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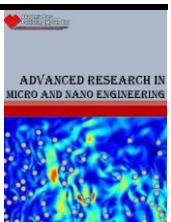

Metal Oxide and Ethylene Glycol Based Well Stable Nanofluids for Mass Flow in Closed Conduit

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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 the more wt.% of the ZnO solid nanoparticles in the Ethylene Glycol had increased the thermal conductivity subsequently with variations in temperature from 20 to 45ºC. Furthermore, Nusselt numbers of Zinc Oxide @ Glycol based nanofluids was 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.%, 0.05wt.%). The absolute average heat transfer of Zinc Oxide @ Glycol based nanofluids using at the highest concentration 0.1 wt.% was enhanced compared to the Ethylene Glycol base fluid. The magnitude of absolute average heat transfer was increased from 600 W/m2k for the EG@DW mixture to 1292 W/m2k for Zinc Oxide @ Glycol based nanofluids. Correspondingly, the heat transfer development at others other three (0.075 wt.%, 0.05 wt.% and 0.025 wt.%) was observed as 600–1167, 600–1010 and 600–970 W/m2k, respectively, which is superior than pure Ethylene Glycol base fluid.

Keywords:
Nanofluids; Mass Flow; Closed Conduit;
Metal Oxides; Characterizations

1. Introduction

In 1883, the turbulence was established as a science problem after Reynolds brings a first experimental study in circular flow channel [1]. Increase in local Reynolds values Re_x, both external boundary flows and internal pipe flow has a pulsating movement, unveiling a substantial deviation among laminar to turbulent flows. Since 20th century era, the study on turbulence flow has extensively done due to its substantial importance for the technology and science betterment [2]. As the turbulence has introduced, the researchers more focused on changes from laminar to turbulent flow studies and their problems in the science and engineering [3]. Similarly, varying studies has been executed on the different shaped heat exchangers and their key effects on to the heat transfer

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improvement [4] [5]. In addition, varying conventional fluid has been used earlier for heat and cooling applications, later they have altered with Nano fluids due to their limitations [6] [7] [8].

Jiao Zhang et al. [9] has 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)-turbulent region and (ii)-laminar sub layer, the mixing length Prandtl theory was adopted here. The bvp4c method has used for the numerical calculations. The outcome arises from the proposed research highlights that the wall slip parameters are much influential onto 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 strengthen for small size wall slip and greater size particles. Among all Nano fluids the Ag/carboxymethyl cellulose showed enhanced encouraging heat transfer for turbulent regions.

Adnan Qamar et al. [10] used ZnO as an alternative liquid for heat transfer enhancement, where it has 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 Nano fluids. The both acetyl acetone and sodium hexa metaphosphate were been chose to add in these Nano fluids for particle stability. The varying tests outcomes showed the acetyl acetone based ZnO Nano fluids were looked more stable for minimum 60 days. The viscosity and thermal conductivity measurements were taken out within temperature range of 20^oC to 60^oC, where it has noticed as the volume fraction of ZnO increases the viscosity and thermal conductivity will increase. At a same volume fraction of ZnO, the substantial improvement in viscosity and thermal conductivity were 16.75% and 23.70%.

W.Ahmed et al. [11] uses 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 Nano fluids and DW were run on a well-designed test rig [12] [13]. The single pot sonochemical assisted technique was adopted for ZnO synthesis, later the synthesised ZnO were dispersed in DW by using 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 all credited to the sonochemical technique. The study outcomes deliberate the higher wt.% of ZnO in DW would led to positive increase in heat transfer and thermo physical properties [14] [11].

The key objectives of the stated study are given as below.

- Preparation of ZnO@Ethylene Glycol based Nano fluids at varying wt.% and their effects on thermo physical and heat transfer properties'.
- The UV-vis analysis for the ZnO confirmation.
- Measurement of thermo physical properties at varying wt.% of the ZnO @Ethylene glycol based Nano fluids.
- Heat transfer measurement by using complete heat test rig.

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 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 engineering university of Malaya Malaysia.

2.3. ZnO Synthesis Flow

A Sodium Hydroxide aqueous solution of (200ml, 1M) was putted drop to drop into another Zinc acetate aqueous solution of (200ml, 2M) in a glass beaker with capacity of 500ml overall. This all process was continued under a high probe sonication by using 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 high speed 6000rpm centrifuge machine with distilled water and ethanol, then washed ZnO was kept for drying in vacuum oven as given in line diagram Fig. 1.[12]

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.%, 0.05wt.%) concentrations. In next step, all these nanofluids were trailed for thermo physical and heat transfer characteristics.

