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Synthesis and characterizations of zinc oxide based nanofluids for heat transfer improvement in single tube circular heat exchangers

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Abstract

The ZnO nanoparticles were synthesized by Sono-chemical technique and later characterized by XRD, FTIR, UV-Vis, FESEM, and EDX to confirm the proper synthesis. The two-step preparation of ZnO-DW based nanofluids were achieved after dispersing ZnO nanoparticles in the base fluid (DW) by using high probe sonicator, where four different (0.025, 0.05, 0.075 and 0.1) wt.% concentrations of ZnO-DW based nanofluids were prepared. All the ZnO-DW based nanofluids were investigated thoroughly about the different thermo physical properties and their optimistic effects on improvement of heat transfer coefficient in a circular heat exchanger. The thermophysical properties such as thermal conductivity, viscosity, density etc. of ZnO-DW based nanofluids showed some promising effects on heat transfer improvement, friction factor and pumping power in a circular heat exchanger. Experimental investigations on heat transfer characteristics were conducted in a circular heat exchanger with constant heat flux boundary condition and at different Reynolds numbers in the turbulent flow regime. The addition of ZnO solid nanoparticles (7g) in the base fluid (DW/7L) provided a surprising improvement of about 37% in the thermal conductivity. The maximum improvement in heat transfer at the highest concentration of 0.1 wt.% ZnO-DW based nanofluid was about 52% more than that of the base fluid. Consolidated results of the experimental investigations with ZnO-DW based nanofluids revealed that the specified nanofluid could be suitable for heat transfer applications.

Keywords: *characterizations, heat transfer coefficient, preparation of ZnO-DW fluids, Reynolds, Synthesis of ZnO*

1. Introduction

Since few decades, the metal oxide based nanoparticles are being immensely investigated and caught more attention of the research community for different applications. The scientific based different applications such as solar cells, sensors, photodiodes, photo detectors, photo catalyst, solar absorption, heat absorption, heat transfer, cooling and nanofluids etc. made them more attractive for research choice (Nava et al. 2017; Ohashi, Hagiwara, & Fujihara, 2017; Ali, Orell, Kanerva, & Hannula 2018). Based on their emerging applications, nanoparticles playing important role in the modern world, including all kinds of metals, metal oxides, carbon structured, graphene and ceramics are being use in engineering industries since long time. Usually nanoparticles have less 100 nm in size and can be of different morphologies depends upon their synthesis and preparation techniques(Nagarajan, Kannaiyan, & Boobalan, 2020; Wensel et al., 2008).

Nanofluids are the new emerging class for heat transfer improvement attained by dispersing different nanoparticles in conventional base fluids such as, water, distilled water, palm oil, Dia thermic oil, ethylene glycol, polyethylene glycol, glycerin and transformer oil etc. (Alawi, Sidik, Xian, Kean, & Kazi, 2018; Gliech et al., 2020). The Choi was the first researcher who introduced term nanofluids to the world, he reveals that the uniform and equal dispersion of nanoparticles with different wt.% concentrations in the base fluid showed enhanced thermal properties (Yu, France, Routbort, & Choi, 2008). Due to the positive and enhancing influence in engineering applications, nanofluids became one of the interesting research topics for science world. As their importance with projectile results has already discovered by different researchers (Lee, Choi, Li, &, Eastman, 1999; Kleinstreuer & Feng, 2011; Nagarajan et al. 2020).

Nanofluids doesn't means simple dispersion of nanoparticles in the base fluid, the synthesis of nanoparticles and dispersion in base fluid with uniform mixing and stability is required (Arya, Sarafraz, Pourmehran, & Arjomandi, 2019; Sivasubramanian, Theivasanthi, & Manimaran, 2019). In fact, nanofluids are the dispersion and suspension of nanoparticles with less than 100nm size well dispersed in base fluid. After dispersing ZnO solid nanoparticles in base fluid the thermo physical properties such as (viscosity, density, thermal conductivity and specific heat) were changed as in comparison to the properties of base fluid (Abdelrazek et al., 2018; Arunkumar, Anish, Jayaprabakar, & Beemkumar, 2019). Different metals and metal oxides nanoparticles such as, Al_2O_3, TiO_2, MgO, CuO, SiC, Cu, TiC, and Ag etc. are being use for nanofluids preparation by one-step or two-step method (Sandhu, Gangacharyulu, & Singh, 2019).

