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Experimental Study on Heat Transfer Improvement in a Circular Passage Using Metal Oxide and Ethylene Glycol Based Well Stable Nanofluids

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ABSTRACT

Zinc Oxide @ Glycol based nanofluids was prepared using the ultra-sonochemical technique and 2 step methods. The heat convection characteristics of as prepared nanofluids were observed for a closed single conduit in turbulent flow regimes. The prepared nanofluids were characterized for UV-vis, FTIR, XRD, FESEM, and TEM analysis to confirm the accurate synthesis of ZnO nanoparticles. Analytical data related to heat transfer properties of the synthesized nanofluids for the heat exchanger, incorporated with the conduit test section were collected. The addition of ZnO solid nanoparticles in the Ethylene Glycol enhanced the value of thermal conductivity and other thermo physical characteristics of the nanofluids. Supreme thermal conductivity was recorded at 45°C for using 0.1 wt.% of Zinc Oxide @ Glycol based nanofluids. Adding more wt.% of the ZnO solid nanoparticles in the Ethylene Glycol increased the thermal conductivity subsequently with variations in temperature from 20 to 45ºC. Furthermore, Nusselt numbers of Zinc Oxide @ Glycol based nanofluids were calculated at different wt.% of ZnO present in Ethylene Glycol base fluid. The occurrence of ZnO nanoparticles into the Ethylene Glycol base fluid intensify the Nusselt (Nu) number by 51.5%, 43.79%, 38%and 24.06% for 0.1 wt.%, 0.075 wt.%, 0.05 wt.% and 0.025wt.% concentrations, respectively. Varying wt.% of ZnO (0.1 wt.%, 0.075 wt.%, 0.05 wt.%). The absolute average heat transfer of Zinc Oxide @ Glycol based nanofluids using at the highest concentration of 0.1 wt.% was enhanced compared to the Ethylene Glycol base fluid. The magnitude of absolute average heat transfer was increased from 600 W/m^2k for the EG@DW mixture to 1292 W/m^2k for Zinc Oxide @ Glycol based nanofluids. Correspondingly, the heat transfer development at the other three (0.075 wt.%, 0.05 wt.%, and 0.025 wt.%) was observed as 600–1167, 600–1010 and 600–970 W/m^2k, respectively, which is superior to pure Ethylene Glycol base fluid.

1. Introduction

In 1883, turbulence was established as a scientific problem after Reynolds bring the first experimental study on circular flow channels [1]. Increase in local Reynolds values Re_x, both external boundary flows and internal pipe flows have a pulsating movement, unveiling a substantial deviation

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among laminar to turbulent flows. Since the 20th century era, the study of turbulence flow has been extensively done due to its substantial importance for technology and science betterment [2,3]. As turbulence has been introduced, the researchers are more focused on changes from laminar to turbulent flow studies and their problems the science and engineering [4]. Similarly, the varying test has been executed on the different shaped heat exchangers and their key effects on the heat transfer improvement [5-7]. In addition, varying conventional fluids have been used earlier for heat and cooling applications, later they have altered Nanofluids due to their limitations [8-10].

Jiao Zhang *et al.,* [11] have used Cu, CuO, Ag, and Fe_3O_4 mixed in water with the addition of carboxymethyl cellulose for the study of heat transfer and pseudo plastic subjected to wall slips. To divide the turbulent layer into two parts (i)-the turbulent region and (ii)-the laminar sub layer, the mixing length Prandtl theory was adopted here. The bvp4c method has been used in numerical calculations. The outcome that arises from the proposed research highlights that the wall slip parameters are much more influential on temperature and velocity, while the laminar sub layer has more variations. The larger wall slips and smaller particle size would cause to reduce the friction loss. And the overall heat transfer will be more strengthened for small size wall slips and greater size particles. Among all Nanofluids, the Ag/carboxymethyl cellulose showed enhanced encouraging heat transfer for turbulent regions.

Adnan Qamar *et al.,* [12] used ZnO as an alternative liquid for heat transfer enhancement, where it has been added in to deionized water at 0.048%, 0.036%, 0.024%, and 0.012% volume fractions. A typical two step method was followed to prepare these Nanofluids. Both acetylacetone and sodium Hexa metaphosphate were been chose to add to these Nanofluids for particle stability. The varying test outcomes showed that acetylacetone based ZnO Nanofluids look more stable for a minimum of 60 days. The viscosity and thermal conductivity measurements were taken out within a temperature range of 20°C to 60°C, where it has been noticed as the volume fraction of ZnO increases the viscosity and thermal conductivity will increase. At the same volume fraction of ZnO, the substantial improvement in viscosity and thermal conductivity were 16.75% and 23.70%.

G. Sriharan *et al.,* [13] Has executed a study on mini hexagonal tube heat sink-MHTHS to see its thermal performance of it. The SiO_2, Al_2O_3, CuO, and Di-ionized water were used to prepare the nanofluids for the proposed study. All the nanofluids were prepared at 0.01 volumetric fraction and Di-ionized water was used as a base fluid. To enhance the thermal performance of the MHTHS, the constant flow rate of DI-ionized water at $30Lh^{-1}$ in a mini channel, varying flow rates like 50, 45, 40, 35, 30, 25, 20, and 15 Lh^{-1} were considered here. From positive outcomes, it has been concluded that the Al_2O_3 and Di-ionized water based nanofluids showed greater thermal performance in comparison with other nanofluids. In a detailed analysis, it has been found the higher volumetric concentration of the nanofluid leads to the more improved thermal performance of the MHTHS inside the hexagonal tube.

Nishant Kumar *et al.,* [14] has performed his studies on TiO_2 and CuO based nanofluids flowing inside a tube and tube side in the shell heat exchanger to see their thermal performances. The effects of the addition of the TiO_2 and CuO solid nanoparticles into the water were analysed in this study. Both nanofluids showed positive improvement. The varying concentrations of both nanofluids were considered for the thermal conductivity, heat transfer analysis, base fluids, time of sonication, and fluid temperature. The 0.01 to 0.06 vol% of solid nanoparticles were used in the base liquid. Further, heat transfer analysis was conducted for varying temperatures and Peclet numbers. Finally, a positive enhancement was noticed in the heat transfer by increasing the vol% of the solid nanoparticles in the base liquid.

Ahmed *et al.,* [15] use ZnO metal oxide dispersed in DW at four varying 0.1, 0.05, 0.075, and 0.1 wt.% concentrations without using any stabilizing agent or surfactant for the heat transfer studies.