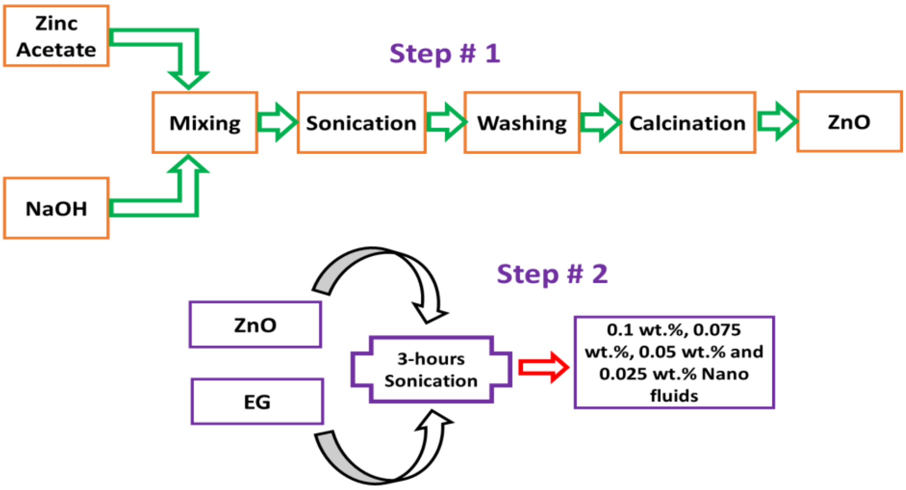


Fig.1. ZnO Synthesis line flow and its nanofluids preparation

2.4. Experimental Setup

The entire heat transfer related experiments were executed on a fully equipped heat transfer test rig available at advanced CFD lab, Faculty of engineering University Malaya. The below given Fig. 2 is representing a complete schematic view of heat transfer test rig, which consist of varying shaped heat pipes like, circular, square and annular. Further, varying adjustment, functional and operational controls were connected where needed. The heat exchanger length was 1.2m where the active area is 1m, the hydraulic diameter of 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 with the main voltage regulator. Pressure DP and chiller are used to see the pressure drop loss and to keep constant temperature of the fluid while its being running inside of the pipe.

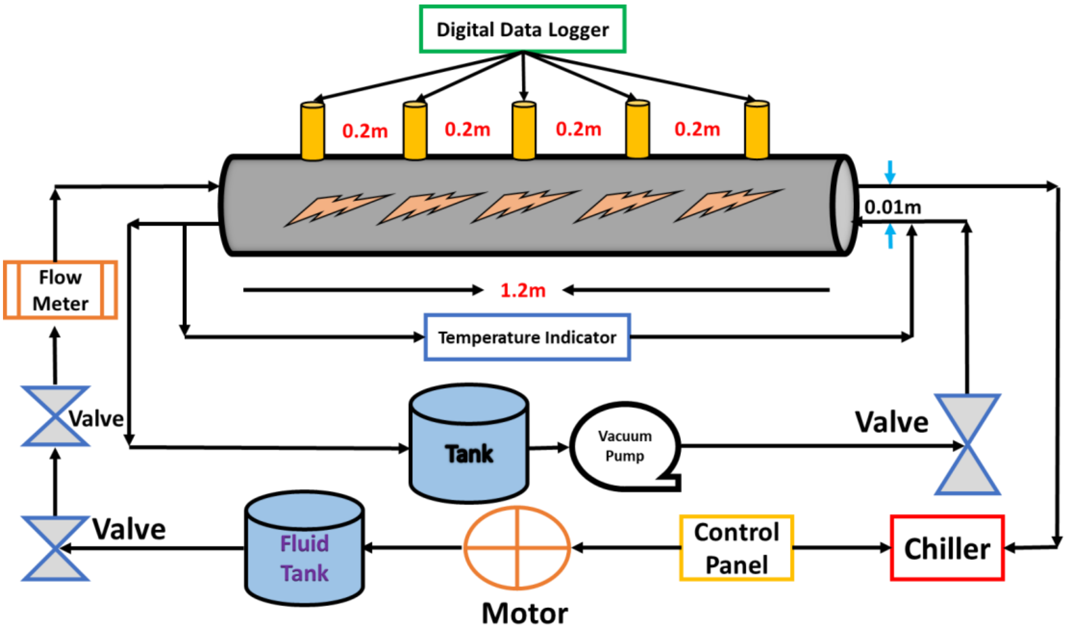


Fig. 2. Schematic overview of Heat Transfer test rig

3. Results and Discussion

3.1 UV-vis spectra

Fig. 3 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 band gap. The maximum wavelength for the ZnO analysis were adjusted within range of 190nm to 800nm, where the prominent peak at 271nm indicates the presence of ZnO which is 100%. These outcomes highlights that the considerable reluctant energy band in visible light that confirms the proper ZnO product.