In engineering industries heat transfer and its improvement has become a challenge for researcher due to different engineering applications in order to increase the efficiency and performance of different systems (Phor, Kumar, Saini, & Kumar, 2019; Tejes, & Appalanaidu, 2017). Different method were been practiced earlier to overcome the heat losses and their effects on systems efficiency such as fluid force convection and extended surface area to improve the heat transfer. In this case nanoparticles with base fluid as a nanofluids has catch the attraction of researchers to improve the heat transfer efficiency in engineering industry. Recent researches on nanofluids exposes enhanced heat transfer results, based on their thermal and hydrodynamic parameters (Mugilan, Sidik, & Japar, 2017; Palanisamy & Kumar, 2019).

The main objective of this study is to synthesis the ZnO nanoparticles by using single pot facile sonochemical technique and characterize them for XRD, FTIR, UV-vis and FESEM analysis to confirm the proper synthesis. Then two-step nanofluids preparation process were led by using high probe sonication to prepare the ZnO-DW based nanofluids with homogeneous dispersion for heat transfer improvement in circular flow passage. Four different wt.% concentrations of ZnO-DW nanofluids such as (0.1, 0.075, 0.05 and 0.025)% were prepared after dispersing ZnO nanoparticles in base fluid (DW by use of high probe sonicator. The high sonication method was uses during nanofluids preparation to increase the dispersion and stability of nanoparticles. The stated study also focused to analyze the thermo physical and thermal behavior of the all wt.% concentrations of the ZnO-DW fluids. Dynamic viscosity, kinematic viscosity, thermal conductivity and density were been studied here, also their effects on average heat transfer and average Nusselt numbers were scrutinized. The sonochemically synthesized ZnO and their nanofluids with water gives longer suspension until 4 weeks and showed improved thermophysical and heat transfer properties.

2. Materials and methodology

2.1 Synthesis of ZnO nanoparticles and preparation of ZnO-DW nanofluids

The ZnO nanoparticles were synthesized by sonochemical technique. The Zinc acetate (Zn $(CH_3COO)_2.H_2O$) as a precursor salt and Sodium-Hydroxide (NaOH) as a strong base have used for chemical reaction. The all-entire used chemical were analytical grade and purchased by Sigma Aldrich Sdn Bhd Malaysia. In first step, the zinc acetate 1M salt were dissolve in distilled water under constant magnetic stirring. At the same time sodium hydroxide pellets 2M was diluted in distilled water under magnetic stirring for few mints. In the second step the sodium hydroxide solution were added drop by drop slowly in zinc acetate solution under the probe sonication, the sonication process was continued for 2 hours. Prior to sonication, the sonicator parameters adjustment is necessary, for this purpose the pulse Amplitude was 70% with 3/2 sec on and off time, net delivered power to probe 750 watts, Highest energy 36000 joules, supply voltage 220AC and probe temperature should be 0℃. With the addition of the sodium hydroxide solution into precursor solution, white dense precipitates were been formed in the distilled water due to chemical reaction between base and precursor. As time passed, these precipitates were increasing and bulk amount of mixture were sonicated for 2-hours continuously under constant sonication without using any kind of stabilizing or surfactant agent. Then white precipitates were washed by distilled water and ethanol several time until its pH became normal, further the product was kept in oven at 60 ºC for drying over the night. Finally, to obtain the particular shape and morphology of the nanoparticles the dried sample was keep in a furnace for calcination at 200 ºC for 3-hours continuously. The line flow for ZnO preparation by ultrasonic assisted technique has shown below in Figure 1.