All the Nanofluids and DW were run on a well-designed test rig [16,17]. The single pot sonochemical assisted technique was adopted for ZnO synthesis, later the synthesized were dispersed in DW by using a high probe sonication procedure. Different characterization tests were been executed for the proper synthesis and ZnO confirmation. The 90% spherical ZnO nanoparticles were formed, and this is all credited to the sonochemical technique. The study outcomes deliberate that the higher wt.% of ZnO in DW would be led to a positive increase in heat transfer and thermos physical properties [15,18,19].

1.1 Key Objectives of the Study

1. Preparation of ZnO@Ethylene Glycol based Nanofluids at varying wt.% and their effects on thermo physical and heat transfer properties.
2. The UV-vis analysis for the ZnO confirmation.
3. Analysis of thermos physical properties at varying wt.% of the ZnO@Ethylene glycol based Nanofluids.
4. Improvement in heat transfer using a circular heat exchanger.

2 Methodology

2.1 Materials

The initial materials for synthesis, Zinc Acetate tetra hydrate, Ethylene Glycol, and Sodium Hydroxide were procured from Sigma Aldrich with purification.

2.2 Equipment

High probe sonicator SONIX Vibra cell was used to produce ultrasonic waves with a 0.5-inch probe horn design by titanium alloy, Max 20KHz frequency, and 750K watt power. Further, to see the ZnO morphology the FESEM analysis was taken by using an OXFORD INSTRUMENT available at NANCAT research centre at the University of Malaya Kuala Lumpur Malaysia. Similarly, the UV-vis image data was collected by using SHIMADZU UV spectrometer UV-1800 available at Advanced CFD lab, Faculty of the engineering university of Malaya Malaysia.

2.3 ZnO Synthesis Flow

A Sodium Hydroxide aqueous solution of (200ml, 1M) was put drop to drop into another Zinc acetate aqueous solution of (200ml, 2M) in a glass beaker with a capacity of 500ml overall. This all process was continued under a high probe sonication by using a sonicator. The resultant solution was left under continuous sonication for 2-hours, 3/2 sec on-off pulse time, 80% amplitude, 0^oC probe temperature, and 360000 Joule delivered energy. Finally, the white dense precipitates were washed several times by using a high speed 6000rpm centrifuge machine with distilled water and ethanol, then washed ZnO was kept for drying in a vacuum oven as given in line diagram Figure 1 [16].

2.4 Nanofluids Preparation

Ethylene glycol was taken as a base dispersant liquid. After characterizations of the obtained product, the facile 2-step simple preparation procedure was followed to prepare the ZnO and Ethylene mixed nanofluids. For this purpose, the above mentioned sonicator and settings were used to disperse the ZnO solids in Ethylene glycol. The 3-hours continuous sonication process was led to prepare nanofluids at changed (0.1 wt.%, 0.075 wt.%, 0.05 wt.%) concentrations. In the next step, all these nanofluids were trailed for thermo physical and heat transfer characteristics.

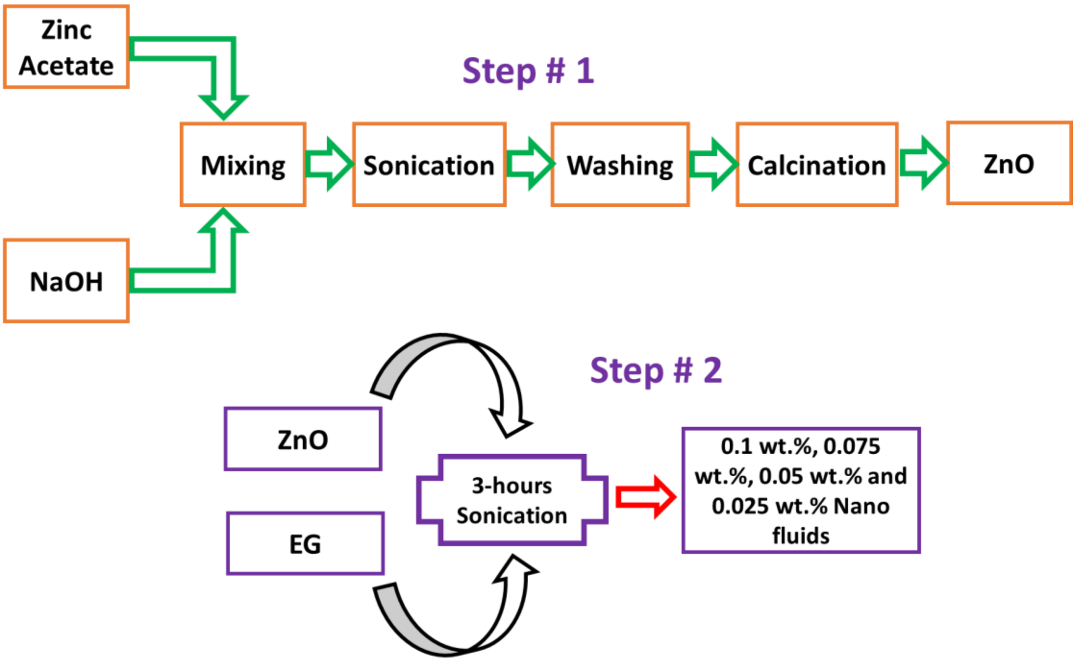


Fig. 1. (a) ZnO Synthesis line flow and its nanofluids preparation

Fig. 1. (b) EG and ZnO+EG based nanofluids at varying wt.% concentrations

2.5 Experimental Setup

The entire heat transfer related experiments were executed on a fully equipped heat transfer test rig available at the advanced CFD lab, Faculty of Engineering University Malaya. The below given Figure 2 is representing a complete schematic view of the heat transfer test rig, which consists of varying shaped heat pipes like circular, square and annular. Further, varying adjustments, functional and operational controls were connected where needed. The heat exchanger length was 1.2m where the active area is 1m, and the hydraulic diameter of the pipe is 0.01m. Five highly sensitive K-Type thermocouples were installed on the outer surface of heat exchangers apart from each other at an equal distance of 0.2m. The circular shaped heat exchanger has heated by an external heater wrapped around it, which is directly connected to the main voltage regulator. Pressure DP and chiller are used to see the pressure drop loss and to keep the constant temperature of the fluid while it is being running inside of the pipe [20,21].

