Heat Transfer and Pressure Drop Characteristics of the Buoyancy-Aided Heat Transfer Oil-Copper Oxide (HTO-Cuo) Nanofluid Flow in Vertical Tube

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Abstract

In this paper, the mixed natural-forced convection is experimentally investigated for the heat-transfer oil-copper oxide (HTO-CuO) nanofluid flows upward in a vertical tube. The flow regime is laminar and the temperature of the tube surface is constant. The effect of the nanoparticles concentration on the heat transfer rate and the pressure dropare studied as Richardson number varies between 0.1 and 0.7. It is observed that the mixed convective heat transfer rate increases with both the nanoparticles concentration and Richardson number. New correlations are proposed to predict the Nusselt number of the nanofluid flow with the reasonable accuracy. In addition, Darcy friction factor of the nanofluid flow is investigated and a new correlation is presented to evaluate the friction factor of HTO-CuO nanofluid flow in vertical tubes. As the heat transfer enhancement methods usually accompany with increment in the pressrure drop, the performance index is evaluated experimentally. As such, the maximum perfomance index of 1.27 is achieved using the 1.5

Index terms— nanofluid; heat transfer oil; mixed convection; vertical tube; laminar flow

1 Introduction

ixed convection heat transfer is widely used in industrial applications, e.g. advanced technologies such as microelectronics cooling, air conditioning, as well as petrochemical, oil and gas industries. Enhancement of the mixed convection heat transfer has a significant role on the energy saving and on the compactness perspectives of heat exchangers. As one the first study, Sider and Tate [1] carried out an experimental investigation on the mixed convection heat transfer in vertical isothermal tubes. Although, they also proposed a correlation to predict the experimental data, the error of correlation was approximately 30%.

During the last decade, some correlations have been presented to predict the mixed convection heat transfer in vertical [2][3] **??**4], horizontal **??**5, **??**], and inclined **??**7, **??**] tubes. As one of the first interesting research work, Joye [3] conducted an experimental investigation on the pressure drop of the laminar mixed convection flow in vertical tubes. In addition, he presented a new correlation to evaluate the pressure drop with the maximum error of 10%.

The inherent relatively low thermal conductivity of conventional fluids, e.g., water, glycol solution, and oil, impacts the convective heat transfer rate. It is accepted that adding nanoparticle to the base fluid is an effective method to enhance its thermal-rheological characteristics and the flow thermal performance. Accordingly, many research works have been carried out to enhance the heat transfer rate using nanoparticles. For the first time, uniform suspension of nanoparticles in a liquid was introduced by Choi and Eastman **??**9] to create a new type of solid. Afterwards, many research works has been conducted to investigate the effect of adding nanoparticles as a heat transfer enhancement **??**10] **??**11] **??**12]. As one of the first study, Lee **??**10] studied four nanofluids consisted of CuO and Al2O3 nanoparticles in water and glycol based fluids. The maximum volume concentration of nanoparticles was 5% leaded to 30% increase in the thermal conductivity. Through the recent years, some empirical and theoretical study have been done in order to be measured the properties of high Prandtl nanofluid and impact of high Prandtl nanofluid on forced convection heat transfer in horizontal ??13] ??14] ??15] ??16] ??17] ??18] ??19] ??20] ??21] ??22]. Based on the [18], three type of nanoparticles such as copper dioxide, titanium dioxide, and aluminium dioxide were used to mix with turbine oil. The result of this investigation is conclude that the heat transfer and Nusselt number increased using nanoparticles. Although, the results show that the influence of using CuO is more than TiO 2 , and Al 2 O 3 . During the recent decades, many experimental and numerical research work have focused on the influence of the nanoparticles on the mixed natural-forced convection heat transfer and pressure drop, in horizontal [23-27], vertical and inclined ??27] ??28][29][30][31][32][33] tubes. According to the [33], mixed convection heat transfer and pressured drop are risen using the nanoparticle and changing the tube inclination. Furthermore, several correlations are proposed to be measured the effect of nanofluid in inclined tube.

Numerical studies on the fully developed laminar mixed convection heat transfer of water in horizontal and inclined [34][35][36][37] tubes have been performed during the recent years. The results demonstrated that the mixed convection heat transfer was enhanced by adding nanoparticle to base fluids or changing the inclination angle. Whereas, Ben Mansour ??28,34] stated although the nanoparticles concentration has no significant effect on the hydrodynamics of the flow, it may enhance the heat transfer coefficient. Based on his results, Darcy friction factor increases monotonically with the inclination angle, while the heat transfer coefficient shows a peak at the angle of 45°.

In this paper, the mixed convective heat transfer and pressure drop characteristics of a buoyancy-aided nanofluid flow in a vertical tube is investigated experimentally. As such, this research is conducted to study the effect of using copper oxide nanoparticles on the heat transfer and pressure drop characteristics of the heat transfer oil flow. The tube wall temperature is constant and the flow rate is low enough to ensure that the flow regime is always laminar.

2 II.

3 Experimental Apparatus a) Nanofluid Properties

In this study, solid particles of copper oxide with the average size of 40 nm and the purity of 99% were used as nanoparticles. XRD (X-ray diffraction) analysis and SEM (scanning electron microscope) image of thenanoparticles are shown in Figs . 1, and 2, respectively. As shown in Figs. 1 and 2, the nanoparticles are almost spherical. In order to obtain a homogeneous and a relatively stable nanofluid, an ultrasonic UPS400 apparatus with the frequency of 24 kHz and the power of 400 W was used. In this study, three samples of nanofluids were prepared including suspension of the heat transfer oil-copper oxide nanoparticles with the mass concentration of 0.5%, 1% and 1.5%. The nanofluids were stable for 216hr, after then the nanoparticles started to precipitate and settled down completely after 14 days.

The range of operations flow and Copper oxide (CuO) nanoparticles are shown in Tables 1 and 2, respectively. The thermal-rheological properties of copper oxide-heat transfer oil nanofluids are reported ??12]. In addition, the ranges of applicability of these correlations and investigation are presented in Table 3. In order to study the heat transfer and the pressure-drop of the nanofluid flow in vertical tubes, an experimental setup was designed as presented schematically in Fig. 3. The flow circuit has several parts including: test section, pre-cooler, reservoir tank, heat exchanger, gear pump, flow meter, differential-manometer, thermocouples and flow control system. In the experiments, a 500 mm smooth tube with inner and outer diameter of 8.92 mm and 9.52 mm was used. The test tube is located in a steam tank to keep the tube wall insulated using fiberglass to reduce its heat losses. Due to installing the pressure transmitter and main line to tube test, steam hoses enduring the 230°C and 7.0 bar are used due to steam hoses which eliminate the effect of elbow and horizontal tube on increasing pressure drop and prevent the heat transfer between fluid and steam tank. In addition, in order to approve the results of experimental investigation, the steam hoses have insulated using fiberglass. The cooling system of the setup has two stages. In the first stage, the cooling water is used to precool the nanofluid using a copper coil embedded in the reservoir tank. In the second one, the cooling water cools down the nanofluid flow to about cooling of the nanofluid inside the reservoir tank, it is pumped to the main line by a gear pump. As the gear pump speed is fixed, a bypass line is used to control the flow rate in the main line. Adjusting the flow rate is accomplished using a globe valve to bypass some of the flow to the reservoir tank. The main line flow rate is such that the flow is always in the laminar regime. After the RTD sensor entered into tube, the tube is attached to a steam hose connected to test tube. This test section, four thermocouples are installed at specified intervals to measure the tube wall temperature. In addition, two thermocouples are installed at the inlet and outlet of the test section to measure the inlet and outlet flow temperatures. The time required for the flow to become steady was about 15 minutes and the data were recorded after 30 min.

