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EXPERIMENTAL ANALYSIS OF HEAT EXCHANGER WITH MINICHANNELS AND NANOFLUIDS

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ABSTRACT

This paper reports experimental investigation of heat transfer carried out in a modified heat exchanger device using nanofluids. Experimental setup of wavy type minichannel made without any leakage and placed in glass wool wooden box to avoid heat transfer to atmosphere . The minichannel experimental set up is made to calculate heat transfer analysis and pressure drop by using nanofluids. Alumina(Al_2O_3) is the nanofuid used in this experminent, as the sonication time is higher, low cost and easy to prepare when compared to other nanofluids The volume concentration of alumina(Al_2O_3) used in this project are 0.5% and 0.8%. The design of the experimental setup has been made in such a way that to create hydro dynamically developing and thermally developing flow to increase heat transfer rate. The results obtained indicates that the Nusselt number, Heat transfer coefficient and Heat transfer rate were increased with increase of Reynolds number for both the DI water and Nanofluid. The average increase of Nusselt number for 0.5% concentration of Alumina is 10% and for 0.8% concentration of Alumina is 15%, the average increase of heat transfer coefficient for 0.5% concentration of Alumina is 8% and for 0.8% concentration of Alumina is 20%, the average increase of heat transfer rate for 0.5% concentration of Alumina is 6% and for 0.8% concentration of Alumina is 12%.

Keywords: *Minichannels, Nanofluid, De-ionized water, Heat transfer, Friction factor*

1. INTRODUCTION

Heat transfer in engineering consists of the transfer of enthalpy because of a temperature difference. Enthalpy is the name for heat energy, to distinguish it from other sorts, such as kinetic energy, pressure energy and useful work. Normally, water is used as a working fluid for most of the heat exchangers. Water is cheap, as compared to others fluids.

The temperature difference is called the driving force. Other things being equal, a greater temperature difference will give a greater rate of heat transfer. A majority of heat exchangers used in thermal power plants, chemical processing plants, air conditioning equipment, refrigerators, petrochemical, biomedical and food processing plants serve to heat and cool different types of fluids. Both the mass and overall dimensions of heat exchangers employed are continuously increasing with the unit power and the volume of production.

The need to optimize and conserve these expenditures has promoted the development of efficient heat exchangers. Different techniques are employed to enhance the heat transfer rates, which are generally referred to as heat transfer enhancement or heat transfer augmentation techniques.

1.2 HEAT EXCHANGER

Heat exchangers are device that facilitate the exchange of heat between two fluids that are at different temperatures while keeping them from mixing with each other. Heat exchanger are commonly used in practice in a wide range of application, from air conditioning systems in a household to power production in large plants.

The distinction between minichannels or microchannels is given by Kandlikar, defines tubes with "channel diameters between 0.01 and 0.2mm as microchannels, channel diameters between 0.2 and 3 mm as minichannels, and channel diameters greater than 3mm as conventional channels". However, others prefer a diameter of 1mm as the demarcation between microchannels and minichannels.

They noted that the Reynolds numbers at the exit of the channels were about two to three times higher than that at the inlet in laminar flow. The reason for this difference was given as the rapid change of fluid properties along the channel length. According to their report, fully developed turbulent flow starts in the Reynolds number range of 1000– 1500 and the laminar-to-turbulent flow transition occurs in the Reynolds number range of 300–800.

1.3 NANOFLUIDS

Nanoparticles research is gaining increasing interest due to their unique properties, such as increased electrical conductivity, toughness and ductility, increased hardness and strength of metals and alloys, luminescent efficiency of semiconductors, formability of ceramics. Nanofluids, the fluid suspensions of nanomaterial, have shown many interesting properties, and the distinctive features offer unprecedented potential for many applications. This review summarizes the recent progress on the study of nanofluids, such as the preparation methods, the evaluation methods for the stability of nanofluids, the ways to enhance the stability for nanofluids, the stability mechanisms of nanofluids, and presents the broad range of current and future applications in various fields including energy, mechanical and biomedical fields. At last, the paper identifies the opportunities for future research.

The idea behind development of nanofluids is to use them as thermo fluids in heat exchangers for enhancement of heat transfer coefficient and thus to minimize the size of heat transfer equipments.

