IOP Conf. Series: Materials Science and Engineering **149** (2016) 012204 doi:10.1088/1757-899X/149/1/012204

Experimental Investigation of Heat transfer rate of Nano fluids using a Shell and Tube Heat exchanger

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Abstract. Nano fluids are used for increasing thermal properties in heat transfer equipment like heat exchangers, radiators etc. This paper investigates the heat transfer rate of Nano fluids using a shell and tube heat exchanger in single and multi tubes under turbulent flow condition by a forced convection mode. Alumina Nanoparticles are prepared by using Sol-Gel method. Heat transfer rate increases with decreasing particle size. In this experiment Alumina Nano particles of about 22 nm diameter used. Alumina Nano fluids are prepared with different concentrations of Alumina particles (0.13%, 0.27%, 0.4%, and 0.53%) with water as a base fluid using ultra-sonicator. Experiment have been conducted on shell and tube heat exchanger for the above concentrations on parallel and counter flow conditions by keeping constant inlet temperatures and mass flow rate. The result shows that the heat transfer rate is good compared to conventional fluids. The properties of Nano fluids and non-dimensional numbers have been calculated.

1. Introduction

Nano fluids are study of behaviour of fluids, which are confined to Nano meter sized structure of particles. Nano fluids are plays an important role in heat transfer applications. Many industrial processes involve the transfer of heat. Heating or cooling in an industrial application may create savings heat energy, reducing time and increasing life of working equipment like heat exchangers, boilers and radiators etc. In this work Shell and tube Heat exchanger is used to estimate the heat transfer rate.

There is a lot of research going on in this area, a few of them are stated below,

Argonne National Laboratory of USA by Choi in 1995 [1] which showed that thermal performance of conventional liquid could be remarkably improved using nanoparticles. Nano fluids can be used for a wide variety of engineering applications like transportation, electronics, medical, food, defence, nuclear, space, and manufacturing of many types Pak and Cho [2] reported on Hydrodynamic and heat transfer study of dispersed fluids with submicron metallic oxide particles.Al_2O_3 and TiO_2 Nano fluids are used in horizontal circular tube with a constant heat flux under turbulent condition. Experimental results have done on this work shows the convective heat transfer coefficient of the Nano fluid with 3 volume concentration Nanoparticles was 12% lower than that of the pure water at a given condition. Brinkman HC [3] performed (1952) the viscosity of concentrated suspensions and solution. This relation used for viscosity of Nano fluid. Xuan and Roetzel W [4] have done work on Conceptions for heat transfer correlation of Nano fluids, their results indicate that higher convective heat transfer performance of Nano fluid caused by the higher thermal conductivity of Nano fluid and the disordered movement of Nano particles. Meher, Basu, and Ghatak [5] in 2005, physicochemical characteristics of alumina gel in hydroxyl- hydrogel and normal form. In this results shows that hydroxyl-hydrogel was prepared in two different cases. Williams et al. [6] through experimental investigations of turbulent convective heat transfer and pressure drop of alumina/water and zirconia/water Nano fluids in horizontal tubes. Pantzalia, Mouza and Paras [7] reporting done in 2009, Investigate the efficiency of Nano fluid as coolants in plate heat exchangers and their results observed that greater heat transfer and thermal conductivity along with more pressure drop. Kwon, Kim and Li C G [8] showed that the paper presents ZnO and Al_2O_3 Nano fluids are used and final results observed that heat transfer coefficient increased to 30% at 6% volume concentration of Al_2O_3 Nano fluid. Albadr et al [14] in 2013, Heat transfer through heat exchanger using Al2O3nanofluid at different concentration. The result show that forced convective heat transfer coefficient is slightly higher than that of base liquid at same inlet temperatures and mass flow rate.

2. Proposed work

This work proposes an experimental investigation of heat transfer rate of Nano fluids using a shell and tube heat exchanger. The sequence of steps involved in this work is shown in figure -1.