Further ZnO nanoparticles were characterize by XRD, FTIR, UV-vis and FESEM analysis to confirm the proper synthesis. In step 2, these nanoparticles were dispersed in distilled water according to specified wt.% concentrations to prepare the different wt.% of ZnO-DW based nanofluids. The ZnO nanoparticles were highly sonicated by using high probe sonicator for 1-hour and 30 mints uninterruptedly. For the dispersion of ZnO nanoparticles in distilled water the sonicator settings were kept same to setting kept during synthesis. For the uniform and equal dispersion of nanoparticles in distilled water the high sonication is needed. After dispersion of ZnO nanoparticles in distilled water the four different wt.% concentrations such as (0.1, 0.075, 0.05 and 0.025) of ZnO-DW nanofluids were primed as shown in the line flow diagram.

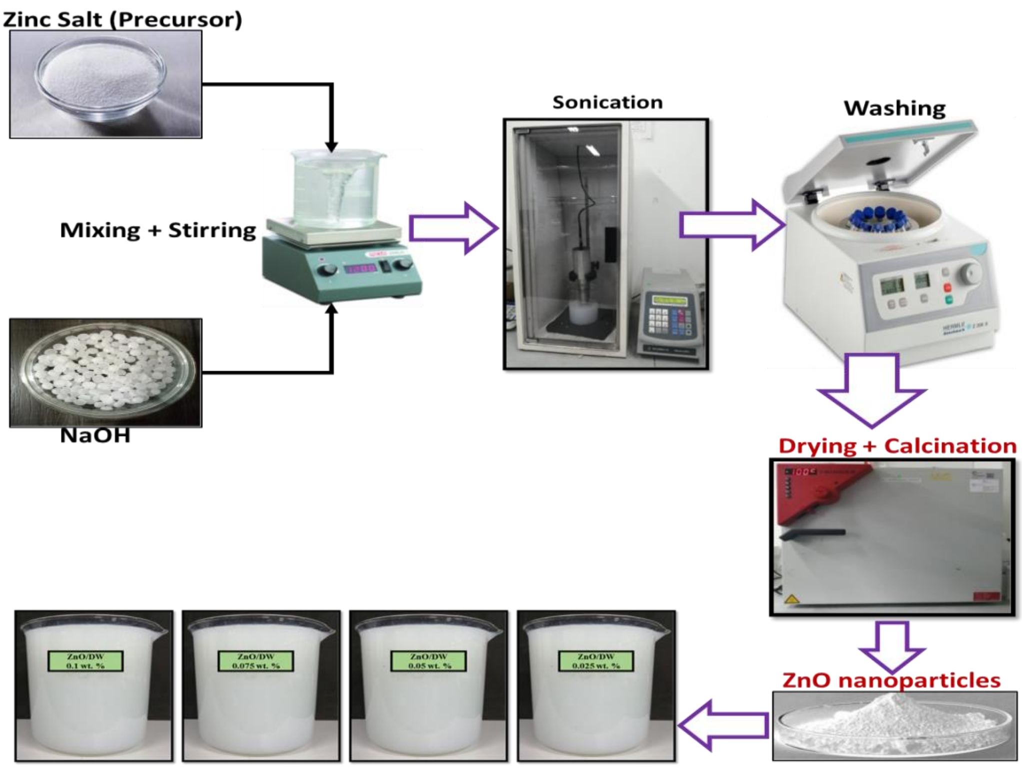
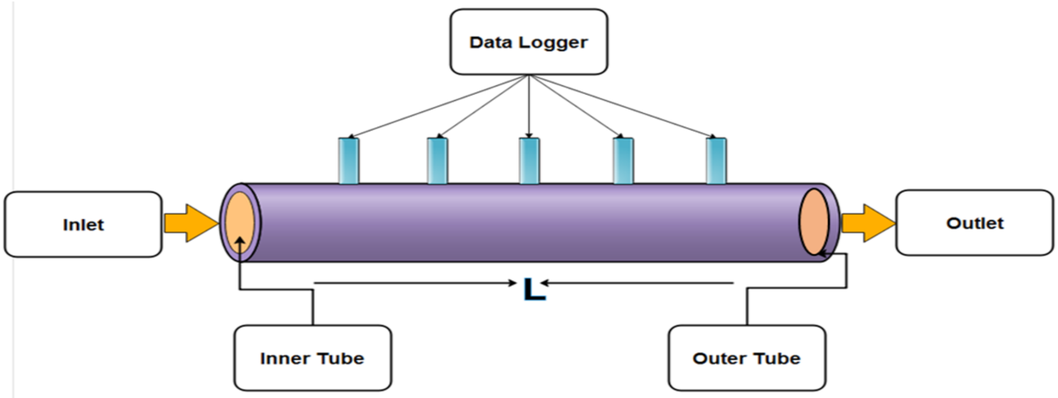