Nanofluids help in conserving heat energy and heat exchanger material. The important parameters which influence the heat transfer characteristics of nanofluids are its properties which include thermal conductivity, viscosity, specific heat and density. The thermo physical properties of nanofluids also depend on operating temperature of nanofluids. Hence, the accurate measurement of temperature dependent properties of nanofluids is essential. Thermo physical properties of nanofluids are pre requisites for estimation of heat transfer coefficient and the Nusselt number.

1.4 LITERATURE REVIEW

[1] Jang and Choi [2012]: The researcher developed a model for nanofluid thermal conductivity that took into account the collision between base fluid molecules, thermal diffusion of nanoparticles in fluids, collision between nanoparticles and nano-convection due to Brownian motion.

[2] John Philip and P.D. Shima [2012]: Develop the thermal properties and possible heat transfer applications. Miniaturization and increased operating speeds of gadgets warranted the need for new and innovative cooling concepts for better performance. The low thermal conductivity of conventional heat transfer fluid has been a serious impediment for improving the performance and compactness of engineering equipments. Initial studies on thermal conductivity of suspensions with micrometer-sized particles encountered problems of rapid settling of particles, clogging of flow channels and increased pressure drop in the fluid. These problems are resolved by using dispersions of fine nano meter sized particles. Despite numerous experimental and theoretical studies, it is still unclear whether the thermal conductivity enhancement in nanofluids is anomalous or within the predictions of effective medium theory. This review provides an overview of recent advances in the field of nanofluids, especially the important material properties that affect the thermal properties of nanofluids and novel approaches to achieve extremely high thermal conductivities.

[3] Das et al and Patel et al [2003]: They reported Nanofluid is not simply a solid–liquid mixture. It must ensure a uniform and stable suspension (like a colloid), and preclude agglomeration or chemical change of the particles or fluid. Nanofluids with dispersion of nano-metric copper, aluminium and their oxides.

[4] Eastmanet al. (2001): Brought out surprising resultsthatnanoparticleslessthan10nm in size can result in about 40% enhancement in the thermal conductivity of a 0.3% volume concentration.

[5] Xuan and Li (2000): The experimental studies on nanofluids confirm that fluids containing nano particles are expected to give more thermal conductivity and lower specific heats over conventional fluids. Normally particles of millimeter or micro meter dimension when suspended in fluids will cause erosion of pipe materials, cloggingof flow passages and sedimentation due to gravity. Studies on

effective thermal conductivities of Nanofluid were investigated under macroscopically in stationery conditions.

1.5 NANOFLUID PREPARATION AND EVALUATION OF PROPERTIES

The working fluid used in this study was prepared using Aluminum oxide nano particles and DI water. The average size of Aluminum oxide particles was from 35nm to 45nm, its surface area ranges from $32m^2/g$ to $40m^2/g$, and molecular weight of particles is 101. The SEM image of nano particles is shown in Fig.1 . The calculated average particle size is 40 nm using Scherrer equation from the results of XRD. The required volume concentrations of 0.1%, 0.5% and 0.8% were prepared. The prepared nano particles were sonicated by an ultrasonic vibrator (manufactured by Lark, India) generating ultrasonic pulses of 180W at 40 kHz. Sonication of nanofluid was done continuously for 30 minutes to obtain a more stable and evenly dispersed nanoparticle suspension. The Table 1 shows thermo-physical properties of nanofluids, which were calculated at the average bulk temperature of the nanofluid.

TABLE 1. 1 PROPERTIES OF AL_2O_3 WATER BASED NANOFLUID

Property	**DI water**	**Al_2O_3**		
		0.10%	0.50%	0.80%
Density (kg/m^3)	996	1000.9	1011	1018.8
Heat capacity (J/kgK)	4177.8	4167.2	4119.3	4084.8
Thermal conductivity ratio (W/mK)	1	1.003	1.015	1.024
Viscosity ($N\text{-}s/m^2$)	0.00086	0.00086	0.00087	0.00087