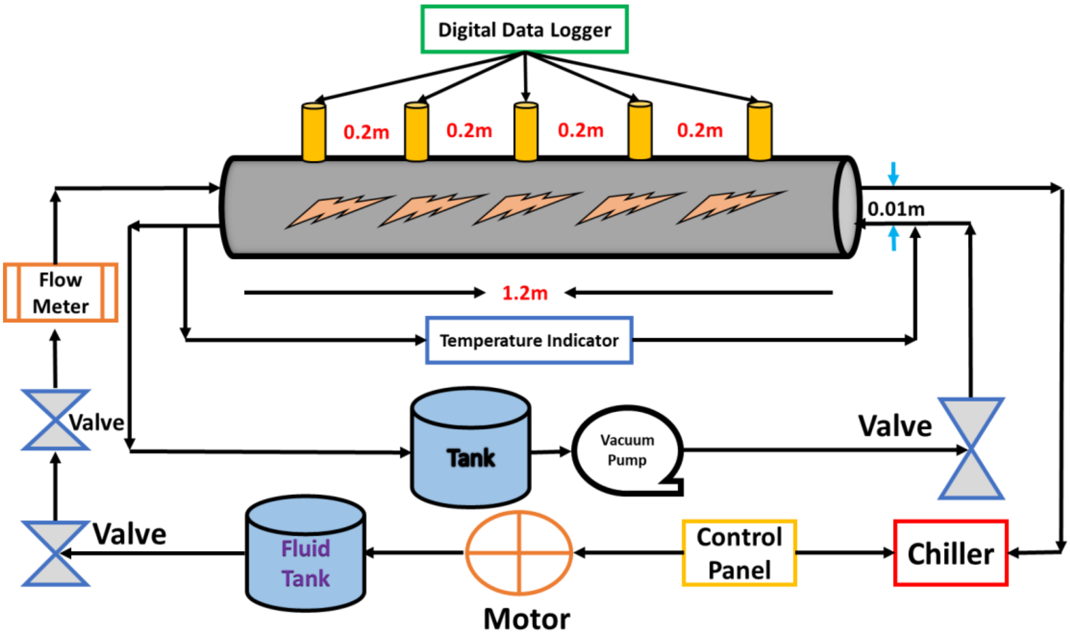


Fig. 2. (a) Schematic overview of Heat Transfer test rig

Fig. 2. (b) Schematic overview of Heat Transfer test rig

3. Results and Discussion

3.1 UV-vis Spectra

Figure 3(a) is showing UV-vis spectra analysis as a key function of the total wavelength for both ZnO and loaded. The given spectral properties were very ordinary to the metal oxides. There is a prominent peak at 371nm towards the reflecting spectra near to the UV-vis region which is the best property of band gap energy. The curvy shape of the spectra is due to the transition in the band gap. The maximum wavelength for the ZnO analysis was adjusted within a range of 190 nm to 800 nm, where the prominent peak at 271nm indicates the presence of ZnO which is 100%. These outcomes highlight that the considerable reluctant energy band in visible light that confirms the proper ZnO product [22].

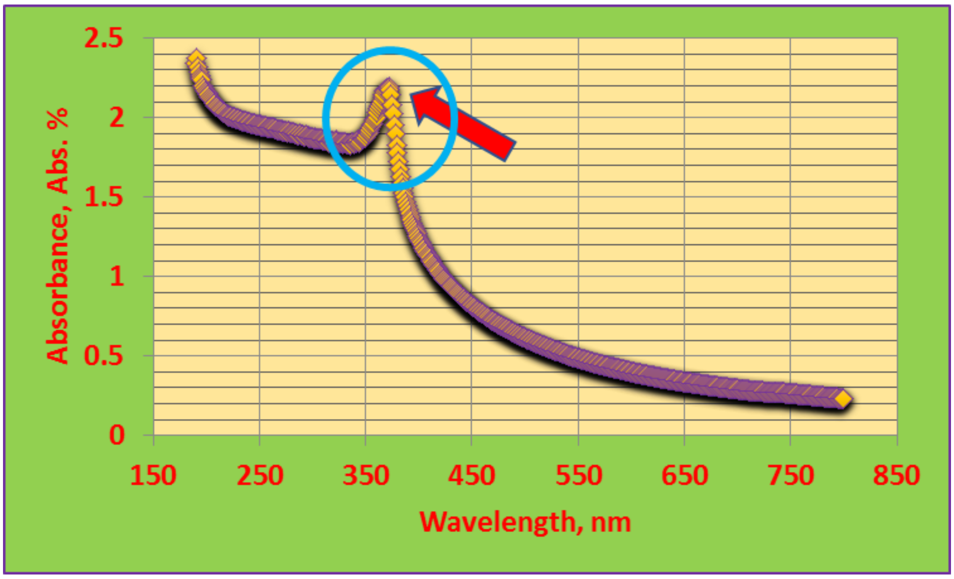


Fig. 3. (a) The UV-vis spectra of ZnO nanofluid

Figure 3(b) is showing four varying wt.% concentrations of the ZnO dispersed in EG base and pure EG without adding solid particles were been tested for UV-vis analysis to see the absorbance ratio % according to light wavelength. The pure EG showed maximum absorbance of 1.52% of the total. Then ZnO solid nanoparticles were added according to 0.025wt.%, 0.05wt.%, 0.075wt.%, and 0.1wt.% in EG and tested for absorbance test accordingly. The maximum absorbance % were recorded 1.54 at 0.025 wt.%, next the 2.11% absorbance has been noticed at 0.05 wt.%, furthermore 2.51 % absorbance was recorded at 0.075 wt.%. Finally, the highest absorbance among all nanofluids was noted at 2.67 %, which is due to the maximum addition of ZnO solid nanoparticles into EG base fluid. Another reason the maximum presence of solid in the liquid would cause to reduce the UV light passing through it.