Figure 1 Single line flow for the synthesis of ZnO nanoparticles and ZnO-DW based nanofluids

2.2 Single tube circular heat exchanger and heat transfer setup

A single tube circular heat exchanger of stainless steel with 1.2m length and 0.01m hydraulic diameter from both sides is the significant part of the heat transfer test rig is using here as an circular heat exchanger. Where the heating area of the single tube heat exchanger has wrapped by wool and covered by aluminum sheet up to 1m length from start to end. Five K-Type highly sensitive thermocouples are attached at different points along the heat exchanger surface separated each other's with an equal distance of 0.2m. In addition, inlet and outlet temperature sensors have attached to the test section. A bushy layer of cotton wool as an insulator has wrapped over the single tube circular heat exchanger to avoid from heat losses. The total delivered power to the heater is 600W, which can control by a voltage transformer. A schematic view of single tube heat exchanger has shown in Figure 2a. For the heat transfer measurements, there is a need of complete setup, which called heat transfer rig. This may consist of different types of heat exchangers to analyze the heat transfer effects of different nanofluids. A pictorial view of heat transfer rig showed in Figure 2b, this rig consists of control panel, voltage supply, input power supply, voltage regulator, fluid tank, chiller, fluid pump, main valve, inlet and outlet valves, flow meter, pressure meter, pump frequency controller, digital data logger, highly sensitive thermocouples, test section, heater and heating insulation etc. These are all necessary parts of heat transfer rig. The adjustment of all these parts for the experimentation is necessary to prior the experimental run.



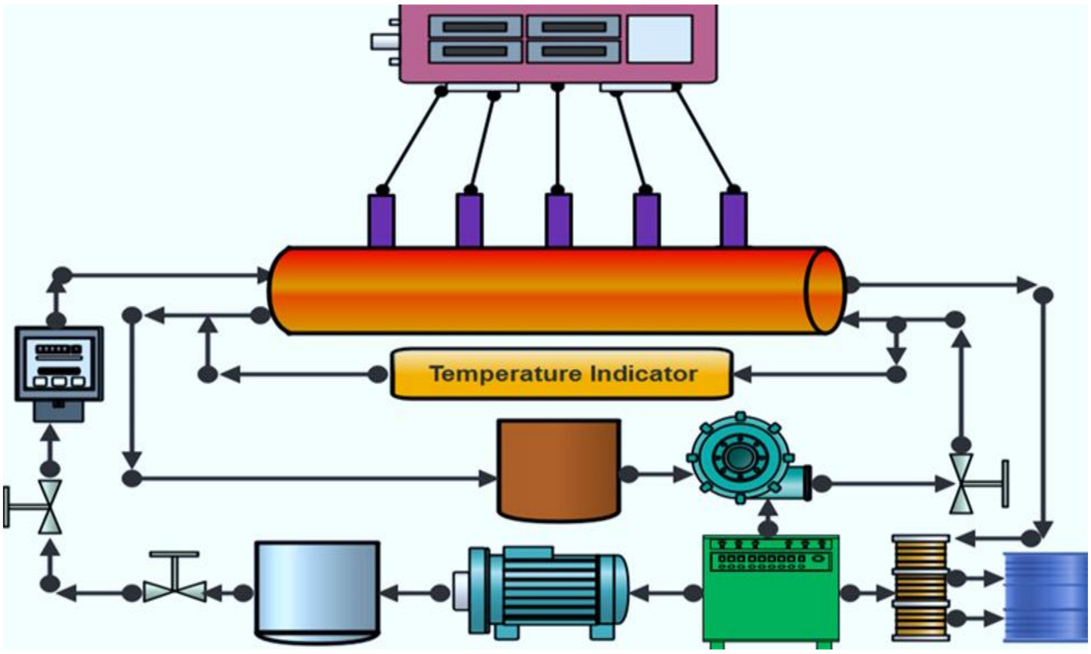


Figure 2 a) Schematic view of circular heat exchanger and, b) Complete schematic diagram of heat transfer test rig