2. EXPERIMENTAL SETUP & TECHNICAL DESCRIPTION

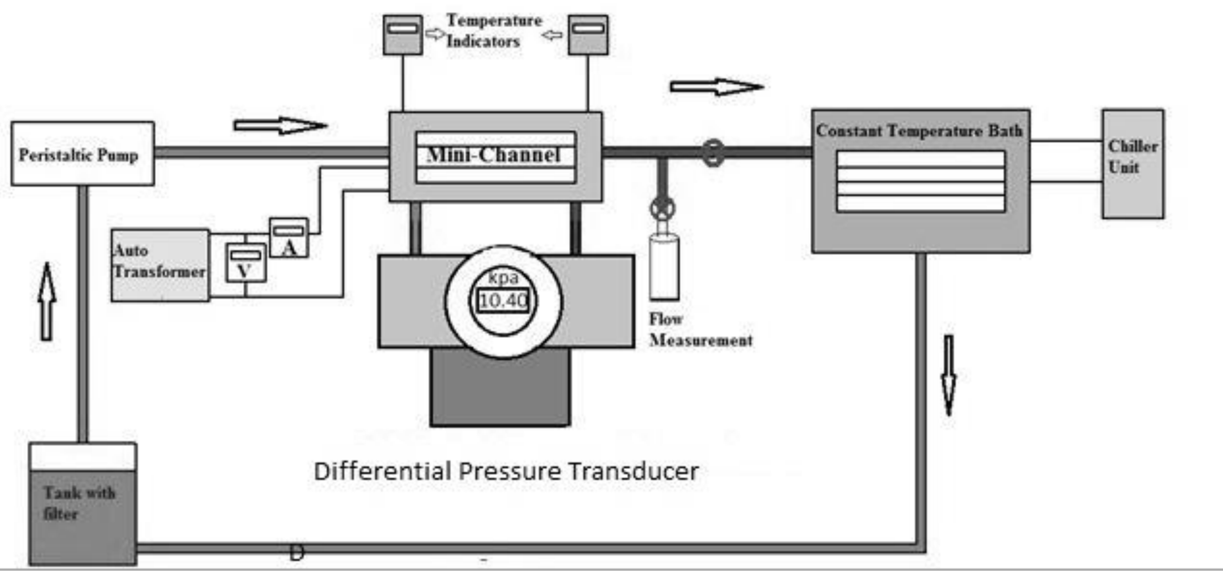

Fig. 2.1 Schematic diagram of the experimental setup

The design of the experimental setup is in such a way that to create hydro dynamically developed and thermally developing flow to increase heat transfer rate. Fluid enters the loop from a reservoir through a filter and is continuously circulated by a peristaltic pump (4 lit/min). Constant temperature bath is at upstream of the setup with a cooler which controls the inlet flow temperature and used to maintain constant temperature of fluid. Then the fluid passes though the inlet manifold, plenum and mini channel heat sink. After passing through the mini channel assembly, it passes through the heat exchanger which is kept in the constant temperature bath, then to the reservoir. The Differential Pressure Transducer and concealed thermocouples are connected to the respective manifold to find Pressure drop, inlet and outlet temperatures of the flow.

Aluminium is selected as the heat sink material because of relatively high thermal conductivity ($K_{Al\ pure}$ =204.2 W/mk), low mass density and high strength. The minichannel is machined by CNC milling on an aluminium slab with 30mm square cross-section and a thickness of 11mm. There are 15 parallel channels of height (e) 1.3 mm, width (w_c) 0.9mm, hydraulic diameter (d_h) 1.063 mm and aspect ratio(α_c) 1.444. The width (w_f) of the fin is 0.9mm.

The substrate temperatures at eight locations were measured by thermocouples which are mounted in the test section at a depth of 8mm from the surface and axially 5mm, 15mm and 25 mm from the leading edge. The channel was covered by a polycarbonate sheet because of its low thermal conductivity (0.2w/mk) and transparency. The aluminium mini channels were heated by a resistance plate heater of size of 50mm×50mm×5mm which directly connected the test sections and made contacted by properly applied thermal Grease. An auto-transformer with a voltage regulator was used to maintain constant current and voltage to the heater, which was placed below the test section. The average fluid temperatures were varied from 30° C to 33°C and the fluid mass flow rate ranged from 0.01 kg/s to 0.027 kg/s. Channel surface roughness was calculated by profile meter and the value of surface roughness (ε) was found to be 40.94μm.