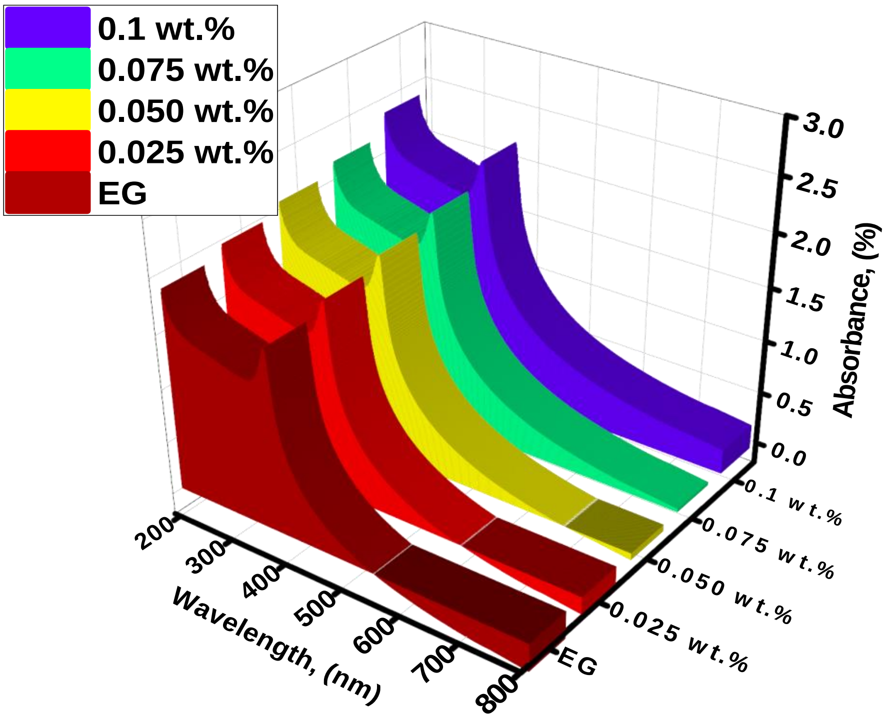


Fig. 3. (b) UV-vis spectra analysis for varying wt.% concentrations of EG based nanofluids

3.2 Nano Fluid Stability Analysis Using Sedimentation Technique

The thermophysical properties of the nanofluids could affect by their dispersion and stability, hence the stability and suspension analysis are mandatory before using them. There could be used varying techniques for this purpose like Zeta potential, Transmission electron microscopy, scanning balance technique, Scanning electron microscopy, light scattering process, UV-vis analysis, and sedimentation of particles method. The sedimentation of particles is a very easy and commonly used technique with different time spams. In this method, when there is nothing change in solid particle wt.% with time, it is called very stable nanofluids. For this method, the nanoparticle stability is noticed by shooting the images of the subject nanofluids at different time intervals using a good quality camera. The nanofluids usually were kept in transparent glass viles, where the sedimentation could easily observe. This is a long time taking observation technique [23,24].

Figure 4 is representing some photos taken by the camera since the day of preparation of nanofluids at four varying 0.025wt.%, 0.05wt.%, 0.075wt.% and 0.1wt.% concentrations of the ZnO nanoparticles in EG base fluid. Although, the images were taken on a daily basis, here the best outcomes were reported on a weekly basis. As can see in Figure 4, all the samples were looking very stable and suspended from the day of preparation until week 7 to week 8, which is longer stable and has not been reported earlier for the metal oxide based nanofluids. During week 8, little bit particles were sediment that can see in the photos. In weeks 9 to 10, the sedimentation rate increases due to the sedimentation of the ZnO nanoparticles. The longer stability and suspension of nanoparticles could due to the viscosity of a base fluid, high sonication ratio, and particle shape/size. Among all wt.% of the nanofluids, the 0.1 wt.% showed good stability due to the maximum presence of ZnO nanoparticles.

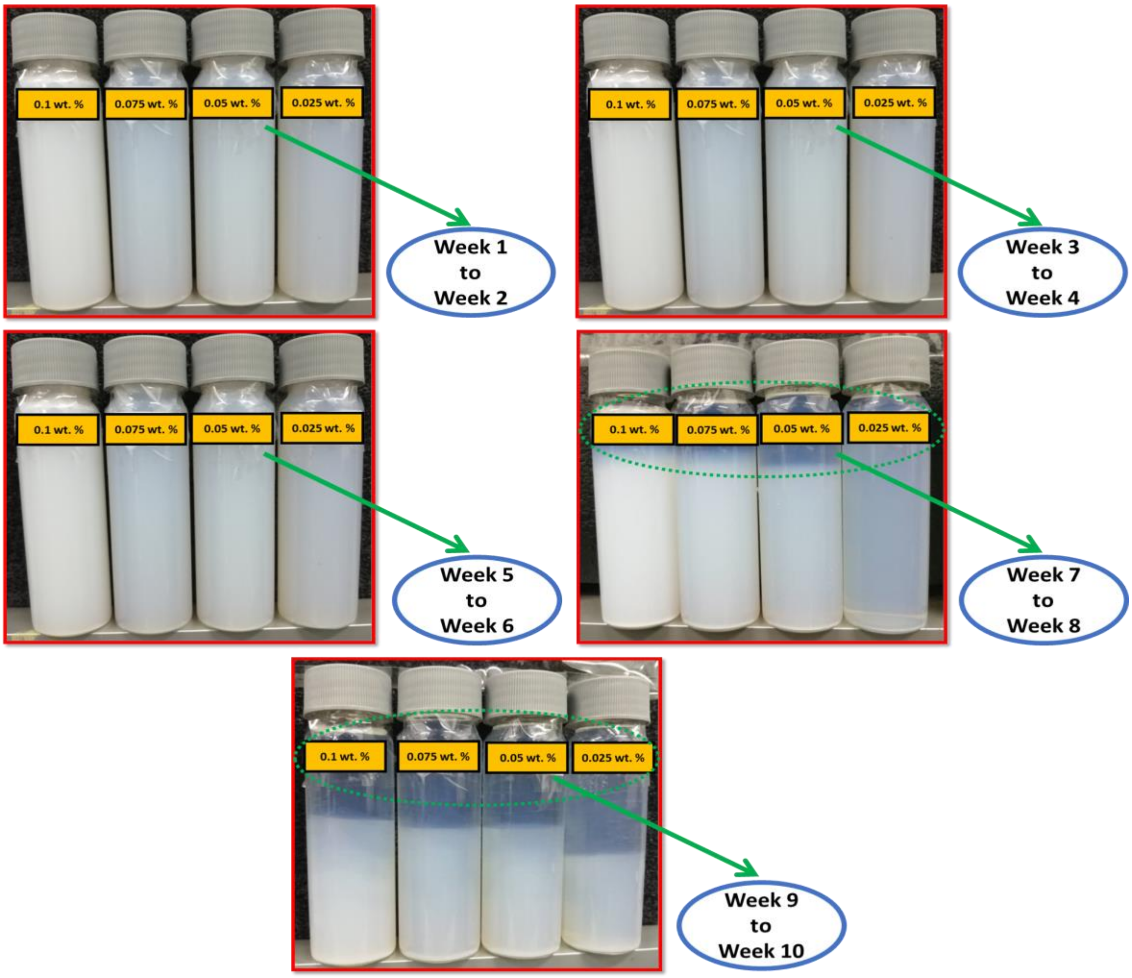


Fig. 4. Nanofluids stability analysis for all ZnO and EG based wt.% concentrations