3. Characterizations

3.1 UV-vis spectrum analysis

The UV–Vis analysis is common and widely used technique to comprehend the optical behavior of nanoparticles. This technique has deployed to check the prominent peak of ultrasonic assisted ZnO nanoparticles. The maximum absorbance level and highest peak of ZnO nanoparticles have checked within the specified wavelength range from 250 to 800nm by using UV-1800 SHIMADZU corporation system where cuvette length is 10mm. Figure 3a describes the radiation effects on the UV-vis spectrum absorption level of the ultrasonically assisted ZnO nanoparticles. The ultrasonic assisted ZnO nanoparticles formation increase according radiation power delivered to the particles. All the ultrasonic assisted ZnO nanoparticles display highest absorbance level of 371 nm at its peak, which is due to the blue lateral shifting of the ZnO particles in bulk quantity. The minimum dilution of ZnO nanoparticles in distilled water with 0.025 wt.% concentration have tested for UV-vis analysis. The prominent peak at 371nm confirms the accurate synthesis of ZnO nanoparticles by sonochemical method.

3.2 XRD analysis

X-ray diffraction analysis of ultrasonic assisted ZnO nanoparticles products were conceded by the CuK_{α} radiations where (λ=1.54056 Å). Figure 3b displays the different XRD patterns for ultrasonically assisted ZnO particles. The XRD analysis was conducted after calcination of ZnO nanoparticles at 200℃ for 3-hours. The calcination process is necessary to see the particles in crystalline form with specific morphology. The XRD patterns are similar to the wurtzite structure ZnO diffractions where the sharp peaks of ZnO nanoparticles indicates virtuous crystallinity of ultrasonic assisted ZnO nanoparticles. No extra peak related to any kind of impurity has noticed during the analysis. The expansion of all the ZnO peaks designated that the all the particles were of Nano scale(Askarinejad, Alavi, Morsali, & Engineering, 2011). The different XRD patterns of ultrasonically assisted ZnO nanoparticles display peaks at different angles such as 2θ = (31.70°), (34.56°), (36.18°), (46.58°), (55.62°), (62.78°), (65.40°), (69.00°) and (70.12)°. Which can be refer to (1 0 0), (0 0 2), (1 0 1), (1 0 2), (1 1 0), (1 0 3), (2 0 0), (1 1 2) and (2 0 1) planes of hexagonal wurtzite ZnO nanoparticles structures (Madsen, Scarlett, Cranswick, & Lwin, 2001; Phuruangrat, Yayapao, Thongtem, & Thongtem, 2014).

3.3 FTIR analaysis

Figure 3c shows the FTIR spectrum analysis of ultrasonically assisted ZnO nanoparticles. The different energy band from 3544 - 3394 cm^{-1} indicates the vibarational modes for O and H ions. When the pH augmented the both O and H peaks becomes more slender due to the supplementary occurrence of both O and H ions from NaOH base solution, which sturdily reacts with Zinc acetate solution at maximum pH values. The supreme vibarational and streching mode has been detected between 1422 - 1560cm^{-1}. The symetric vibrations and stretcihnes occurs among 1451-1320cm^{-1} due to the maximum presence of C and O ions. Additionally both peaks have shifted ramblingly due to deviated morphological structures of the nanoparticles in alkaly conditions. The projecting peak of ultra sonic assisted ZnO nanoparticles seems amongst 550 - 400cm^{-1} range defines the $Zn(OH)_2$ are finally transmuted to ZnO nanoaprticles. Consequently, the particle size effect to the shifting rates of different peaks due to which FTIR analysis helps to FESEM for morphological images.