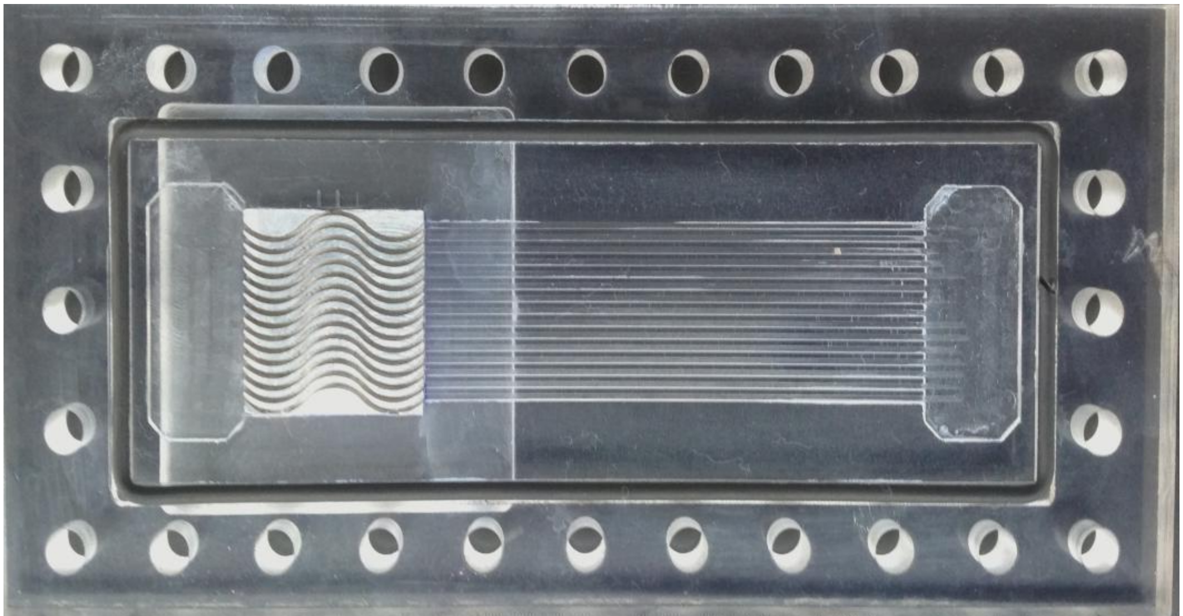

Fig. 2.2 Photographic View of Experimental Setup

2.1 TEST PROCEDURE

First, the set up was properly checked for water leak from lower mass flow rate to higher mass flow rate. Then heat flux was controlled by auto transformer. The flow rate of fluid was checked by a measuring jar with stop watch. By controlling the RPM of the pump, the mass flow was chosen as per requirement. The flow with constant heat flux was allowed to run for an hour to reach steady state condition. Once the system reached steady state the temperatures were recorded using 16 ports Data Taker, dtUSB version 1.2.0 0 of Thermo Fisher Scientific Australia Pty Ltd. Pressure differences were recorded from differential pressure Transducer in kpa. The mass flow rate was controlled by varying the speed of the peristaltic pump. According to the velocity of fluid, the Reynolds number varied from 608 to 1976 and Prandtl number for water is around 5. The properties of water are taken at the mean temperature of fluid. The heat losses of this experiment were 5% to 8% of heat supplied.

2.2 FORMULA USED TO CALCULATE THERMO –PHYSICAL PROPERTY OF Al_2O_3

ρ_w=3.6g/cc k_s=76.5W/mK C_{ps}=880J/Kg-K

The density of Al_2O_3/water nanofluid was determined using Pak and Cho's equation

$$\rho_{nf} = (1-\phi)\rho + \phi\rho_s \qquad (1)$$

Φ - Alumina nanoparticle volume concentration.
ρ_{nf} - Density of nanofluid.
ρ_s - Density of nanoparticle.

The specific heat of the nanofluid was calculated using Xuan and Roetzel's equation

$$C_{p,nf} = \frac{(1-\phi)\rho C_p + \phi \rho_s C_{ps}}{\rho_{nf}} \qquad (2)$$

Cp_{nf} - Specific heat of nanofluid.