4 b) Test Set Up

5 c) Instrument

To measure the nanofluid temperature in the test section inlet and outlet, two RTD PT 100joined to thermometers are used with the accuracy of ±0.1°C.. The RTD sensors entered in tubes are sense the central temperature of fluid as the inlet and outlet temperatures. In addition ,in order to determine the tube wall temperature which is constant during the tests, four Ktype thermocouples with the SU-105 KPR sensor were welded on the tube with the 100 mm interval, T 1 (100 mm), T 2 (200 mm), T 3 (300 mm), and T 4 (400 mm). Since the velocity of fluid which is near the surface tube is zero or have downward flow. Thus, the fluid temperature which is near the wall tube is approximately equal with the temperature of surface tube. In addition, the temperature of film flow calculated using the temperature of surface tube and bulk temperature is required to determine the Grashof and Richardson number. The surface temperatures which are obtained for T 1 , T 2 , T 3 , T 4 are 98.1, 97.8, 98, 98.1, respectively. 15°C in a shell and tube heat exchanger. After initial temperature which is near the wall tube is approximately equal with the temperature of surface tube. Thus, it is possible to use the temperature of tube surface as wall fluid temperature. A PMD-75 pressure transmitter with the accuracy of ±0.075% was implemented to measure the pressure drop. To measure the flow rate, a 1000 ml scaled separation funnel was used. In this method, the flow rate may be directly measured by means of measuring the funnel filling time using a digital timer with the accuracy of 0.01s.

Error analysis of the heat transfer and the pressure drop measurements were performed based on Kline and McClintock [39] method using the data depicted in Table 4. The specimen of computing the error analysis is mentioned in appendix 1.

Accordingly, the maximum measurement error of Darcy friction factor, Nusselt number, and the performance index were 6.8%, 4.3% and 6.5%espectively.

6 III.

7 Result and Discueeion

Hydro-dynamically fully developed laminar flow relies on Reynolds number, which increases up to 730 in this work. As a consequence, the flow of pure heat transfer oil and nanofluid are assumed fully-developed (L/D > 0.05Re). Furthermore, owing to the high Prandtl number of the pure heat transfer oil and nanofluid, the flow is in the thermal entrance region (L/D < 0.05RePr). The Darcy friction factor and the Nusselt number are used to evaluate the nanofluid flow pressure drop and heat transfer coefficient, respectively. White [40], and Bergman et al [41]:ð ??"ð ??" = ?? 2 ???? 5 2?????2 ???**(1)**???? = ????? ?? ?????? ???? ? ?? ?? ??? ?? ,?? ?? ?? ??? ?? ,?? ?**(2)**

T w is surface temeperature. T b,i, and T b,o are bulk inlet temperature and bulk outlet temperature.

To verify the accuracy of the experimental results, in Fig. 4, the experimental mixed convection Darcy friction factor and Nusselt number of the pure heat transfer oil flow in a vertical tube are compared with the results of classic Joye [3] and Eubank and Proctor [2] correlations, respectively. The Joye [3] and Eubank Proctor correlation [2] are reported as is followed: ??? ?????? = ? 128 ?????? ???? 4 ? (????) ? ???? .??. ? ?? ?? ?? ?? ? 0.38 ? (3a) Î?"?? Î?"?? ?????? = 1 + 1565 ???? ?? 3 4 ? ???? 1 2 ? (0.952+????) 3 4 ? ???? 2 × (?? ?? ?) ?? 2 (3b)

8 a) Heat Transfer

At first, the effect of the nanoparticles concentration on the mixed thermally developing heat transfer rate in vertical tubes is investigated. Fig. **??** shows that Nusselt number increases with both Gz number and the nanoparticles mass concentraion. The maximum Nuesselt number is reached at the concentration of 1.5% leads to 16% enhancement with respect to the base fluid flow. The experimental results for Nusselt number are compared with the prediction of Eubank and Proctor [2] correlation in Fig. **??**. The maximum error of Eubank and Proctor is 24%. It is evident from Fig. **??** that this equation cannot predict accuratelythe mixed convection Nusselt number of nanofluid flows. As a consequence, to predict the thermally developing Nusselt number of nanofluid flows accurately, Eubank and Proctor correlation [2] should be modified based on the obtained experimental results of this study as:Nu = 1.8 ? ?? ?? ?? ?? ? 0.14 ????? + 0.12 ????????? ?? ?? ? 0.44 ? 1/3 (5)

Rang of applicability of correlation is mentioned in Table 3. In which the thermo-physical properties of the nanofluid is used to evaluate Graetz and Nusselt numbers. **??**). As shown in Fig. 7, the maximum discrepancy between the predictions of Eq. (**??**) and the obtained experimental results is less than 10% which iscompletely acceptable for this type of flow. Nu ??ð ??"ð ??" Nu ??ð ??"ð ??" = 1.17 ?1 + ? ???? ???? 2 ? 0.8 ? 0.4 (6)

Rang of applicability of correlation is mentioned in Table 3. Fig. **??** shows the comparison of the experimental data with the results of Eq. (**??**). As the maximum error of the correlation is 12%, it can be used to estimate the effects of mixed heat transfer of the nanofluid flow in vertical tubes with an acceptable accuracy. Rang of applicability of correlation is mentioned in Table 3. Fig. 12 compares the experimentalDarcy friction factor data with the predictions of Eq. (**??**). Accordingly, - 3. Fig. 12 compares the experimental Darcy friction factor data with the predictions of Eq. (**??**). Accordingly, the presented correlation computes the frcition factor of laminatr bouancy-aided nanofluid flow in vertical tubes with a good accuracy. effect of simultaneous increase in the heat transfer and the pressure drop, the prefromance index may be defined as:?= h nf /h bf Î?"P nf /Î?"P bf (8)

The preformance index larger than one shows thatusing nanoparticles is more in favor of heat trasfer improvement rather than in pressure drop increment. The performance index of the system can be calculated based on the heat transfer rate and the pressure drop of the pure heat transfer oil and the HTO-CuO nanofluid flow. Fig. 13 indicates the effect of Richardson number and the nanoparticles mass concentraion on the perfomance index. Based on the results, it is observed that although the performance index is not always larger than unity, its maximume is aboud 1.27 which is achieved with 1.5% nanoparticles concentraion and Richrdson number of 0.7.

9 Appendix

The Kline and McClintock are defined by:U R = ?? ? ?R ?V i U V i ? 2 n i=1 ? 1 2 ? (9)

where U R is the overall uncertainty in the result, ?? ?? ?? is uncertainty in one variable, n is number of variable.

In order to compute the uncertainty of the friction factor, Nusselt number, and performance index, some independent variable error should be required to be where U R is the overall uncertainty in the result, ?? ?? ?? is uncertainty in one variable, n is number of variable.

In order to compute the uncertainty of the friction factor, Nusselt number, and performance index, some independent variable error should be required to be calculated. The error of system is presented in Table 5. The error of thermos-physical and nanofluid flow

10 Conclusion

The effects of CuO nanoparticles on the mixed natural forced convection heat transfer rate and pressure drop buoyancy-aided heat transfer oil flow in vertical tubes were investigated experimentally. The result may be summarized as follows:

Adding nanopartilces enhanced the mixed convection heat transfer rate up to 50%.