3.4 FESEM analysis

The field emission scanning electron microscopy (FESEM) helps to see the exact morphology and shape of the particles. The FESEM has been directed to examine the ZnO nanoparticles composition, morphology, particle shape and its size, by EDX mapping, Zeiss/Supra 35-VP energy dispersion X-rays spectrometer at NANOCAT research center of the university Malaya. The FESEM analysis confirms the morphological structure of the particles. Figure 3d displays the FESEM images taken out of ultrasonically assisted ZnO nanoparticles. The FESEM analysis shows the uniform and homogenous morphological structures of the ZnO nanoparticles when the maximum pH value vary from 10 and 11 up-to its alkali conditions. It can observed in the FESEM image of the ZnO nanoparticles the mostly particles are in spherical shape, where this ultra sonication synthesis technique offers the less nanoparticle agglomeration. The FESEM image of ZnO nanoparticles has focused at maximum magnification 100KX, 10.00kV with high vacuum mode.

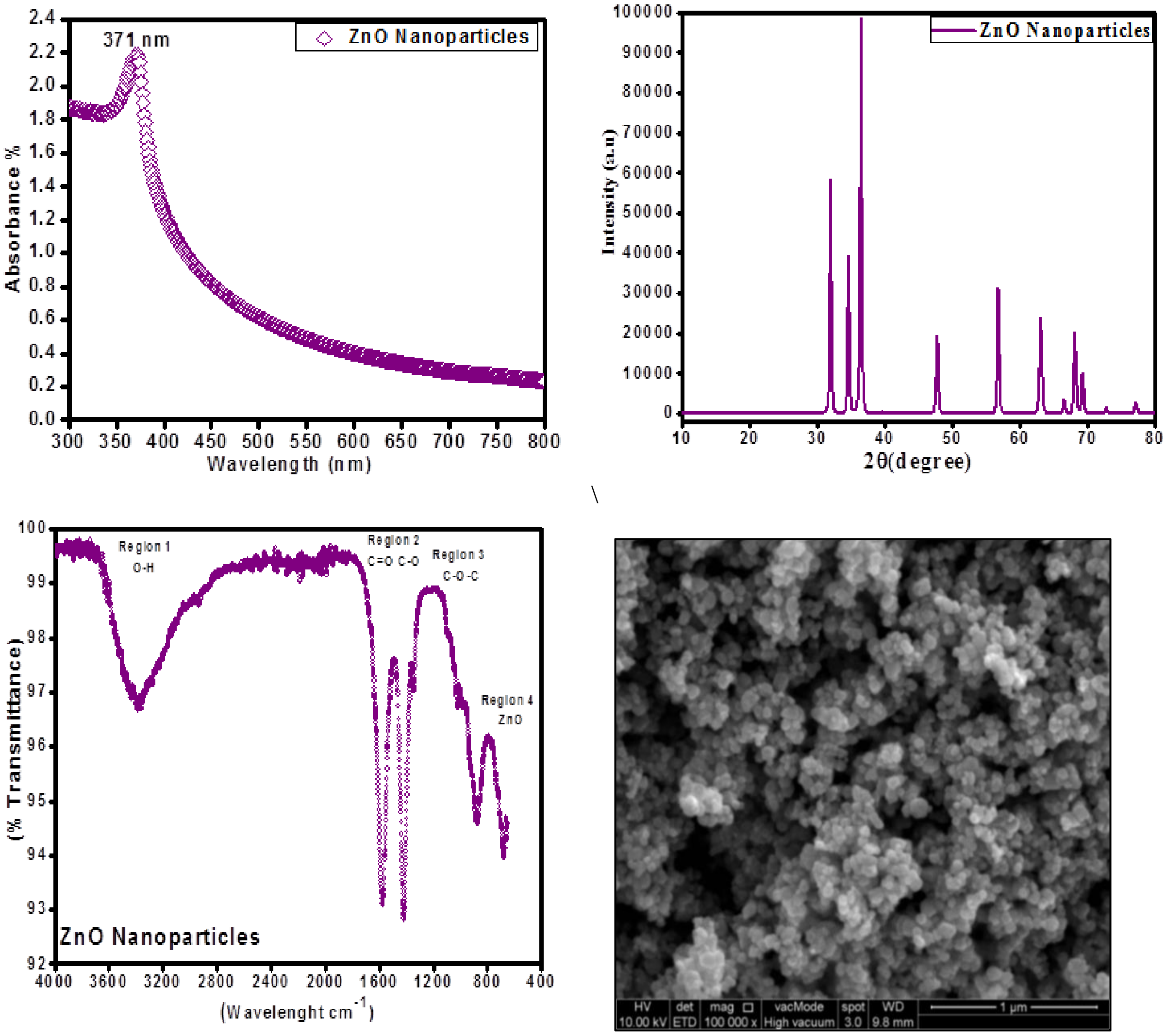


Figure 3 a) UV-vis analysis of ultrasonic assisted ZnO nanoparticles, b) XRD analysis of ultrasonic assisted ZnO nanoparticles, c) The FTIR spectra analysis of ZnO nanoparticles, and d) FESEM image showing morphology of ultrasonic assisted ZnO nanoparticles.

4. Result and discussions