The viscosity of the nanofluid was calculated using the viscosity correlation proposed by Einstein

$$\mu_{nf} = \mu\,(1 + 2.5\,\varphi) \qquad (3)$$

μ_{nf} - Viscosity of nanofluids.

The effective thermal conductivity of the nanofluid was calculated using the Maxwell model 34. For nanofluid with volume fraction less than unity, Maxwell equation is given by,

$$\frac{k_{nf}}{k} = \frac{k_s + 2k + 2\varphi(k_s - k)}{k_s + 2k - \varphi(k_s - k)} \qquad (4)$$

K_{nf}- Thermal conductivity of nanofluid.

3. RESULTS AND DISCUSSIONS

Table 3.1 REYNOLDS NUMBER [Re] Vs NUSSELT NUMBER [Nu]

REYNOLDS NUMBER (Re)	**NUSSELT NUMBER [Nu]**					
	Al_2O_3 NANO FLUID				DI WATER	
Conc.	0.50%		0.80%			
	O.5% Al_2O_3 40 W	O.5% Al_2O_3 60 W	O.8% Al_2O_3 40 W	O.8% Al_2O_3 60 W	DI 40 W	DI 60 W
608.115	6.736	6.927	7.121	7.267	6.523	6.671
808.793	6.932	7.121	7.289	7.368	6.629	6.754
1009.468	7.089	7.283	7.350	7.645	6.833	6.848
1216.229	7.265	7.445	7.936	7.923	6.905	6.957

1641.912	7.444	7.646	8.292	8.288	7.049	7.105
1824.344	9.236	9.430	9.601	9.760	7.740	7.762
1976.375	9.003	9.555	9.851	10.039	7.786	7.921

Table 3.2 REYNOLDS NUMBER[Re] Vs. FRICTION FACTOR [*f*]

REYNOLDS NUMBER (Re)	**Friction Factor [*f*]**					
	Al_2O_3 NANO FLUID				DI WATER	
Conc.	0.50%		0.80%			
	O.5% Al_2O_3 40 W	O.5% Al_2O_3 60 W	O.8% Al_2O_3 40 W	O.8% Al_2O_3 60 W	DI 40 W	DI 60 W
608.115	0.514	0.436	0.439	0.427	0.466	0.446
808.793	0.421	0.427	0.417	0.400	0.439	0.353
1009.468	0.408	0.419	0.385	0.394	0.411	0.348
1216.229	0.404	0.398	0.378	0.370	0.357	0.342
1641.912	0.374	0.390	0.371	0.363	0.354	0.320
1824.344	0.310	0.348	0.357	0.363	0.347	0.314
1976.375	0.270	0.325	0.345	0.309	0.329	0.293

Table 3.3 REYNOLDS NUMBER [Re] Vs. HEAT TRANSFER CO-EFFICIENT [h]

REYNOLDS NUMBER (Re)	**HEAT TRANSFER CO-EFFICIENT[h]**					
	Al_2O_3 NANO FLUID				DI WATER	
Conc.	0.50%		0.80%			
	O.5%Al_2O_3 40 W	O.5% Al_2O_3 60 W	O.8%Al_2O_3 40 W	O.8%Al_2O_3 60 W	DI 40 W	DI 60 W
608.115	3916.810	3939.376	4023.880	4087.872	3841.646	3853.720

808.793	3999.559	4075.351	4207.249	4257.585	3903.523	3922.150
1009.468	4063.706	4205.503	4237.805	4288.932	4023.536	4033.598
1216.229	4145.312	4281.372	4326.006	4372.558	4066.390	4089.592
1641.912	4508.602	4549.090	5499.898	5525.921	4151.332	4166.855
1824.344	5302.187	5363.347	6415.127	6505.504	4558.206	4578.958
1976.375	5438.563	5548.135	7428.921	7530.831	4585.537	4604.982

Table. 3.4 REYNOLDS NUMBER [Re] Vs. HEAT TRANSFER RATE [Q]