Two new correlation was presented to predict the thermally developing mixed convection Nusselt number. As the maximum error of the correcletions is about 10%, they are reliable to estimate the heat transfer rate of the nanofluid flow with a good accuracy.

The maximum increment of the flow friction factor, due to adding nanopaticles, was about 20%. To estimate the Darcy friction factor, a new correlation was developed based on the experimental data which may predict the HTO-CuO flow behaviour in vertical tubes with the maximum error of 12%.

The system performance index was introduced to evaluate the effect of nanoparticles on the heat transfer rate and the pressure drop simultaneously. The majority of the results were larger than unity which indicates that using nanoparticles is more in favor of heat trasfer improvement rather than in pressure drop increment. The maximum performance index of 1.27 was obtained in the nanoparticle concentration of 1.5% and Richardson number of 0.7.

11 V.

characteristic used to calculate the Nusselt number are presented as it is followed:U ? = ?? 1 Q U m ? 2 + ? ?m Q 2 U Q ? 2 ? 1 2 ? (10)

where U p is density uncertainty in the result, U m is weight uncertainty, ?? ?? is volume uncertainty used for measuring density . The error of volumetric flow rate is obtain 11: where U V is volumetric flow fluid uncertainty, U V 1 is volumetric flow fluid, and U t is the duration of base fluid or nanofluid loading the flowmeter system. Mass flow uncertainty is calculated by:U Q = ?? 1 t U V ? 2 + ? ? V V 2 U t ? 2 ? 1 2 ? (11)U m?= ??? U Q ??2 + ?QU ? ? 2 ? 1 2 ? (12)

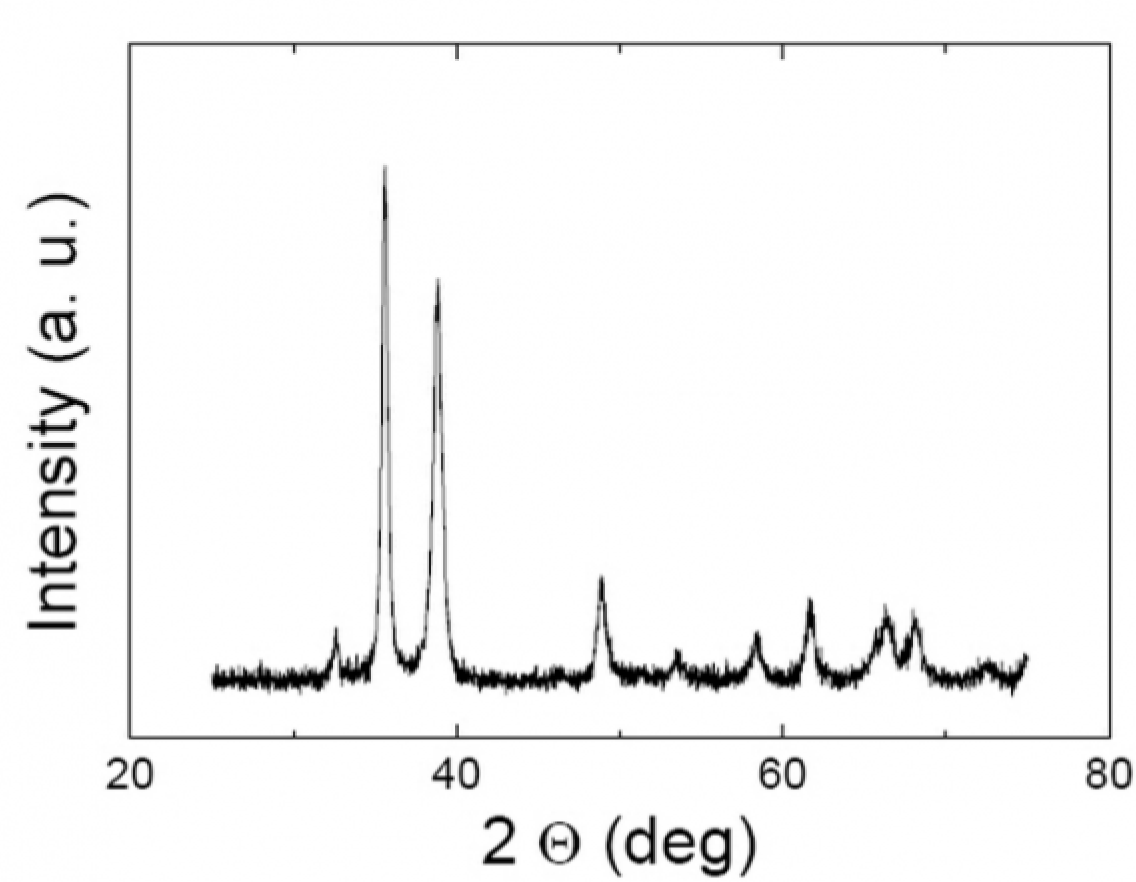
where U m? is mass flow, U V ? is volumetric flow fluid, U ? is density uncertainty. The convection coefficient is calculated by:Uh nf ???? = ± ?U Cp nf 2 + U m2 + U (T b ,O ?T b ,i) 2 + U D 2 + U L 2 + U (T w ?T b) 2 ? 1 2 ? (13)

Where Uh nf ???? is convection coefficientU m?, U D ,U L are mass flow , error of diameter, and length, respectively.U Nu nf ??????? = ± ?Uh nf ???? 2 + U D 2 + U k 2 ? (**14**)

where ?? ???? ??ð ??"ð ??" ???????? is average Nusselt, U D , and U k are diameter and conductivity error, respectively. Characteristics of nanofluid are calculated [39]. The characteristics of concentration of 0.5% which is perceived as specimen are presented in Table 6. In addition, the results of specimen uncertainties are reported in Table 7. Others uncertainties like friction factors error are calculated according the equation 9. [1] [2] [3]

[2] Heat Transfer and Pressure Drop Characteristics of the Buoyancy-Aided Heat Transfer Oil-Copper Oxide (HTO-Cuo) Nanofluid Flow in Vertical Tube

[3] Year 2017 A Heat Transfer and Pressure Drop Characteristics of the Buoyancy-Aided Heat Transfer Oil-Copper Oxide (HTO-Cuo) Nanofluid Flow in Vertical Tube



1

Figure 1: Fig. 1 :

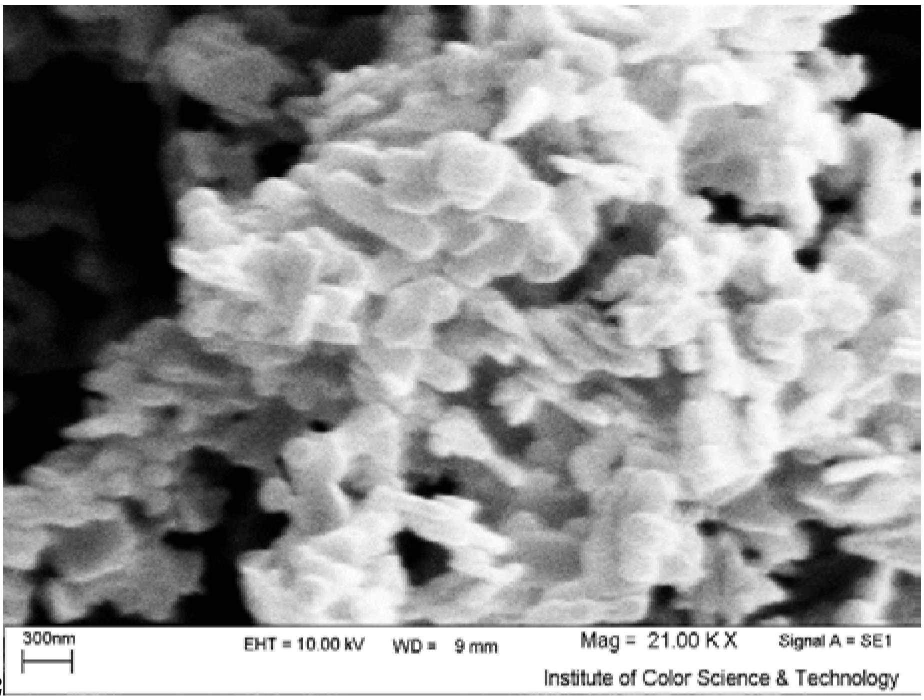


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Figure 2: Fig. 2 :