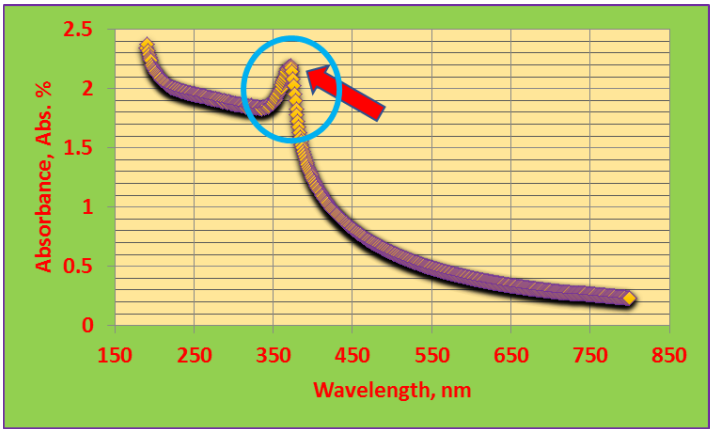


Fig. 3. UV-vis spectra analysis of ZnO nanofluids.

3.2 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/Nano materials lab level # 2, faculty of engineering University of Malaya. The temperature range for all these three analyses were selected within 20°C to 45°C maximum. The final 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 later paper. The kinematic/dynamic viscosities and densities graphs showed and higher viscosity and density for pure EG, while both were dropping while ZnO loaded into EG. At 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 temperature as given in Fig.4.