REYNOLDS NUMBER (Re)	**HEAT TRANSFER RATE [Q]**					
	Al_2O_3 NANO FLUID				DI WATER	
Conc.	0.50%		0.80%			
	O.5%Al_2O_3 40 W	O.5% Al_2O_3 60 W	O.8%Al_2O_3 40 W	O.8%Al_2O_3 60 W	DI 40 W	DI 60 W
608.115	57.893	83.282	57.875	79.745	53.474	54.108
808.793	60.373	79.842	54.976	72.912	53.756	81.672
1009.468	61.341	77.727	54.536	69.231	60.646	79.725
1216.229	61.255	73.895	49.997	70.533	59.255	79.400
1641.912	74.104	73.967	61.057	88.222	54.889	80.265
1824.344	59.252	81.070	45.022	124.222	56.749	82.410
1976.375	61.693	64.084	69.874	140.696	56.874	77.766

3.1 COMPARISON BETWEEN DI WATER AND NANOFLUID(Al_2O_3)

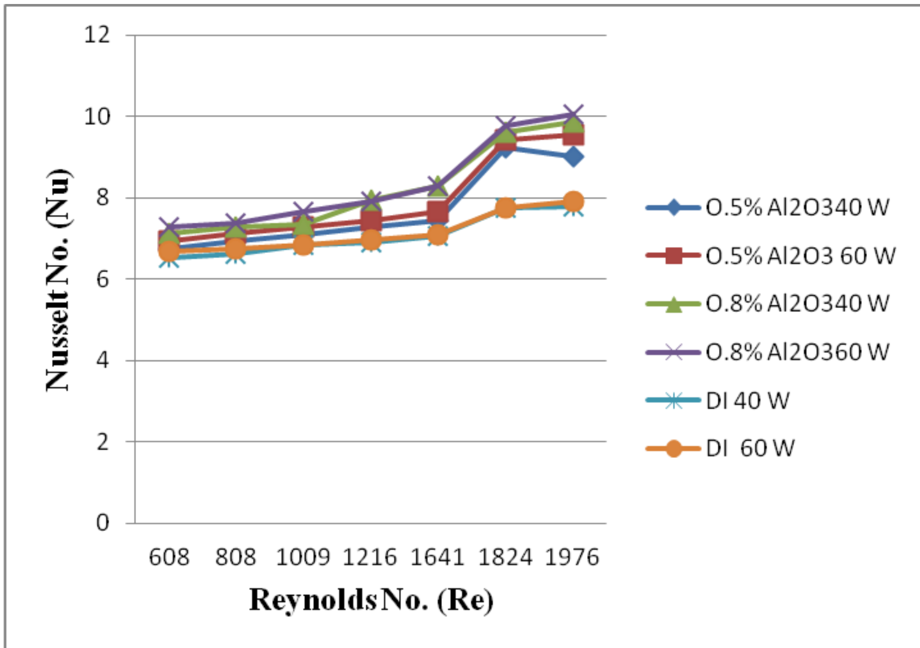

Fig. 3.1 GRAPH BETWEEN REYNOLDS NUMBER AND NUSSELT NUMBER.

