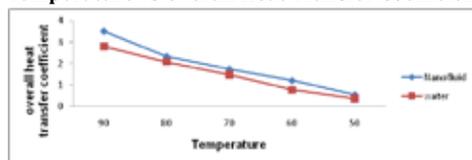


Figure 6: variation of overall heat transfer coefficient with temperature (water and Nano fluid as a working fluid).

Overall heat transfer coefficient increased with increase in the temperature, but Nano fluid having high overall heat transfer coefficient compared with water. Because of Heat transfer rate of Nano fluid is high, metal particle added into base fluid, so increasing the heat absorbing rate of Nano fluid and increasing the overall heat transfer coefficient comparing with water. Silicon nitride nanoparticle withstand up to 1200K, so increasing temperature and the overall heat transfer coefficient of Nano fluid will increase.

Temperature vs. LMTD

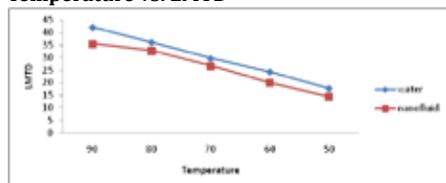


Figure 7: variation of LMTD with different temperature (water and Nano fluid used as working fluid).

LMTD is increasing with the increase in the temperature, but Nano fluid LMTD is low comparing with water. Because Heat transfer rate of Nano fluid is high, metal particle added into water, so increasing the heat absorbing rate of Nano fluid and LMTD is low comparing with water. Silicon nitride nanoparticle withstand up to 1200K, so increasing temperature and the LMTD of Nano fluid will decrease.

Temperature vs Pressure Drop (Tube Side)

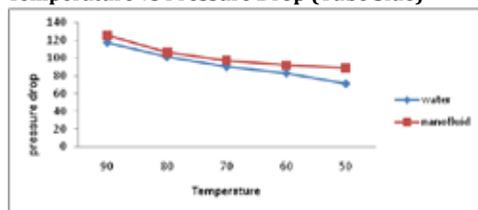


Figure 8: variation of pressure drop with different temperature (water and Nano fluid as working fluid).

Mass flow rate is decreasing with decrease in the temperature, because viscosity of Nano fluid is low at high temperature, so increasing the mass flow rate but Nano fluid contain the metal particle, so mass flow rate of Nano fluid is low comparing with water, and so pressure drop of Nano fluid is high. Pressure drop is depends on flow rate of fluid, mass flow rate of Nano fluid is low, so increased the pressure drop of Nano fluid.

Temperature vs. Heat Transfer Rate

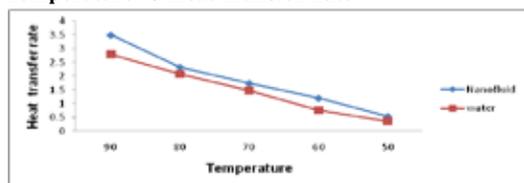


Figure 9: variation of heat transfer rate with different temperature (water and Nano fluid used as a working fluid).

Heat transfer rate is decreasing with decrease in the temperature, but Nano fluid heat transfer rate is high comparing with water. Because metal particle added into water, so increasing the heat-absorbing rate of Nano fluid and increasing the overall heat transfer coefficient comparing with water. Silicon nitride nanoparticle withstand up to 1200K, so increasing temperature and the heat transfer rate of Nano fluid will increase.

Temperature vs Reynolds number (Tube side)

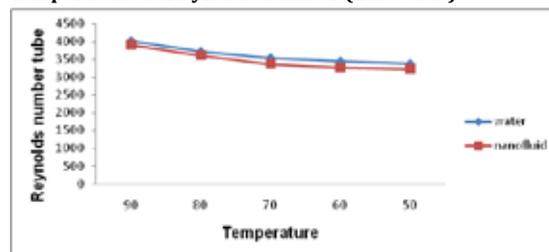


Figure 10 variation of Reynolds number with different temperature (water and Nano fluid used as a working fluid).

Reynolds number is decreasing with decrease in the temperature, because viscosity of Nano fluid is low at high temperature and so at high Reynolds number of Nano fluid having high heat transfer rate. But Nano fluid contains the metal particle, so mass flow rate of Nano fluid is low comparing with water. So Reynolds number of Nano fluid is low comparing with water.

Friction Factor vs. Pressure Drop (Tube side)

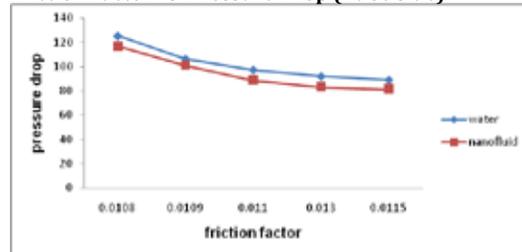


Figure 11: variation of pressure drop with different friction factor (water and Nano fluid used as a working fluid).

Reynolds number is decreased with decreasing in the temperature, because viscosity of Nano fluid is high, and so decreasing the friction factor at high temperature and increasing the Reynolds number of Nano fluid, thus decreasing the pressure drop of fluid but Nano fluid contain the metal particle, hence the pressure drop of Nano fluid is high comparing with water.

Friction Factor vs. Pressure Drop (Shell Side)

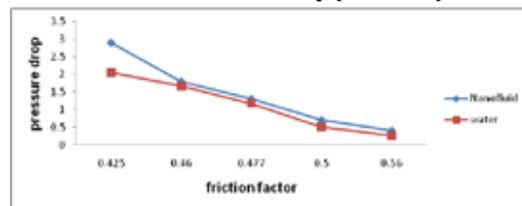


Figure 12: variation of pressure drop with friction factor (water and Nano fluid used a cooling fluid fluid).

Reynolds is decreased with decreasing in the temperature, because viscosity of Nano fluid is low, and so decreasing the friction factor at high temperature and increasing the Reynolds number of Nano fluid; so decreasing the pressure drop of fluid but Nano fluid contain the metal particle, and pressure drop of Nano fluid is high comparing with water. But silicon nitride nanoparticle having low density, thus pressure drop of Nano fluid is slightly high comparing with water.

CONCLUSION

In this work the convective heat transfer of Nano fluid which depends on many parameters such as particle volume fraction,

particle size, particle material, temperature, and base fluid type are considered. The detailed experimental investigation of the effects of most of these parameters on heat transfer has not been performed yet. A systematic study about these aspects of Nano fluid heat transfer provides valuable information for the optimization of heat transfer enhancement with Nano fluid.

This works mainly considered the melting point and structural stability of nanoparticle, where melting point is an important parameter which is used to avoid the particle together at the time of clustering and collision. In this work silicon nitride-water Nano fluid is used because of its high melting point, low density, and high structural stability. An increase of 11% of effectiveness is obtained, when nanoparticles are used than with water.

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