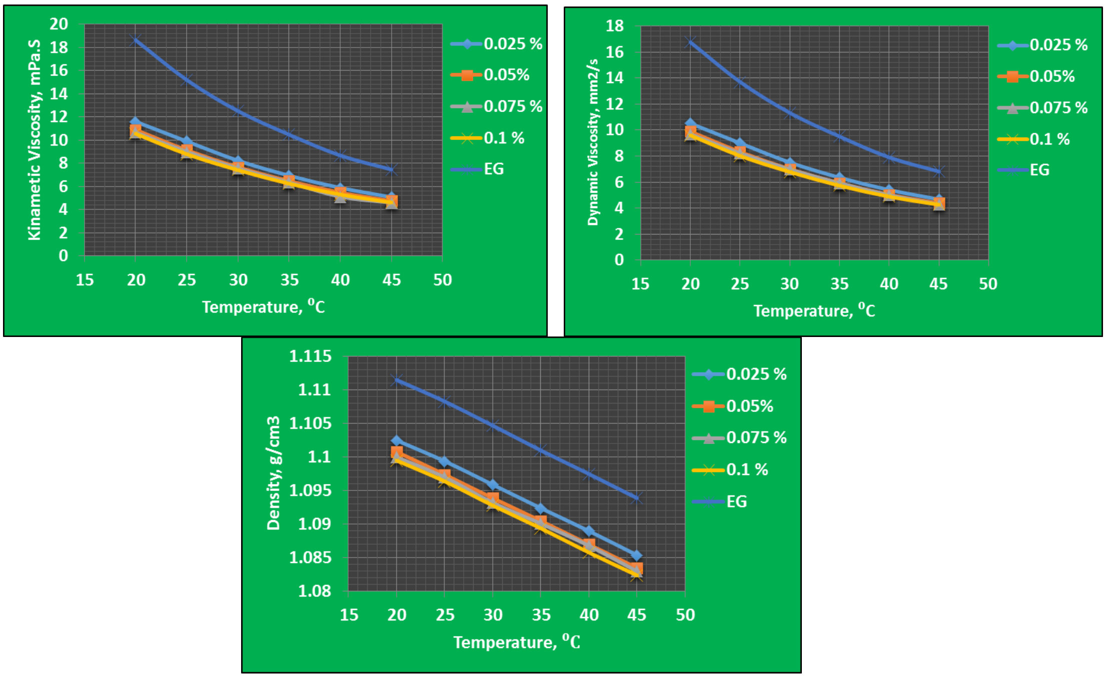


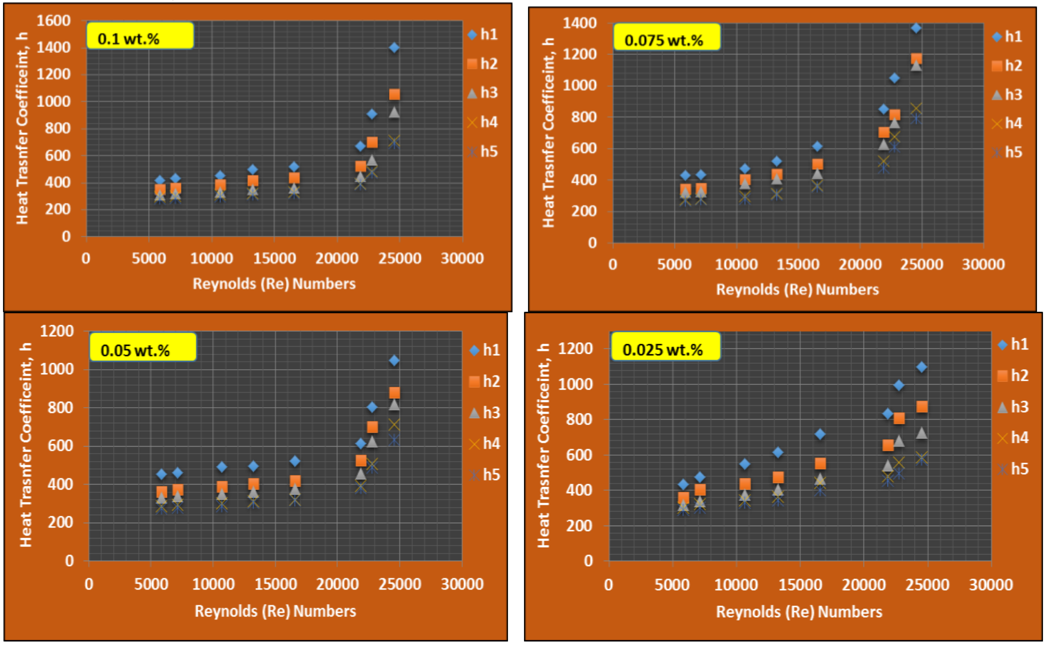
Fig. 4. Viscosities and Densities analysis of ZnO nanofluids

3.3. Heat transfer Analysis in Circular shaped Heat Exchanger

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 Fig.2. The uniform heat flux of 10343.35 W/m^2 was applied to 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 the further analysis [14] . To produce above mentioned heat flux the regulator was adjusted on 220v maximum voltage [15].

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 0.025wt.% concentrations of ZnO and Ethylene glycol based nanofluids. It has commonly observed for fluids if the flow rate increased the heat transfer improvement will increase accordingly, which is common phenomena. The deep study exposes that the higher if 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 maximum presence of ZnO solid particles in the base fluid. On the other hand, the circular shape of heat exchanger is offering les wall friction which is too plus advantage for heat transfer improvement.

Fig. 5 are representing the local and average heat transfer improvement according to wt.% loading of ZnO into EG base fluid. The higher 0.1wt.% of ZnO is showing highest heat transfer improvement as compares to other, because the maximum loading of ZnO would cause to increase heat transfer rate. Similarly, the 0.075 wt.%, 0.05 wt.% and 0.025 wt.% of the ZnO loading gives improved heat transfer results as compare to the EG base fluid. It has noticed all the improvements were taken on highest value of the Reynolds.



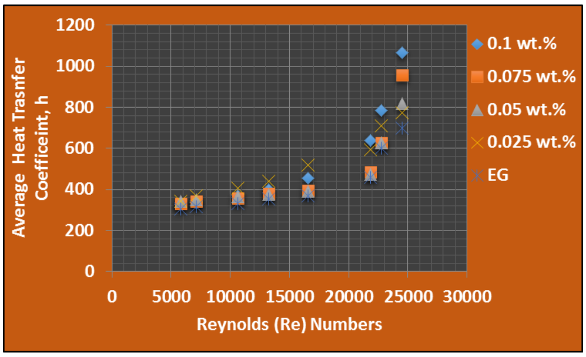


Fig. 5. Local and Average heat transfer variations

4. Conclusion

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

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

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There are two categories of combustion, which are deflagration and detonation. Internal combustion engines such as piston engines and gas turbine engines use the deflagration type of combustion to produce power. The plausibility of increasing the efficiency through detonation was first proposed by Zel'dovich. In the combustion community currently, the rotating detonation engines (RDEs) are among their specific interest because compared to traditional deflagration engines, RDEs use detonation waves in a rotating manner to combust propellants and increase stagnation temperature and pressure, which results in increase in pressure after combustion while deflagration process also increase temperature with slight loss in stagnation pressure. The alternative aspects of pressure gain combustion vary in how the detonations are manipulated. The two types of detonation engines that gain the interest of the combustion community are pulse detonation engines and rotating detonation engines.