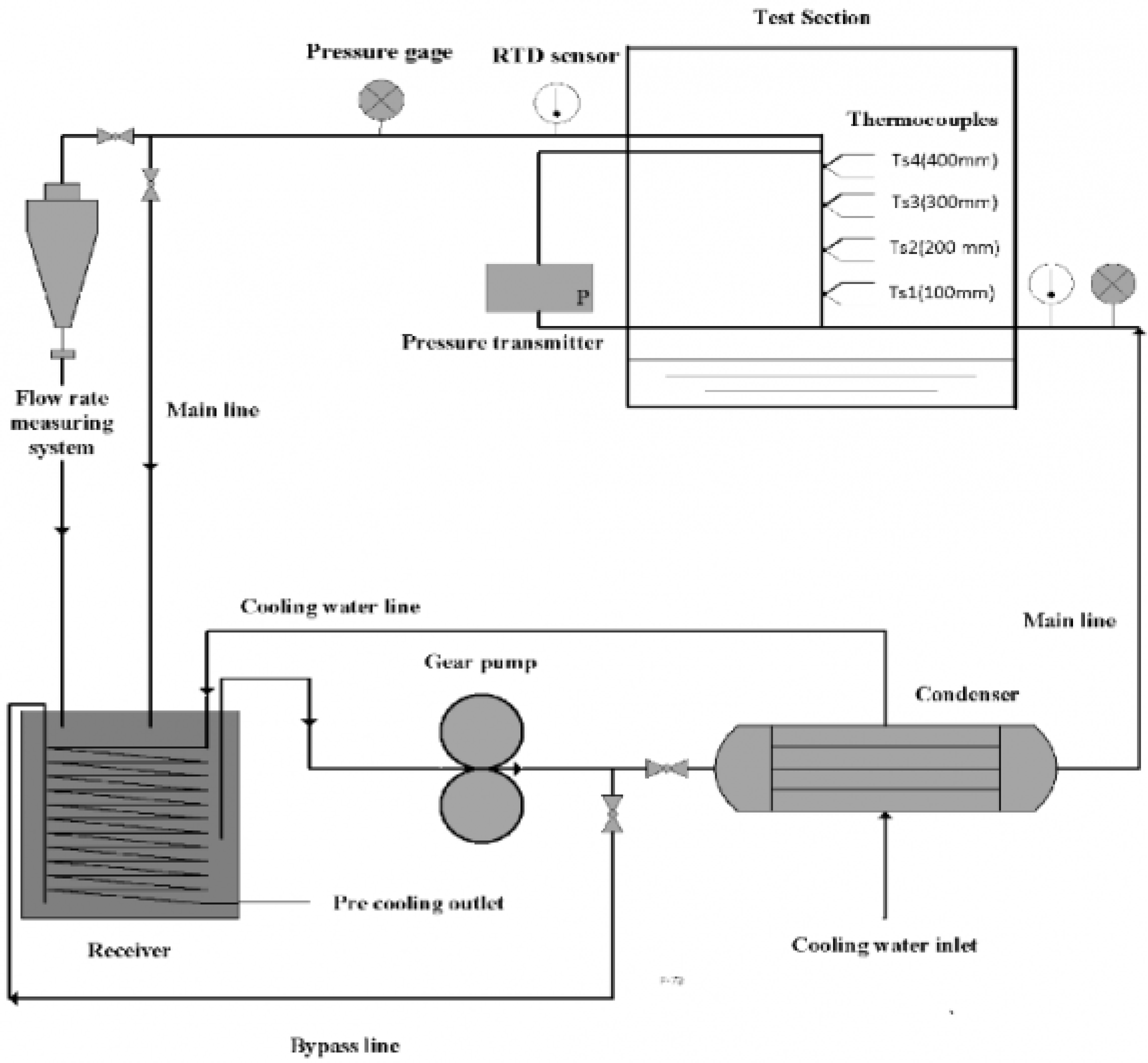

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Figure 3: Fig. 3 :

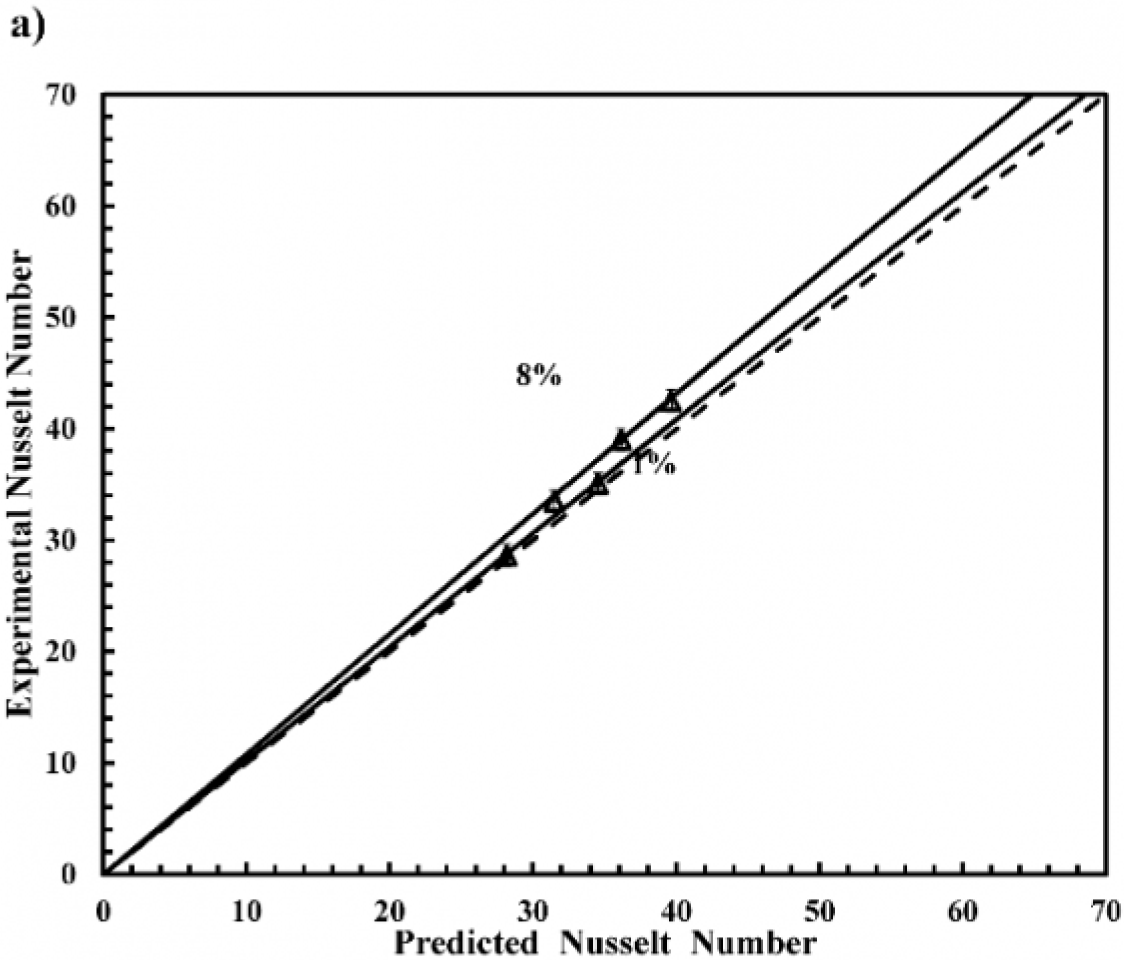

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Figure 4: Fig. 4 :