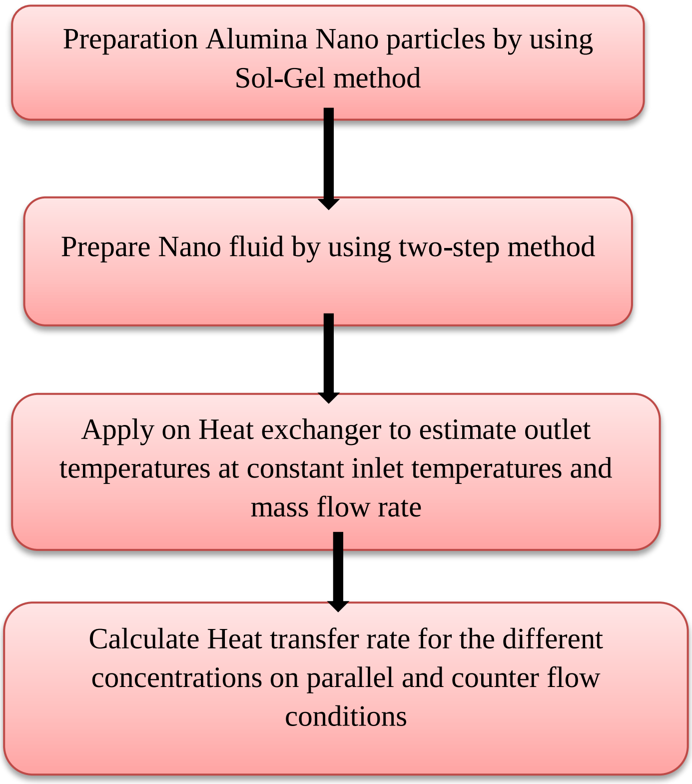


Fig.1. Flow chart

Alumina Nano particles are prepared by usingchemicals with the help of Sol-Gel method. Particles are dispersed in distilled water by using sonicator and thus Nano fluid prepared. Nano fluid is applied on tube side and hot water on shell side of shell and tube heat exchanger. Temperatures obtained on experiment takes the readings and calculate heat transfer rate on both parallel flow and counter flow heat exchanger.

3. Preparation of Nano fluids

Aluminium oxide is a mixture of aluminium and oxygen, it is known asalumina. Al_2O_3 Nano powder has wide range of applications such as electronic ceramics, high strength materials and catalysts. A mixture of alumina particles are generally obtained by sol-gel method.

Fig.2. Aluminium chloride hexahydrate gel formation

Fig.3. Ultrasonic cleaner

For the preparation of aluminium oxide Nano particles most important materials are aluminium chloride hexahydrate ($Al_2Cl_3.6H_2O$), ammonium hydroxide (NH_4OH), distilled water and Triton X100.$Al_2Cl_3.6H_2O$ solution takes into the beaker and small amounts drop wise NH_4OH solution was added in that solution to complete reaction maintain the pH 7. In this process Triton X100 as the surfactant solution. Then white colour precipitate gel is formed shown in fig.2. And after that washing with hot distilled water is done on ultra-sonicator cleaner more than two times shown in fig.3. That precipitate is taken out and dried in hot air oven at 100^0C for 15 hours to remove water. After 15 hours dried content is taken out and grained and finally powder is formed. The powder is calcined at 500^0C, 600^0C, 7000C, 800^0C, 900^0C and 1000^0C for 2 hour each. Then alumina Nano powder is done. Alumina Nano fluid was prepared by using two-step method only. The concentration of Nano powder can be calculated by the following formula.

$$\text{Concentration } (\%) = (X/Y) \times 100$$

Where X = Volume of solute (2, 4, 6 & 8gm) and

Y = Volume of solutions (1500ml of water)

Alumina Nano powder is dispersed into a 1500 conventional base fluid such as water at different volume concentrations 0.13%, 0.27%, 0.4%, and 0.53% by using ultra sonicator. This method is most economic because to produce Nano fluids in large scale.

Table1. Properties of base fluid and Nano particles at atmospheric temperature 29^0C

	ρ (kg/m^3)	C_p (J/kgk)	K (w/m k)	μ (kg/m-s)	A (m^2/s)	Pr
Water	997.6	4178	0.61	$838.2*10^{-6}$	$0.147*10^{-6}$	5.7
Al_2O_3	3925	744	43			

4. Experimental Investigation

Shell and tube heat exchanger consists of set of tubes called as bundles. In this work consists of shell side heated water and tube side alumina Nano fluid. It consists of two flow loops. One loop is attached to shell side inlet and second loop is tube side. In this work two submersible pumps are used as shown in fig.4. Each pump flow rate is 0.3 kg/s. the complete system will be very dynamically and simple to use. Shell and tube heat exchanger 670 mm long consists and brass material used for experiment as shown. In this tube diameter 7.54 mm and wall thickness 1.96 mm and tube long 610mm consists of 20 tubes. Two thermometers are used to calculate outlet temperatures of shell and tube heat exchanger and the surface area of heat exchanger is 0.289 m^2.