3.3 FESEM Analysis of the Synthesized ZnO

The FESEM analysis of synthesized ZnO nanoparticles was conducted at SEM/FESEM lab at the NANOCAT CENTER Institute for advanced studies building, University of Malaya Kuala Lumpur Malaysia. The sample was placed on a carbon electrode holder. An advanced FESEM machine with model JSM7800F having a maximum 0.7nm resolution was used, also equipped for EDS analysis using OXFORD microprobe.

Figure 5 is showing the images taken during FESEM analysis of the synthesized ZnO nanoparticles making it easy to see the shape (morphology) and size of the particles. The varying sizes of 17nm, 14nm, and 12nm were observed and the pure spherical shape of mostly nanoparticles was also seen. The highest magnification was the use of 50KX with 10.00kv, det (ETD), high vacuum, WD of 9.8mm, and active area of 2µm for image taking. The mostly ZnO particles were of spherical shape which is mainly credited to the high probe sonication technique for the ZnO synthesis. The high probe sonication technique helps to maintain equal pulse energy during the chemical reaction, so as result the uniform and regular particles shape formed.

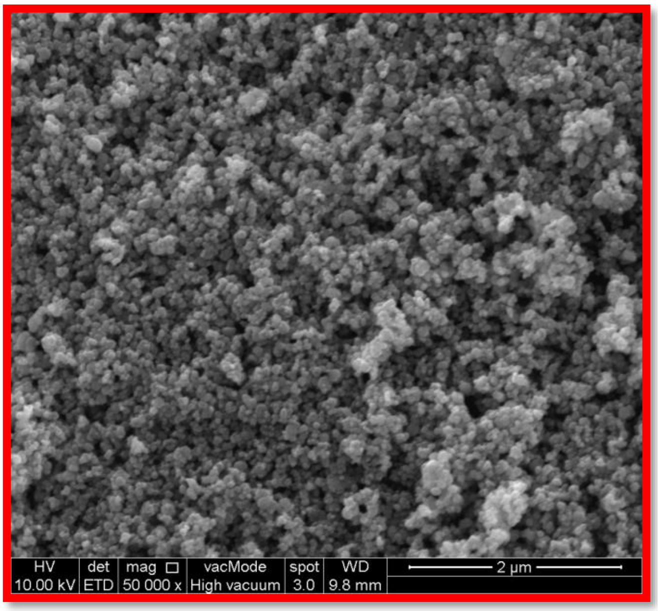


Fig. 5. FESEM image of the ZnO nanoparticles (NPS)

3.4 Thermo Physical Characteristics

All the 0.1 wt.%, 0.075 wt.%, 0.05 wt.% and 0.025wt.% concentrations of ZnO and Ethylene glycol based nanofluids were tested for dynamic/kinematic viscosity and density analysis by using viscometer available at Micro/Nanomaterials lab level # 2, faculty of engineering University of Malaya. The temperature range for all these three analyses was selected within 20°C to 45°C maximum. The outcomes showed that the wt.% loading of ZnO into pure EG liquid increases the viscosity and density will decrease with the temperature variations, which is uncertain, and why it's happening will discuss in a later paper. The kinematic/dynamic viscosities and densities graphs showed higher viscosity and density for pure EG, while both were dropping while ZnO loaded into EG. At the highest temperature both the kinematic/dynamic and densities are low for all wt.% of ZnO and Ethylene glycol based nanofluids and pure EG as well. While this effect has to be found revere at low temperatures as given in Figure 6.