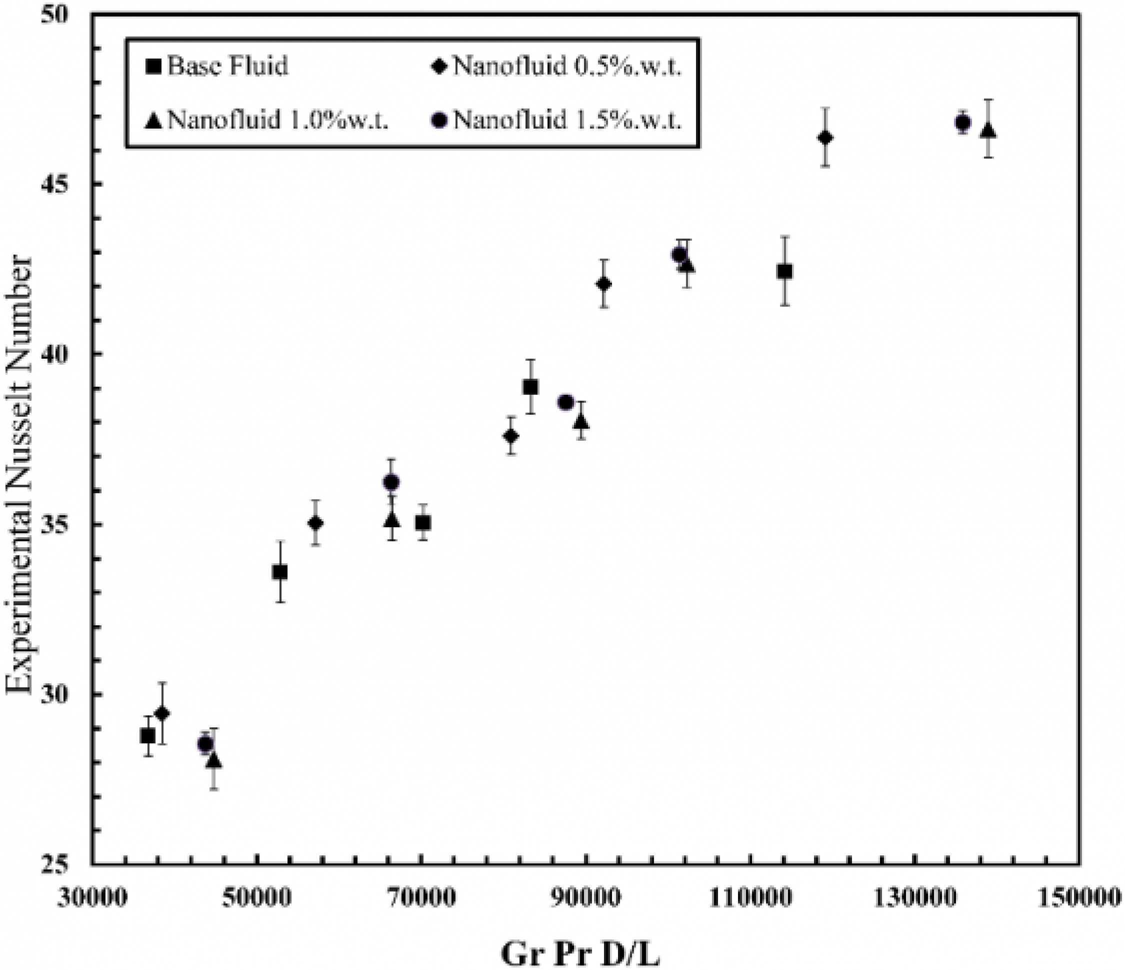

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Figure 5: Year 2017 A

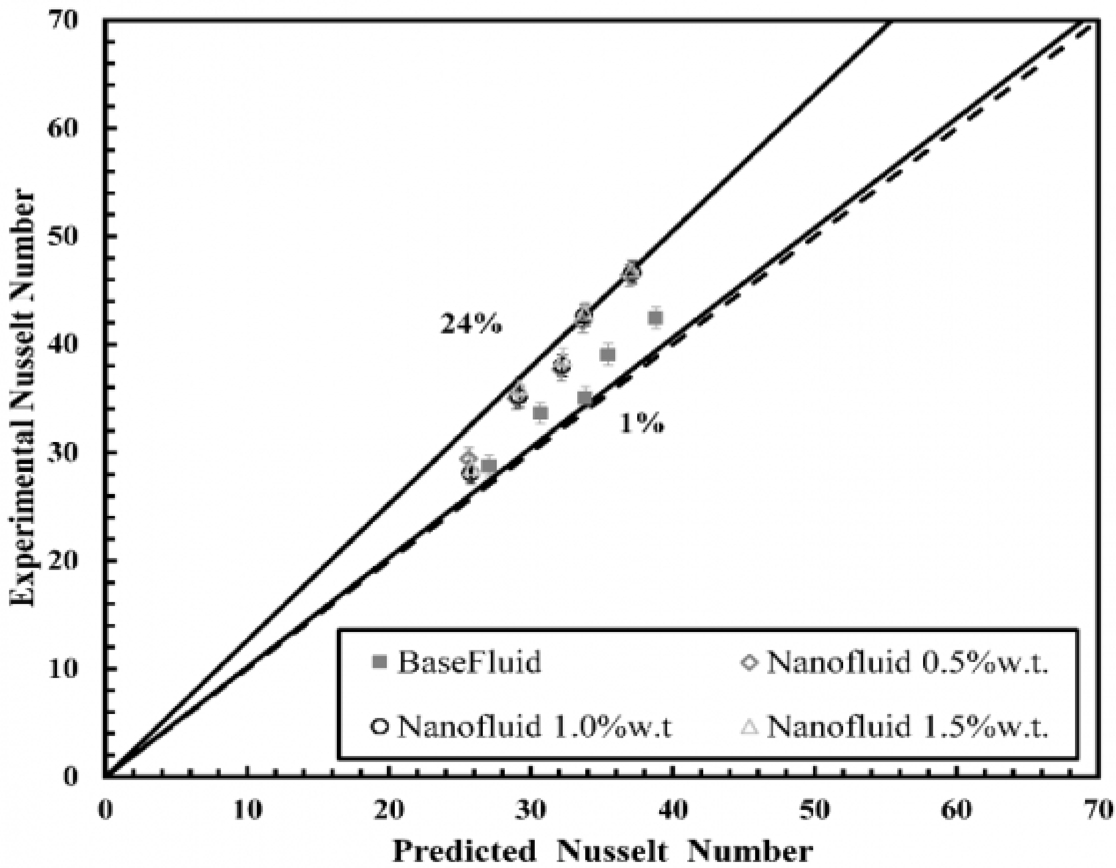

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Figure 6: Fig. 5 :Fig. 6 :