We prepared the ZnO-DW based nanofluids and their different wt.% concentrations by using 2-step high probe sonication technique for the study of their different thermophysical properties such as thermal conductivity, kinematic viscosity, dynamic viscosity, density and their effects on heat transfer improvement. The ZnO have synthesized by using sonochemical-assisted technique and were been characterized for XRD, FTIR, UV Vis and FESEM analysis. In addition, average particles size has checked by using particle size analyzer. It is also important that different wt.% concentrations of ZnO-DW based nanofluids effects to the all thermos physical properties due the maximum and minimum presence of solid particles in water. All the thermo physical properties were analyzed to see the effect of ultrasonic assisted ZnO based nanofluids by using advance KD-2 Pro thermal analyzer and rheo-meter at university of Malaya engineering faculty.

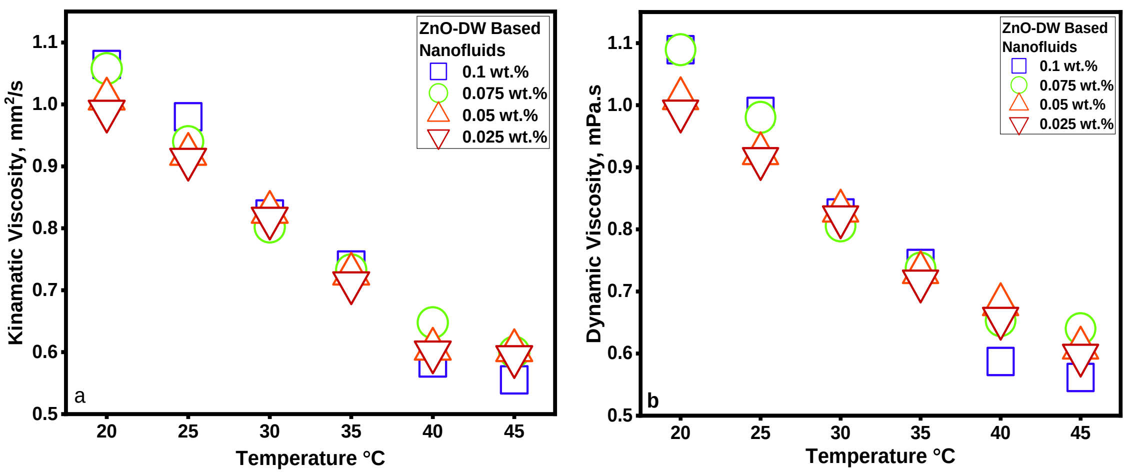
4.1 Thermo physical properties of ZnO based nanofluids

The effects of wt.% concentration of ultrasonic assisted ZnO nanoparticles and temperature on to kinematic viscosity of the ZnO-DW based nanofluids (i.e. as compare to the based fluid such as distilled water) are shown in Figure

4a. The experimental outcomes exposes that the kinematic viscosity of ZnO-DW based nanofluids increased with increase in wt.% ZnO nanoparticles, while it decreases with increase in temperature values. The earlier researches stated that increase in viscosity cause to reduce the friction losses in different systems which attributes to its positive behavior. The Figure 4b describes the maximum kinematic viscosity for 0.1 wt.% of ZnO-DW based nanofluids at minimum temperature, while the same concentrations gives lowest viscosity at higher temperature range.