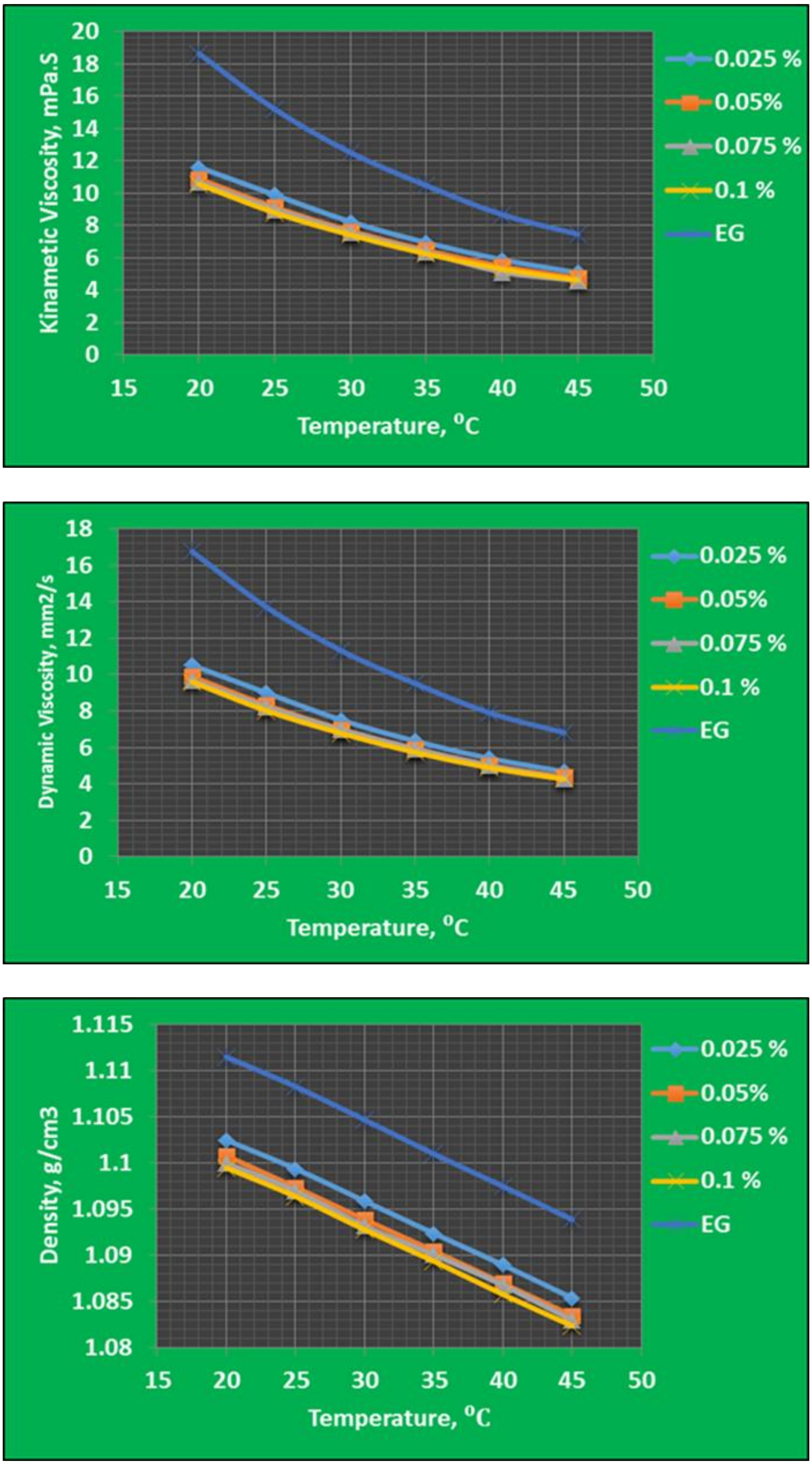


Fig. 6. Viscosities and Densities analysis of ZnO nanofluids

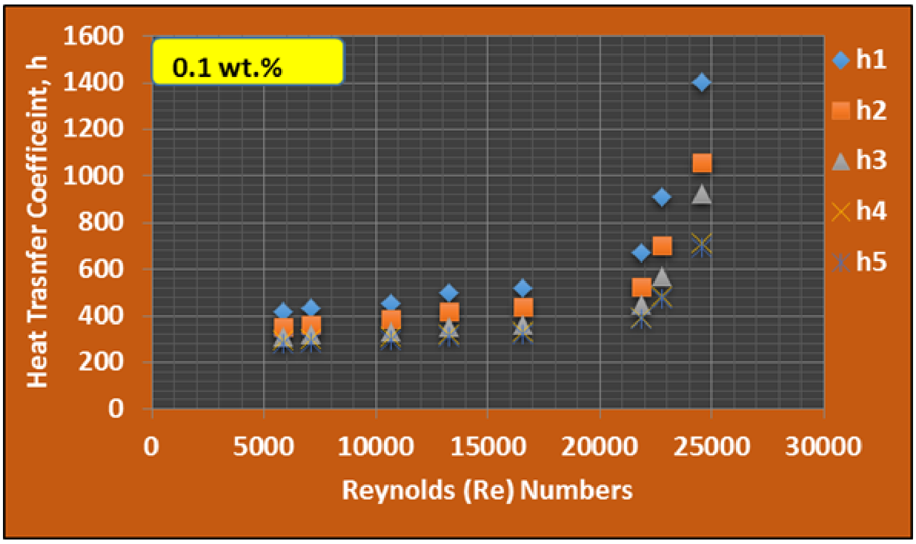
3.5 Heat Transfer Analysis in Circular Shaped Heat Exchanger

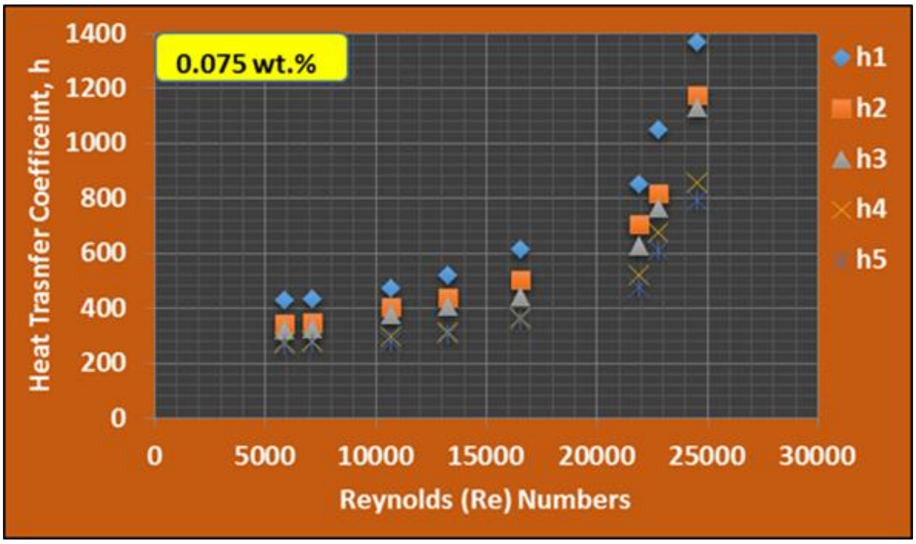
3.5.1 Heat transfer coefficient measurement

Four varying 0.1 wt.%, 0.075 wt.%, 0.05 wt.% and 0.025wt.% concentrations of ZnO and Ethylene glycol based nanofluids and pure EG were run on to a complete heat transfer test rig given in above Figure 2. The uniform heat flux of 10343.35 W/m^2 was applied to a circular shaped heat exchanger externally while 8 different flow rates were selected for the purpose. The entire experiment for the heat transfer improvement was executed in turbulent flow regimes. Later, the flow rates in m/s were converted into Reynolds by using varying equations for further analysis [18]. To produce above mentioned heat flux the regulator was adjusted on 220v maximum voltage [25].

To see the effects of flow rates and wt.% loading of ZnO on to heat transfer the varying test runs were executed for pure EG and all 0.1 wt.%, 0.075 wt.%, 0.05 wt.%, and 0.025 wt.% concentrations of ZnO and Ethylene glycol based nanofluids. It has commonly observed for fluids if the flow rate increases the heat transfer improvement will increase accordingly, which is common phenomenon. The deep study exposes that the higher we added ZnO nanoparticles into EG base fluid, it may vary the viscosity and density of the fluid. These variations in thermo physical properties would lead to a positive change in heat transfer improvement. Later, the heat experiment showed that if the wt.% of ZnO in EG base has increased it led to heat transfer improvement which is credited to the maximum presence of ZnO solid particles in the base fluid. On the other hand, the circular shape of the heat exchanger is offering less wall friction which is too plus advantage for heat transfer improvement.