For the RDE, this detonation engine controls an annular injection channel and the propellant flow rate to such a degree that a single detonation wave triggered into the channel travels continuously around the base of the channel. By the time the wave passes continuously, fresh reactants are injected behind it to ensure that the moment the detonation wave travels the circumference of the channel, reactants are sufficiently refilled to sustain the wave. Another difference between RDEs and PDEs is the operating frequency. In PDE, the detonations occur in the range between 10 to 100 times per second but for RDE, its wall may be heated by the detonation waves for more than 3000 times per second. As a result, RDEs gain heat at a faster rate and face higher temperature than PDEs. Because of the much heat generated, RDE run times are measured in seconds.

Based on previous studies and experiments, a cooling system was designed for the RDE where it uses water as coolant to remove the heat away. For this numerical study, instead of using water, nanofluids will be used as replacement and will be applied in the simulation that will be conducted to study the nanofluids characteristics and suitability as the cooling element for RDE.

2. Methodology

This study involves multiple systematic methodology, which will be executed in sequence. The first step is to select the three different type of nanofluids for RDE cooling, as well as the suitable mass flow rate of the nanofluids supplied. The next step includes to identify or select the boundary conditions and conducting assurance of the solution method. The third step is initialization of the program and then followed by the final step, which is to execute and simulate the process. It is also very important to validate or evaluate the simulation process with previous researchers to ensure the process are correctly conducted. In general, the research work flow are shown below in Figure 1.

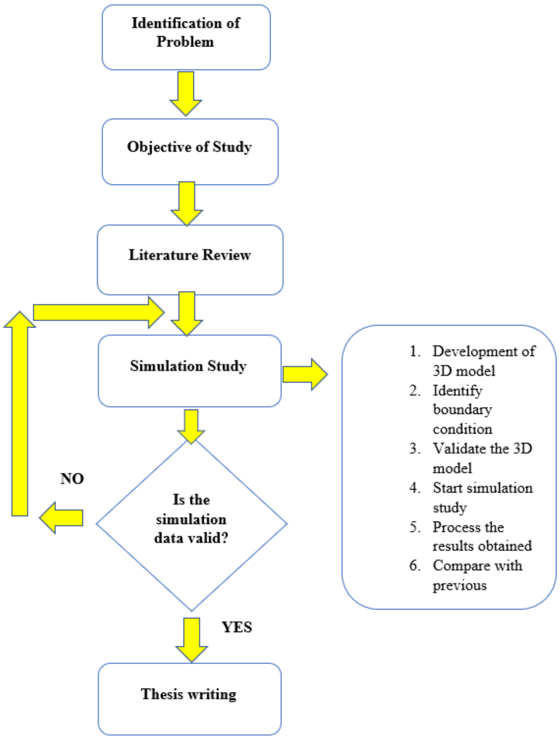

Fig. 1. Process flow of research work

2.1 Simulation Process of ANSYS FLUENT

The 3D cooling model of RDE consist of an inlet, a cooling chamber, where the cooling happens and an outlet. The nanofluids starts flowing through the inlet, then shoots out directly to the wall of RDE and goes out through the outlet. Below are the dimensions and the 3D model of the cooling system, with the nanofluid flow shown in arrows;

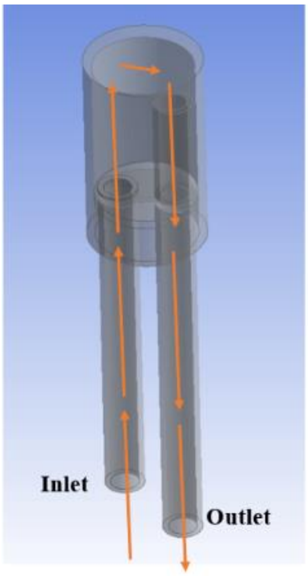

Fig. 2. Three-dimensional model of cooling

Table 2
Dimensions of each part in the model

Model Part	Inlet	Outlet	Cooling chamber
Inner diameter (mm)	10	10	34
Outer diameter (mm)	12	12	36
Length (mm)	125	180	70
Thickness (mm)	2	2	6

For the material of RDE, mild steel was used because it has high melting point, weldable and cost effective. The table below shows the material properties of mild steel;