Fig.4. Experimental setup

5. Evaluation of Heat transfer rate and Properties of Nano fluids

5.1. Heat transfer rate

Density of Nano fluid calculated by using Pak and Cho [2] relation

$$\rho_{nf} = (1-\varphi)\rho_{bf} + \varphi\rho_p$$

Where the density of Nano fluid is ρ_{nf} , φ is the volume concentration of Nano particles, ρ_{bf} is density of base fluid and ρ_p is the density of Nano particles.

Calculated the specific heat of Nano fluid from Xuan and Roetzel [4] relation is

$$(C_p)_{nf} = \left[\frac{(1-\varphi)(\rho C_p)_{bf} + \varphi(\rho C_p)_p}{\rho_{nf}}\right]$$

Where the specific heat of Nano fluid is $(c_p)_{nf}$ and $(c_p)_p$ is the specific heat of Nano particles.

Heat transfer rate can be calculated by following equation as

$$Q = m(C_p)_{nf}\,\Delta T$$

Where the heat transfer rate is Q, m is the mass flow rate of Nano fluid and ΔT is the temperature difference of the cooling fluid.

The logarithmic mean temperature difference defined as the following relation

$$\Delta T_{lm} = \left[\frac{(T_{bi} - T_{no}) - (T_{bo} - T_{ni})}{lm\left(\frac{T_{bi} - T_{no}}{T_{bo} - T_{ni}}\right)}\right]$$

Where the log mean temperature difference is ΔT_{lm}, T_{bi} and T_{bo} are the base fluid inlet and outlet temperatures and T_{ni}, T_{no} are the Nano fluid inlet and outlet temperatures.

The overall heat transfer coefficient is defined as the following relation

$$Q = UA_s \Delta T_{lm}$$

Where the overall heat transfer coefficient is U and A_s is the surface area of the heat exchanger

5.2. Properties of Nano fluid

Thermal conductivity of Nano fluid was calculated by using Yu and Choi [11] relation

$$\frac{K_{nf}}{K_{bf}} = \left[\frac{K_p + 2K_{bf} - 2\varphi(K_{bf} - K_p)}{K_p + 2K_{bf} + \varphi(K_{bf} + K_p)} \right]$$

Where K_{nf} , K_{bf} and K_p are the thermal conductivity of Nano fluid, base fluid and Nano particles

Drew and Passman [9] suggested Einstein's equation for calculating the viscosity of Nano fluid as followed

$$\mu_{nf} = (1 + 2.5\varphi)\mu_{bf}$$

Where μ_{nf} and μ_{bf} are the viscosity of Nano fluid and base fluid

Friction factor calculated by using Gnielinski equation for base fluid and Duangthongsuk and Wong wises relation for Nano fluid as follows

$$f = [1.58 \ln \mathrm{Re} - 3.82]^{-2}$$

And

$$f = 0.961 \mathrm{Re}^{-0.375} \varphi^{0.052}$$

5.3. Non dimensional numbers

Reynolds number and Prandtl number calculated by using following relation

$$\mathrm{Re} = \frac{\rho V D}{\mu}$$

$$\mathrm{Pr} = \frac{\mu}{\rho \alpha}$$

Where velocity of fluid is V , thermal diffusivity of fluid is α and viscosity of fluid is μ

Thermal diffusivity and Peclet number calculated by using given equations

$$\alpha = \left[\frac{K}{\rho C_p} \right] \text{And}$$

$$Pe = \left[\frac{VD}{\alpha} \right]$$

Nusselt number was calculated by the following relations

$$Nu = \left[\frac{(0.125 f)(\mathrm{Re} - 1000)\mathrm{Pr}}{1 + 12.7(0.125 f)^{0.5}(\mathrm{Pr}^{\frac{2}{3}} - 1)} \right] \text{For base fluid}$$

And

$$Nu = [0.074 \mathrm{Re}^{0.707}\, \mathrm{Pr}^{0.385}\, \varphi^{0.074}] \text{For Nano fluid}$$

6. Result Analysis

Both inlet and outlet temperatures of shell and tube heat exchanger readings measured from experimental system. First calculated heat transfer flow characteristics of distilled water and after the calculated different volume concentration of Al_2O_3/water Nano fluid at the same mass flow rate and inlet temperatures of both cold and hot conditions. In this work Nano fluids are used experimentally at low volume concentrations such as 0.13%, 0.27%, 0.4% and 0.53% respectively. These are applied on heat exchanger and calculate forced convective heat transfer rate on both parallel and counter flow conditions at the same inlet temperature conditions.