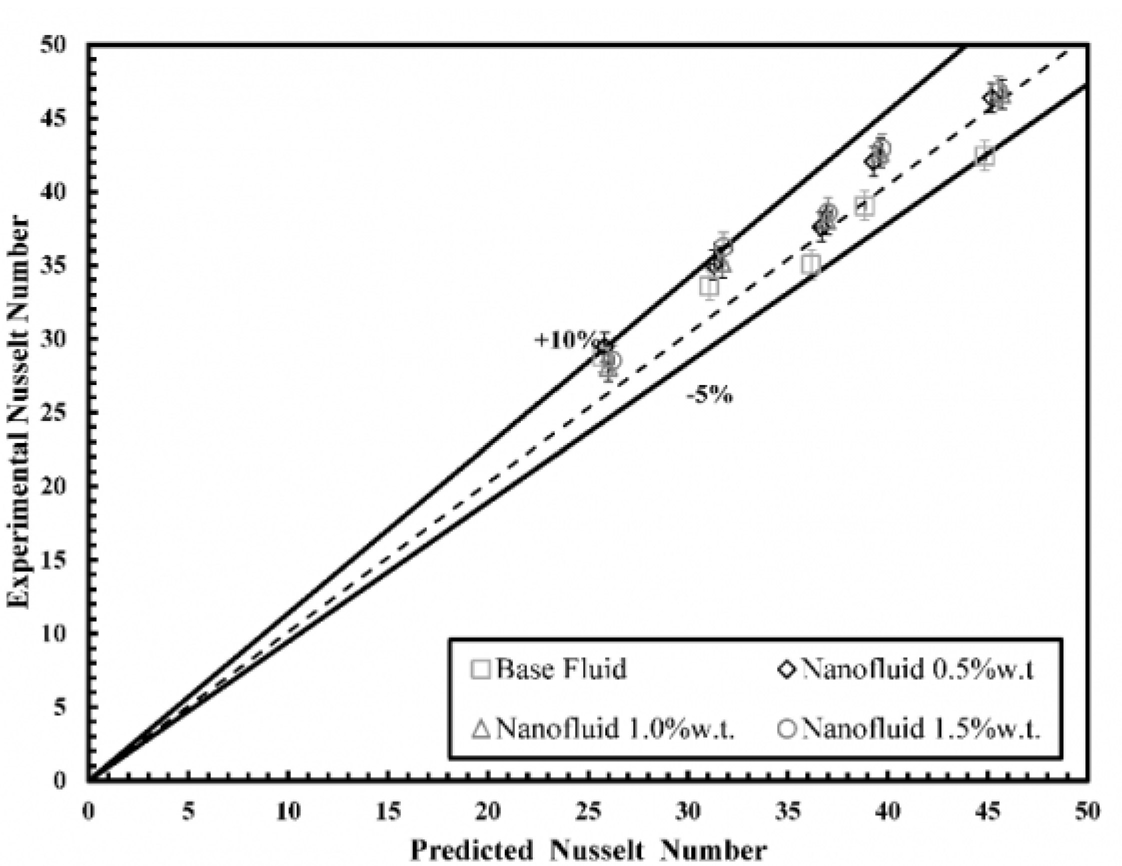

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Figure 7: Fig. 7 :

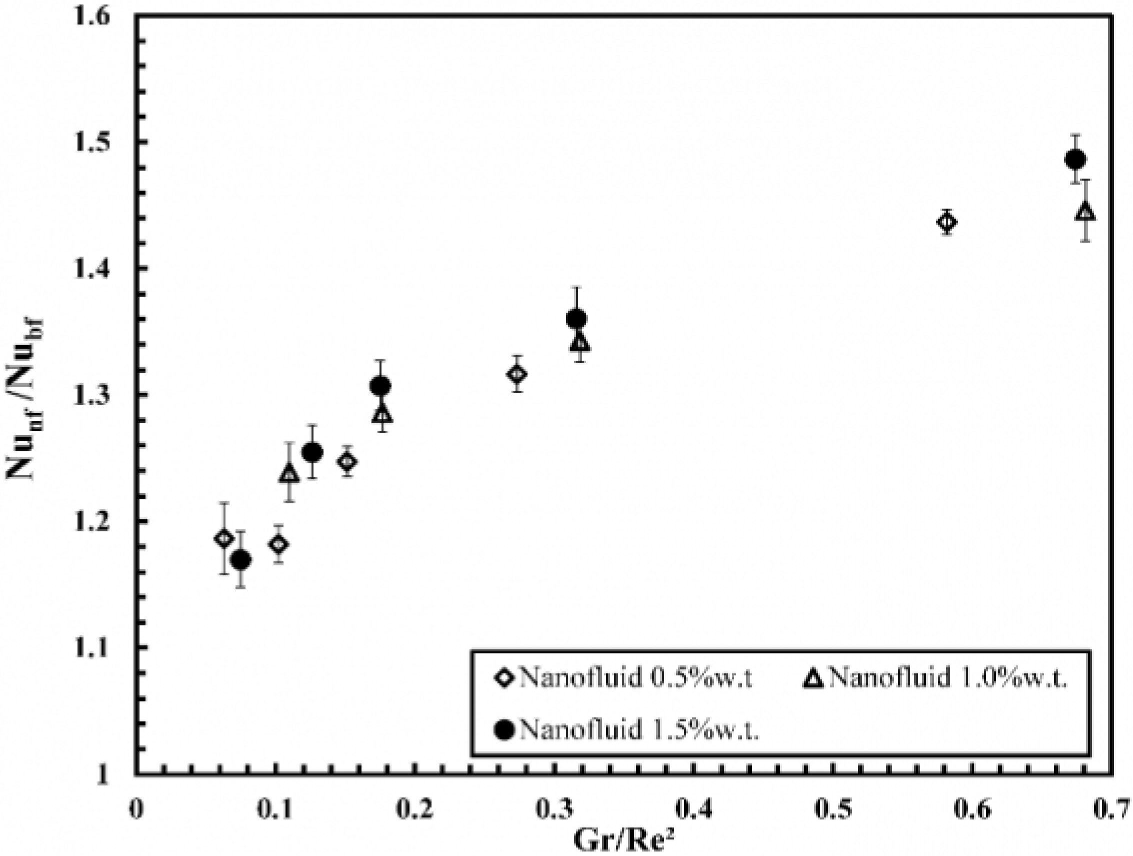

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Figure 8: Fig. 8 :Fig. 9 :