Table 1
Material properties of mild steel

RDE Material	Mild steel
Density	7700 kg/m^3
Thermal conductivity	46.8 W/m.K
Specific heat capacity	519 J/kg.K

Mild steel is declared as the solid part of the 3D cooling model of RDE in the software. For the nanofluids, there are three which are titanium dioxide, copper oxide and aluminium trioxide nanofluids. The main reasons why nanofluids were choose as the coolant is because of their higher specific surface area which increases the heat transfer between surface and fluids, plus their thermo-physical properties such as thermal conductivity and surface wettability can be adjusted by varying their concentration to suit different applications. The thermo-physical properties of the nanofluids can be seen based on Table 2. Each of the nanofluids were supplied at three different mass flow rate which the rate are at 0.0034 kg/s, 0.0102 kg/s and 0.0170 kg/s.

Table 2
Thermo-physical properties of nanofluids

Label	Nanofluid 1	Nanofluid 2	Nanofluid 3
Type of nanofluid	TiO_2-EG-H_2O	CuO-H_2O	Al_2O_3-H_2O
Thermal conductivity (W/m.K)	0.432	0.616	0.661
Viscosity (kg/m.s)	0.00125	0.000612	0.000612
Density (kg/m^3)	1049.5	1061	1007.4
Specific heat capacity (J/kg.K)	3463.3	3998	4017.8

For the meshing setup, Figure 2 below shows the meshing of the 3D model, which uses maximum face size of 0.1 m. This meshing was achieved after many trials and errors to obtain valid results and prevent any errors from happening.

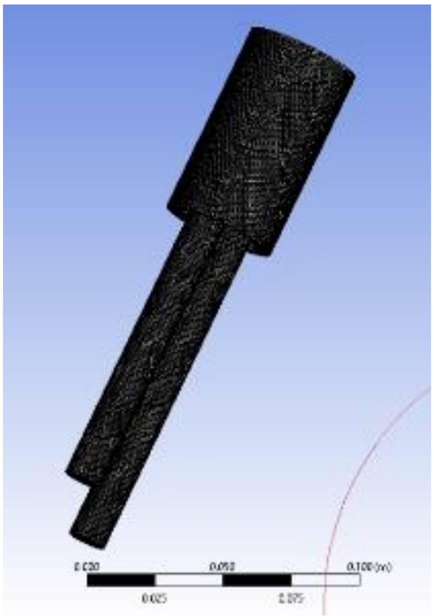

Fig. 2. Meshing of 3D model of cooling

For the boundary conditions, the temperature of detonation was preset to 300°C, and the inlet temperature was set to room temperature which was 27°C. Figure 3 below shows the contour of temperature distribution that have been set.

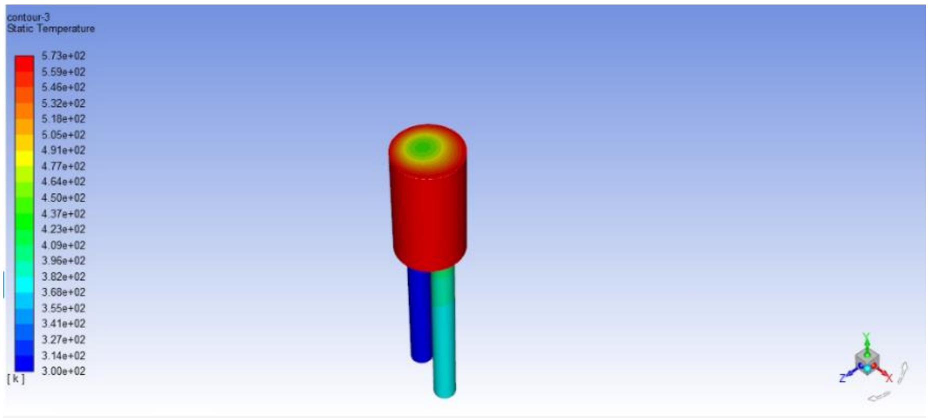

Fig. 3. Temperature distribution of the cooling model

After running the simulation, the next step is to process the data obtained. The data were tabulated and then shown in the form of graph to better understand and analyze the trend produced.

3. Result and discussion

3.1 Heat Transfer Analysis

After running the simulation, the outlet temperature was taken to obtain the value of temperature difference, so that the value of rate of heat transferred can be obtained. Figure 4 below shows the result of temperature difference with increasing mass flow rates.