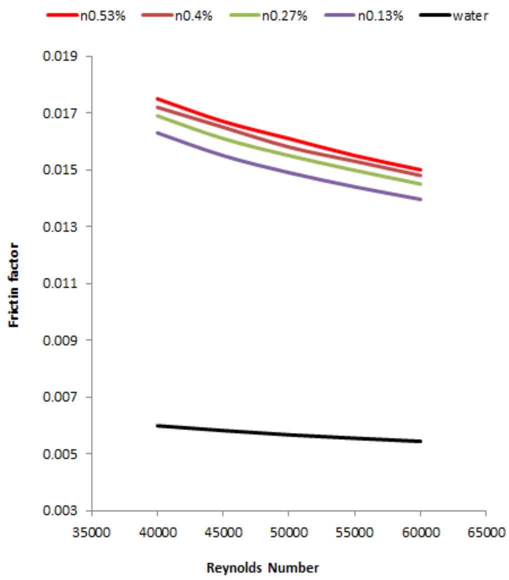
Table2.Experimental results for base fluids and Nano fluids.

	Parallel Flow condition			Counter Flow condition		
	LMTD	*U*	*Q*	*LMTD*	*U*	*Q*
Water	53.46	162.25	2506.8	52.5	247.83	3760.2
0.13%	50.83	296.79	4359.89	49.99	422.49	6103.8537
0.27%	48.11	323.62	4499.607	47.484	468.42	6428.01
0.4%	44.89	438.173	5583.08	41.48	677.43	8120.85
0.53%	38.43	520.215	5777.65	37.44	800.96	8666.47

The properties of the different volume concentrations of the Nano particles are observed. Before starting this experiment calculated Al_2O_3 Nano particles characteristics like density, thermal conductivity and viscosity at atmospheric conditions. In this work first calculated distilled pure water conditions like hot and cold fluid. Inlet and outlet temperature readings have been measured after that calculate overall heat transfer rate. Next we are taken hot water in shell side and Nano fluids on tube side. In this measuring temperature readings are taken on experiment and calculated heat transfer rate on both parallel and counter flow conditions. The volume concentrations are increased then automatically heat transfer rate increases. Comparing flow conditions counter flow heat transfer rate is more than parallel flow condition. Highest heat transfer rate is calculated for 0.53% volume concentration is 8666.47 watts. In these final results the overall heat transfer rate is more than two times increases.

Fig.5. shows that relation between Reynolds number and friction factor. In this friction factor and Reynolds numbers calculated from the different volume concentrations of Nano fluids and base fluids and plot the graph. The result shows Reynolds numbers increases then friction factor values decreases.

Fig.6. shows the relation between Nusselt number and Peclet numbers calculated for both base fluid and different volume concentrations of Nano fluids. In this Peclet number increases then the Nusselt number also increases as well as Reynolds number also increases.



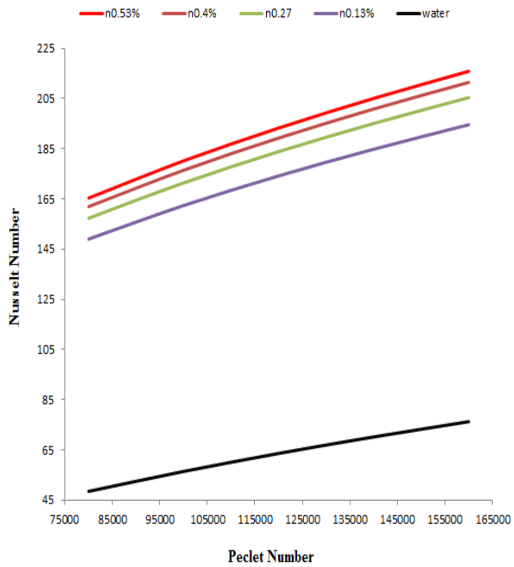


Fig.5.friction factor (vs.) Reynolds number **Fig.6.**Nusselt number (vs.) Peclet number

7. Conclusion

Heat transfer rate on shell and tube heat exchanger by using alumina Nano fluid has been investigated experimentally under forced convective turbulent flow condition. Heat transfer rate, overall heat transfer coefficient and Reynolds number were calculated for both parallel flow and counter flow conditions experimentally at all volume concentrations of Nano fluid. Important results were observed in this work are as follows

1. When compared to flow conditions counter flow heat transfer rate is higher than parallel flow condition.
2. If the volume concentration of Nano fluid increase, the heat transfer rate also increase.
3. Highest heat transfer rate is calculated for counter flow condition at 0.53% volume concentration is 8666.47 watts. The overall heat transfer rate of Nano fluid is more than two times increases than that of base liquid.
4. Reynolds number increases with the decrease in friction factor of Nano fluids.

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