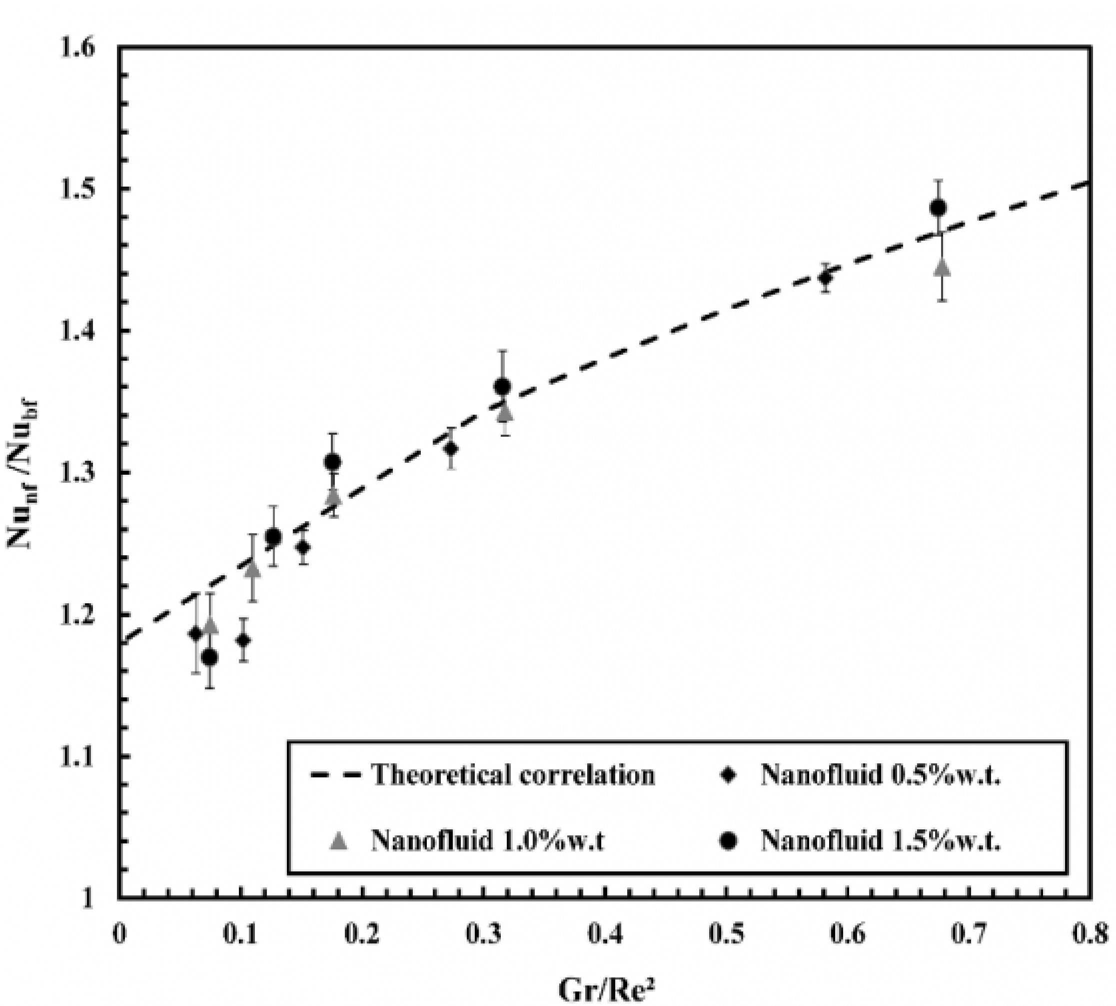

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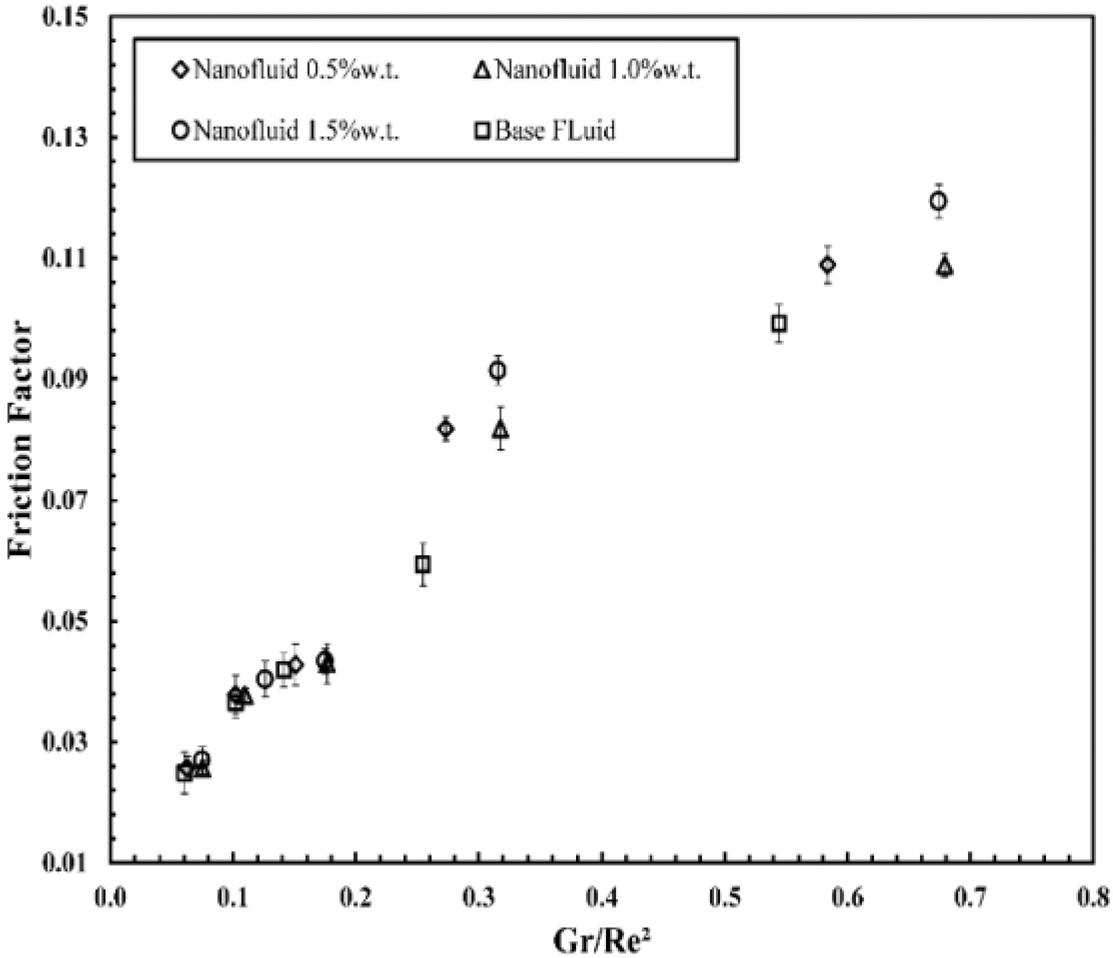
Figure 9: Fig. 10 :Fig. 11 :



12

Figure 10: Fig. 12 :

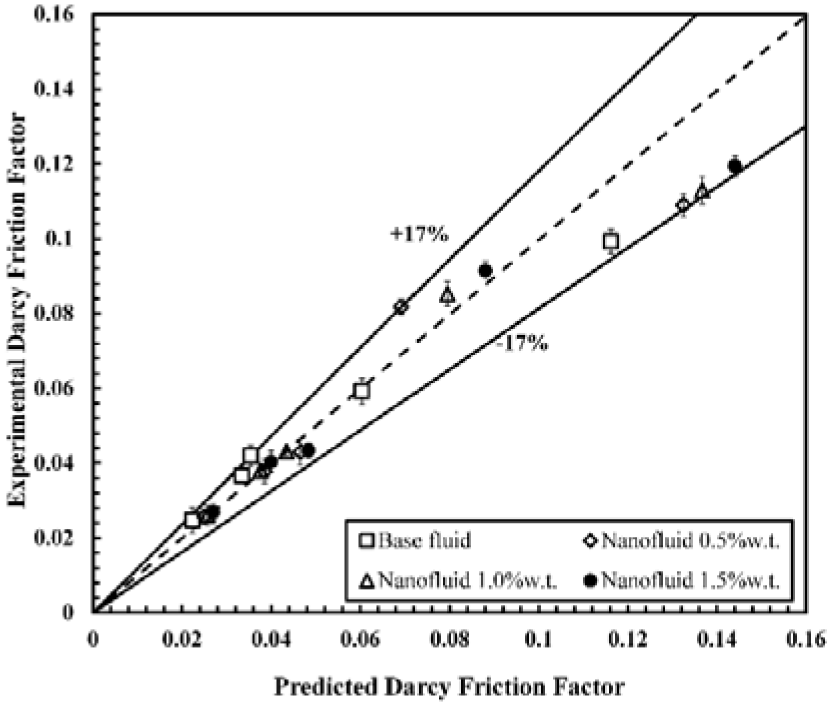


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Figure 11: Fig. 13 :