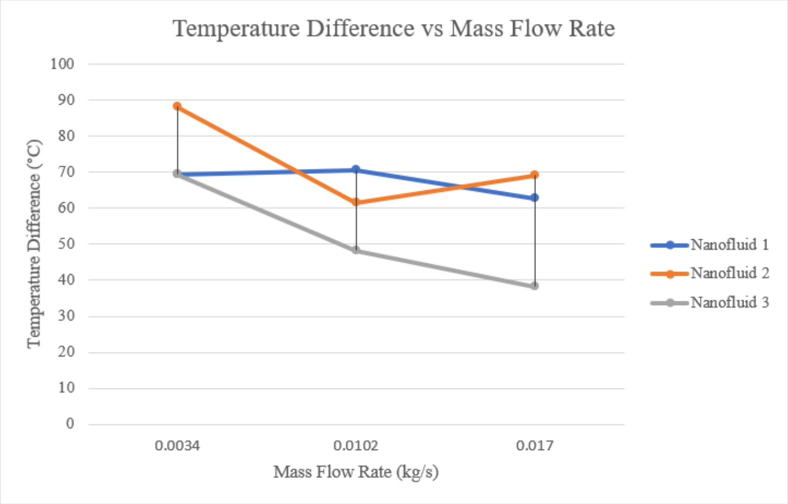

Fig. 4. Graph of temperature difference against mass flow rate

To better explain the outcomes or effect of the mass flow rate of nanofluids towards the heat transfer, based on Figure 5, a graph of heat transfer against mass flow rate of coolant was prepared and it clearly shows that to obtain higher heat transfer, the mass flow rate should be increased. This trend obeys the equation of the heat transfer, $Q = mc\Delta T$, which indicates the heat transfer rate is directly proportional to the mass flow rate. The graph on Figure 5 shows the trendline to further proved the relationship and it also indicates how much heat is being removed from the wall of RDE towards the nanofluids.

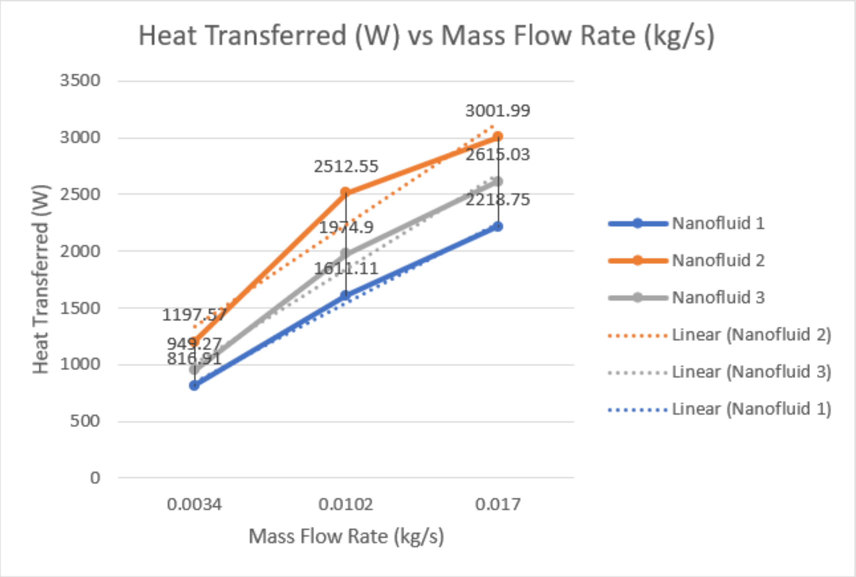

Fig. 5. Graph of heat transferred against mass flow rate

The mass flow rate can be used to determine whether the coolant flow is laminar or turbulent. In practice, the system would be most effective as a cooling system when the flow is turbulent, as no nanofluids are boiled near the wall, as the wall temperature can easily rise to the boiling point of nanofluids in a matter of seconds and could even go much higher if the RDE is set to run for an extended period of time. Figure 6 below shows the graph of Nusselt number against Reynold number.