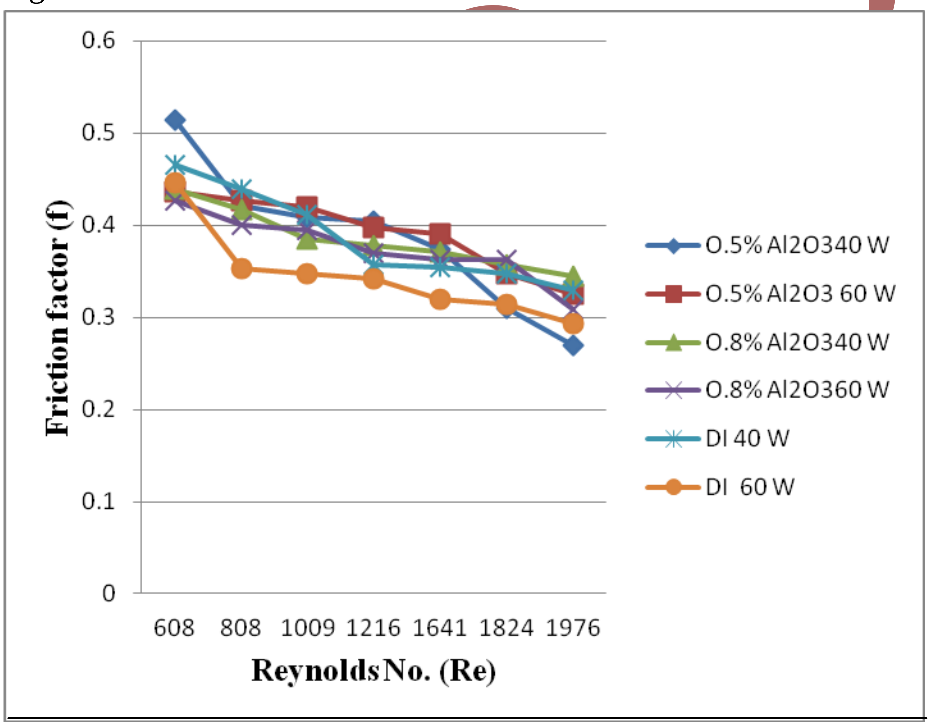

Fig. 3.2 GRAPH BETWEEN REYNOLDS NUMBER AND FRICTION FACTOR .

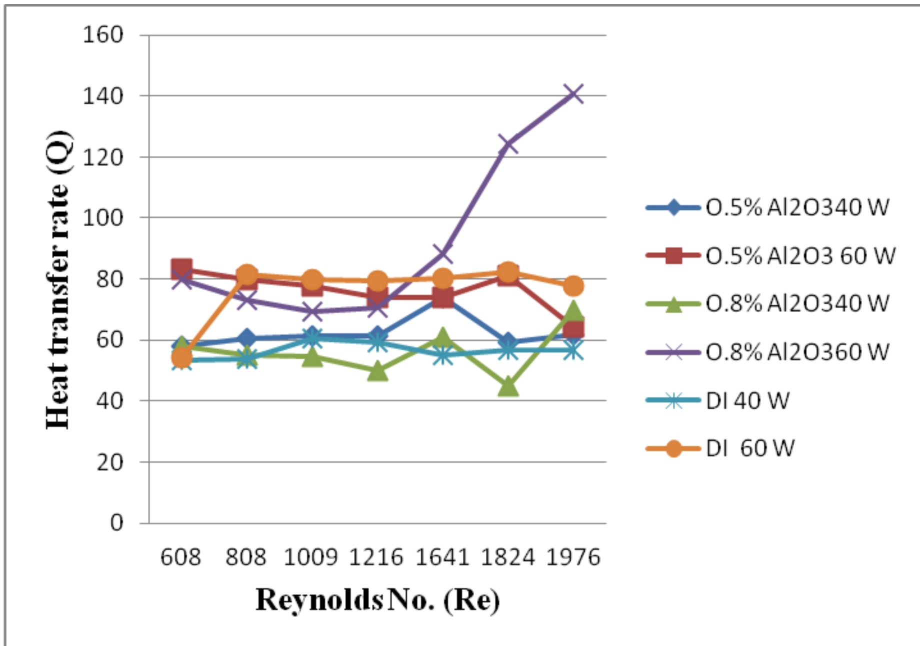

Fig. 3.3 GRAPH BETWEEN REYNOLDS NUMBER AND HEAT TRANSFER RATE

From the above details it is observed that, Nanofluids has higher heat transfer rate and thermal conductivity compared to DI water.

CONCLUSION

From that above result it is obtained that, Nanofluids has higher heat transfer rate and thermal conductivity when compared to DI water. In this experiment 0.5% and 0.8% volume concentration alumina(Al_2O_3) nanofluids are used. The results obtained indicates that the Nusselt number, Heat transfer coefficient and Heat transfer rate were increased with increase of Reynolds number for both the DI water and Nanofluid. The average increase of Nusselt number for 0.5% concentration of Alumina is 10% and for 0.8% concentration of Alumina is 15%, the average increase of heat transfer coefficient for 0.5% concentration of Alumina is 8% and for 0.8% concentration of Alumina is 20%, the average increase of heat transfer rate for 0.5% concentration of Alumina is 6% and for 0.8% concentration of Alumina is 12%.

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