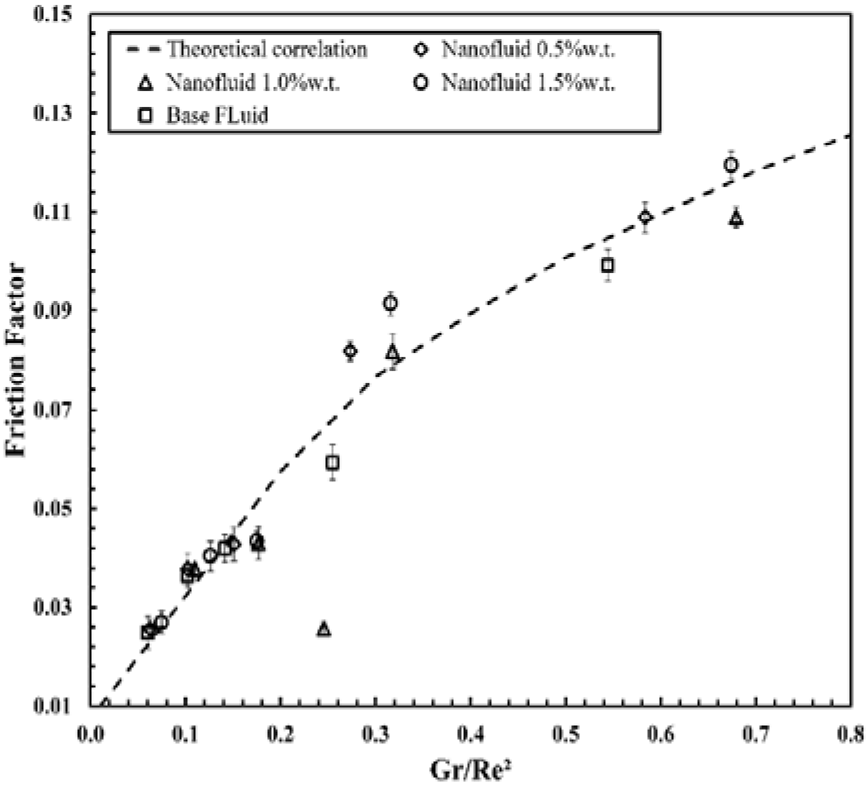

Figure 12:

1

Thermo-physical property	Temperature (°C)		
	8	3	100
Density (kg/m 3)	855		815
Heat capacity (kJ/kg.K)	2.03		2.30
Kinematic viscosity (mm 2 /s)	32		5.2
Thermal conductivity (W/m.K)	0.133		0.128

Figure 13: Table 1 :

2

Thermo-physical property	Value
Morphology	Nearly spherical
Particle size (nm)	40
Purity	99%
Bulk density (kg/m 3)	790
True density (kg/m 3)	6400
SSA (m 2 /g)	20
Thermal conductivity (W/mK)	20

Figure 14: Table 2 :

3

Items	Value
Gr	8000 to 37400
Pr	330 to 385
Re	200 to 750
D/L	0.0178
Ri	0.1 to 0.7
Gz	1387 to 3676
a	0.0005 to 0.00083

Figure 15: Table 3 :

4

Property	Instrument	Range	Accuracy
Inlet/outlet temperature	RTD PT 100	-200 to 400°C	±0.1°C
Tube surface temprature	K-type thermcouple	-200 to 999°C	±0.1°C
Flow rate	Separation funnel	0 to 11	±100 ml
Pressure drop	PMD-75	10 mbar to 40 bar	±0.075

Figure 16: Table 4 :

5

Variables		Uncertainty
Diameter	U D	±0.033 mm
length	U L , U x	mm
Temperature of TC	U Ts ,U Ti	±0.035°C
Temperature of RTD	U Ts ,U Ti	±0.03°C
The uncertainty of flowmeter	U v2	±1 ml
Specimen of weight used for density	U m	±0.5 mgr
Specimen of Volume used for density	U v1	±0.5 milt
Heat capacity	U cp	±3%
Thermal conductivity	U k	±2.5%
Dynamic viscosity	U ?	±3%
Pressure drop	U Î?" p	±0.075%

Figure 17: Table 5 :

6

Items	Value
Volumetric flow (m 3 /s)	1.15×10 -4
Tube surface temprature (°C)	98
Bulk temperature(°C)	49.65
Heat capacity(J/kg K)	1.71
Density(kg/m 3)	854.6
Duration of nanofluid loaded the flow rate measuring system(second)	8.7
Heat conductivity(w/m.k)	0.1497
Dynamic viscosity (Pa.s)	0.152
Pressure drop (Pa)	12220.2

Figure 18: Table 6 :

7

Items	Value
U Q (uncertainty of volumetric flow rate)	1.15×10 -4
U ? (uncertainty of density)	0.023
?? ???(uncertainty of mass flow)	0.0023
?? ???? (uncertainty of Reynolds)	0.023
?? ???? (uncertainty of Prandtle)	0.007
?? ?? ?? ?? (uncertainty of inlet bulk tempearture)	0.0018
?? ?? ?? (uncertainty of wall tempearture)	0.0096
?? ?? ?? ?? (uncertainty of out let bulk temperature)	0.002
?? ??? ?? ?? ??? ?? ?? ? (uncertainty of defrential between inlet and outlet temperature)	- 0.00034
?? (?? ?? ??? ??) (uncertainty of defrential between wall and bulk temperature	- .00104
?? ? ??ð ??"ð ??" ????? (uncertainty of mean convection heat transfer)	0.0293
?? ???? ???? (uncertainty of Nusselt number)	0.0156
?? ??? (uncertainty of pressure drop)	0.016
?? ð ??"ð ??" (uncertainty of friction factor)	0.0267
?? ?? (uncertainty of performance index)	0.0578

VII. Nomenclature

Cp	0 B specific heat capacity (kJ kg. K ?)
D	1 B tube diameter (m)
F	2 B Darcy friction factor (? 2 ?D 5 ?p)/ 2Lm?2
g	3 B gravity (kg m 2) ?
Gr	4 B Grashof number (??tD 3 ? 2 g/? 2)
Gz	5 B Graetz number (Re Pr D L ?)
h	6 B convection coefficient (w m 2 . k) ?
K	7 B thermal conductivity (W m. k ?)
L	8 B tube length (m)
m	9 B mass (kg)
m?	1 0 B mass flow rate (kg/s)
Nu	1 1 B Nusselt number (h ? k) ?
Q	1 2 B volumetric flow rate (m 3 /s)
Re	1 3 B Reynolds number (?uD ? ?)
Ra	1 4 B Rayleigh number (GrPr)
Ri	1 5 B Richardson number (Gr Re 2) ?
Sp. G.	1 6 B Specific gravity-density relative to that of water at 4°C (m 3 /kg)
T	1 7 B temperature (K)
V 1	1 8 B volume of flow rate measuring system (m 3)
Î?"P	1 9 B Pressure drop (Pa)
Greek symbols	

Figure 19: Table 7 :

.1 Acknowledgment

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