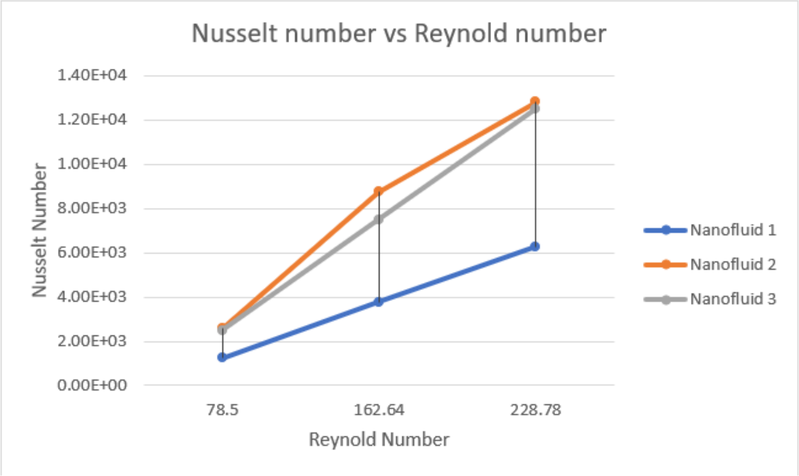

Fig. 6. Graph of Nusselt number against Reynold number

Observed from the standpoint of heat transfer, it is apparent that as the mass flow rate of nanofluids increases, so does the temperature difference between the input and output coolant temperatures, as depicted in Figure 4.3. This demonstrates that increasing the flow rate eliminates the properties of laminar flow, allowing the coolant to flow with a more turbulent nature as a result. When the nanofluid flow is turbulent, it is possible to gain greater efficiency in thermal transfer.

3.2 Validation of Simulation Result

Based on Figure 7, the numerical data obtained through ANSYS FLUENT was valid because both the experimental data and numerical data shows a similar trend of increasing linearly with mass flow rate of nanofluid or water, based on the trendline. At the same time, Figure 4.6 also shows that nanofluid perform better than water as coolants because the heat transferred by nanofluids were much larger compared to water. Even so, the data of the heat transferred for nanofluids was obtained numerically, not experimentally. For better result, it is better to try to run the RDE cooling with nanofluids experimentally.

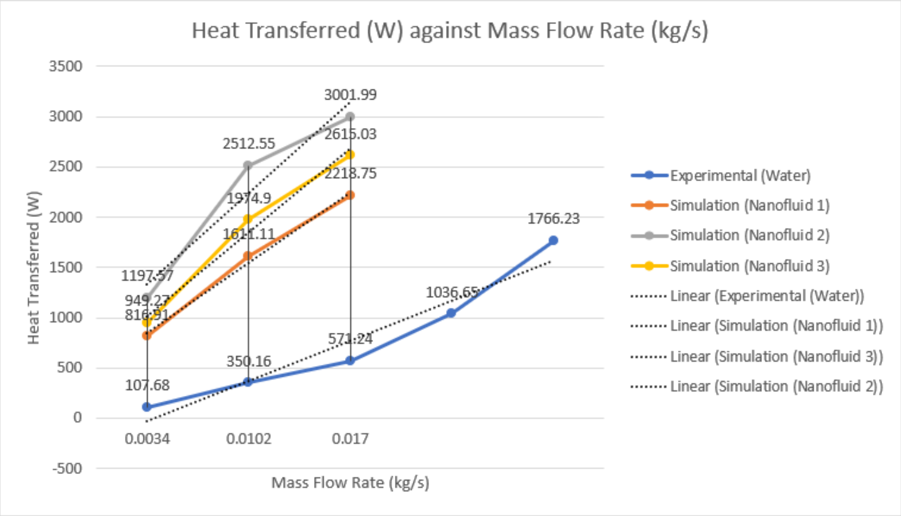

Fig. 6. Comparison between experimental and numerical data

4. Conclusion

In this thesis, the numerical simulation conducted proves that nanofluids can be used to remove heat from the RDE and the result was even better compared to when using water. Three different nanofluids were used, which are titanium dioxide, copper oxide and aluminium trioxide nanofluids, and based on the simulation data and graphs plotted, the best nanofluid that can remove the most heat compared to the other two was the copper oxide nanofluid. This simulation study has achieved the objective, which was to analyze the heat transfer performance of different nanofluids for cooling of RDE. In short, this study has proved that nanofluid can be the best replacement as the coolant for RDE instead of using water. Because this simulation study has successfully met the objectives, this study somehow can be a meaningful beginning to develop and further improvise the RDE cooling system.

Based on the findings obtained from this research, it can be seen that there were issues on the design of the cooling flow of RDE. Thus, it might be good to improve the design of the cooling flow, especially at the inlet, outlet and the way the coolant flows into the core of RDE. The issue that will arise is that there might be some coolants left in the cooling chamber of RDE that may disturb the detonation process. The flow could be design in such a way that the inlet and outlet of the cooling allows the coolant or nanofluid to flow in and out without leaving too much of them in the cooling chamber. Another aspect that need to be improved is the material of the RDE. It is better to use strong and thick stainless steel instead of mild steel because stainless steel tends to have better corrosion resistance, which makes it more durable and long lasting. In short, the suggestions explained perhaps can solve the issues regarding the flow and material of RDE.

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