Figure 7 are representing the local and average heat transfer improvement according to wt.% loading of ZnO into EG base fluid. The higher 0.1 wt.% of ZnO is showing the highest heat transfer improvement as compared to other, because the maximum loading of ZnO would cause to increase in heat transfer rate. Similarly, the 0.075 wt.%, 0.05 wt.%, and 0.025 wt.% of the ZnO loading give improved heat transfer results as compared to the EG base fluid. It has been noticed all the improvements were taken on the highest value of the Reynolds.




0.075 wt.%
Heat Trasnfer Coefficeint, h
1400
1200
1000
800
600
400
200
0
0
5000
10000
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Reynolds (Re) Numbers
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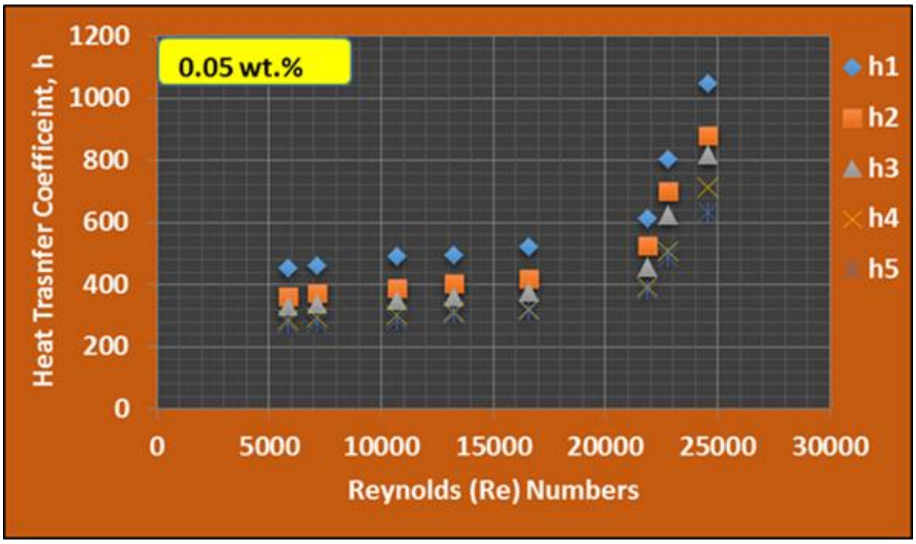
0.05 wt.%
Heat Trasnfer Coefficeint, h
1200
1000
800
600
400
200
0
0
5000
10000
15000
20000
25000
30000
Reynolds (Re) Numbers
h1
h2
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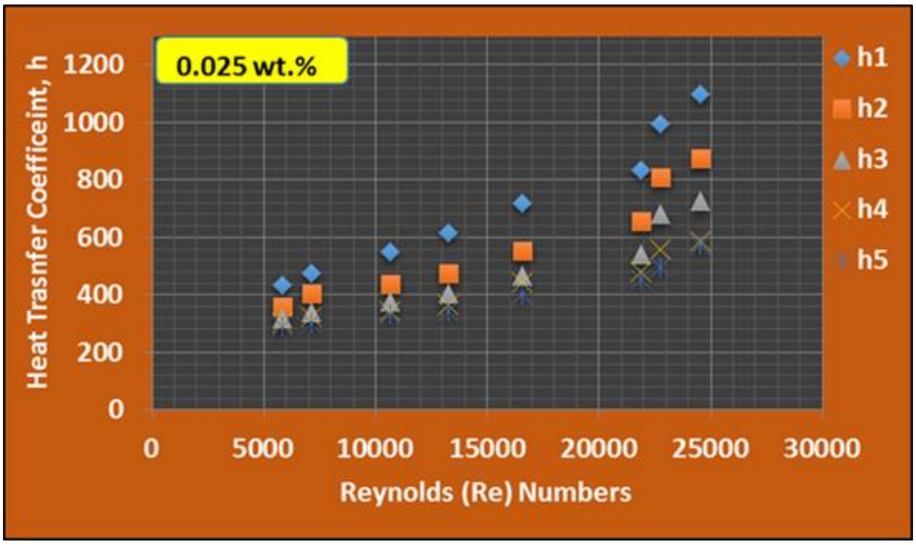
h4
h5


0.025 wt.%
Heat Trasnfer Coefficeint, h
1200
1000
800
600
400
200
0
0
5000
10000
15000
20000
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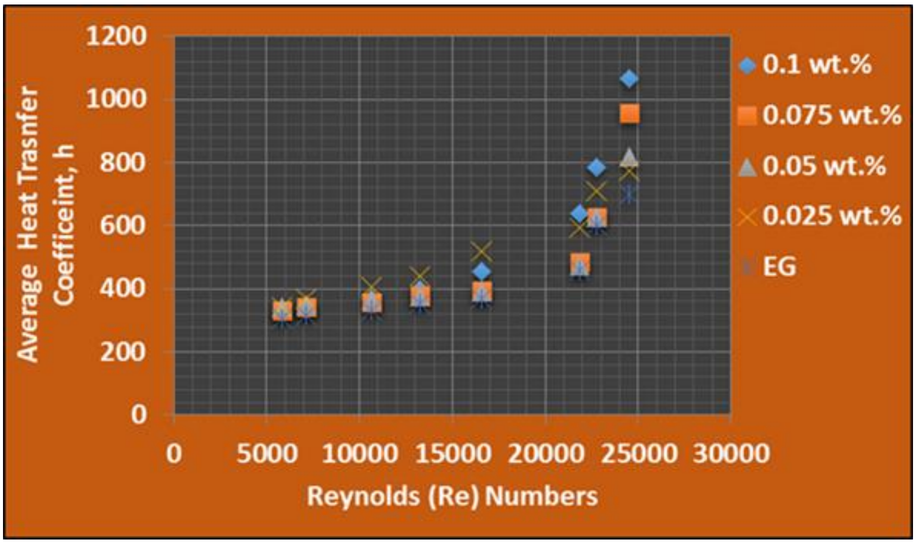

Fig. 7. Local and Average heat transfer variations

3.5.2 Nusselt numbers (Nu) measurement

Based on heat transfer analysis for all wt.% concentrations of ZnO and EG based nanofluids and pure EG fluids, the Nusselt numbers (Nu) at varying points of the circular shape heat exchanger were also calculated as given in Figure 8. At the input of the heat exchanger varying flow rates (Reynolds) were applied and constant heat flux was maintained around it. The laminar flow rate was maintained within the range of 5000 to 25000 Reynolds numbers. The deep calculation proved as the flow rate increased the Nusselt values at varying points were increased from inlet point to outlet point for all fluids and nanofluids. At 0.1 wt.% concentration, the highest value of Nusselt numbers was recorded which is about 25, at 0.075 wt.% concentration the lower than 0.1wt.% and higher than other wt.% concentrations was noticed which is almost 23, similarly at 0.05 wt.% the Nusselt values was 19 while at 0.025 wt.% the Nusselt value was recorded up to 17. The highest value of Nusselt numbers is credited to the maximum flow rate and maximum presence of the solid ZnO nanoparticles in the EG base. Finally, the average Nusselt numbers (Nu_{ave}) were also calculated for comparison to see the overall improvement. It has been found the highest wt.% concentration of ZnO and EG nanofluids showed maximum improvement on the highest Reynold number. Based on this analysis the 0.1wt.% concentration is the suitable choice for the heat transfer improvement in circular shaped heat exchangers.

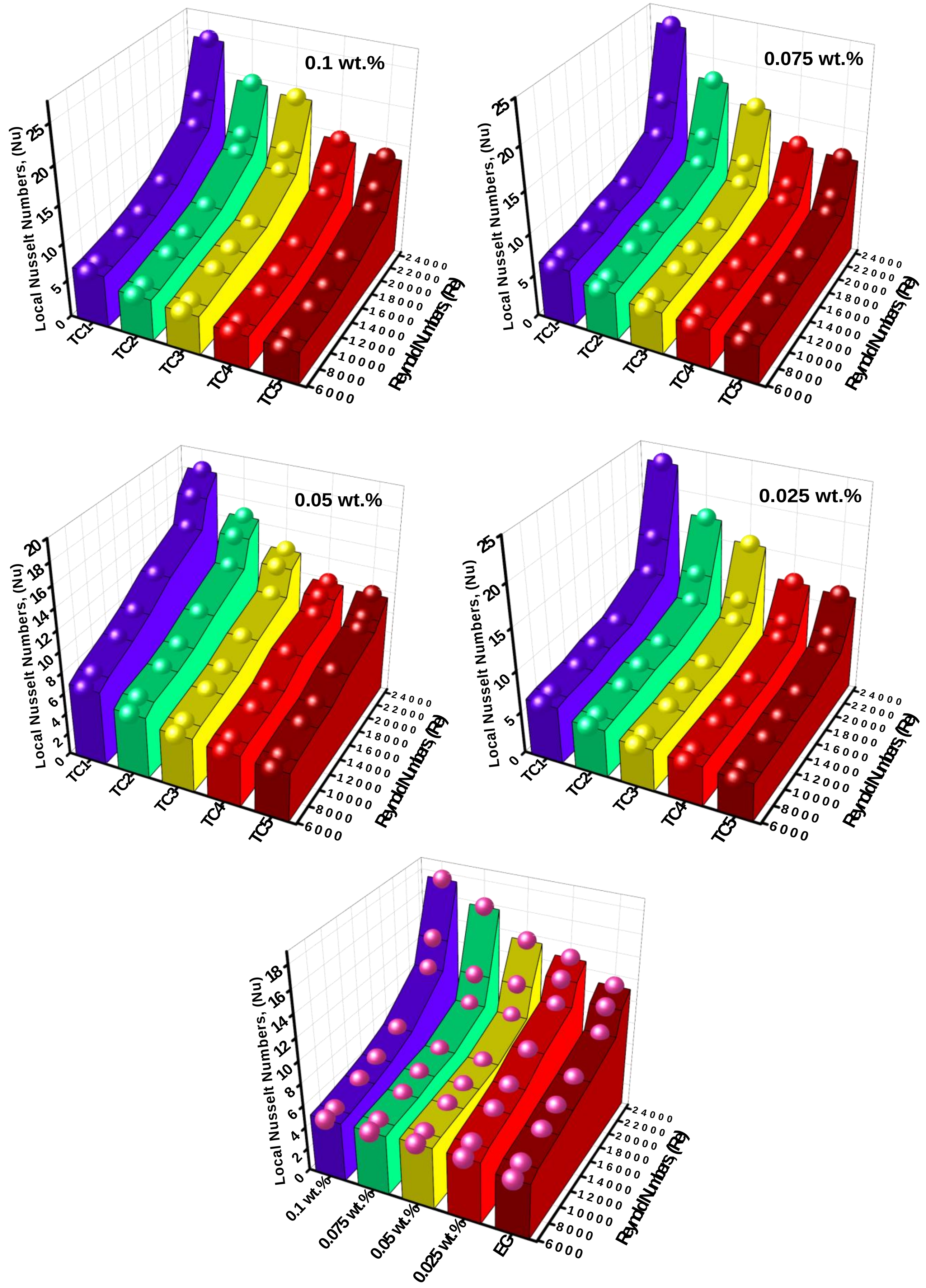

Fig. 8. Local and Average heat transfer variations

4. Conclusion

The presented study was mainly focused on the synthesis of ZnO, and preparation of ZnO and Ethylene Glycol based nanofluids for heat transfer studies in a square shaped heat exchanger. In the first step, the ZnO was synthesized by using the facile single pot sonochemical method. In the second step, the ZnO and Ethylene glycol based fluids were prepared. In the third step, the experimental setup was kept ready including the square shaped heat exchanger. Finally, the EG and ZnO loaded varying wt.% of the nanofluids were tested for thermophysical and heat transfer characteristics. After complete experimental execution, the following outcomes arises.

i. The single pot sonochemical synthesis gives the mostly similar shape of ZnO nanoparticles and could produce more yield.
ii. The addition of ZnO into the EG base will vary its viscosities and densities of it.
iii. At the highest temperature both viscosity and densities of EG and its nanofluids seem less.
iv. All the wt.% concentrations of the ZnO loaded nanofluids give improved heat transfer as compared to EG base.
v. The maximum loading of ZnO at 0.1 wt.% showed a higher improvement in heat transfer.
vi. The circular shape of the heat exchanger is the most suitable choice for heat transfer studies as it offers less wall friction.

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