Dynamic viscosity is an important property of any nanofluids, which specifies the internal resistance behavior of the fluids. There are series of engineering problems occurred when deals with such fluids who have higher viscosity, they needs lot of energy for pumping and mixing of the fluids (Yu, Xie, Li, & Chen, 2011). Prior to run the nanofluids for viscosity check, we checked distilled water viscosity first. To make sure the accuracy of the viscometer to quantify the dynamic viscosity, distilled water have tested as a standard fluid according to the range of temperatures followed in this study for ZnO-DW based nanofluids. The viscosity of distilled water were noticed 1.11×10^{-3} Pa s while the reference is 1.13×10^{-3} Pa s at 20 C and the maximum error is ±1.31 %. While at 45°C temperature the viscosity drops down to 0.870×10^{-3} Pa·s while the reference value is 0.788×10^{-3} Pa·s and the maximum error is ±2.31 %. The Figure 4b describes the dynamic viscosity of ZnO-DW based fluid with its varying wt.% concentrations such as (0.1, 0.075, 0.05 and 0.025). The declining trend shows as the temperature increased the dynamic viscosity for concentration will decreased. While viscosity will increase with increase in wt.% concentration of ultrasonic assisted ZnO nanoparticles. This increasing and decreasing behavior attributed to natural behavior of the nanofluids.

The density measurement have conducted to analyze the volumetric behavior of the ultrasonic assisted ZnO-DW based nanofluids with their different (0.1, 0,075, 0.05 and 0.025) wt.% concentrations with volume fraction varies from 20°C to 45°C K and maximum atmospheric pressures is 50 MPa. The experimental density ρ of ZnO-DW based nanofluids of four different (0.1, 0.075, 0.05 and 0.025) wt.% concentrations with the temperature variation from 20°C to 45°C were measured here. The overall density behavior ZnO-DW based nanofluids is similar to the base fluids behavior. The Figure 4c portrays the density behavior of four different concentrations of ZnO-DW based nanofluids, the declining trend shows that as the temperature value increased the density of nanofluids will little bit drop down as compare to at low temperature. All the nanofluids concentrations shows and slight decrease in density with rise in temperature value. This behavior is same like to the distilled water behavior(Pastoriza-Gallego, Lugo, Cabaleiro, Legido, & Piñeiro, 2014).



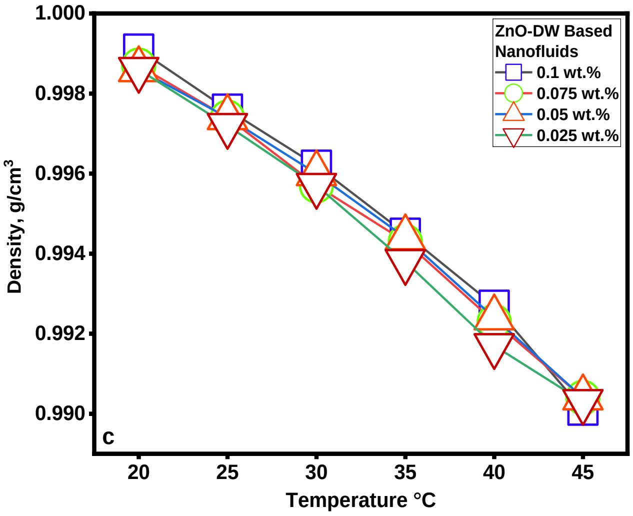


Figure 4 a) Viscosity behavior of ZnO-DW based nanofluids with different wt.% concentrations, b) Dynamic viscosity profile of ZnO-DW based nanofluids with varying wt. %, and c) Density profile of ZnO-DW based nanofluids.

4.1.1 Hydrodynamics properties of ZnO based nanofluids

The pumping power for nanofluids plays vital role for contributing the kinematic viscosity, dynamic viscosity and density in heat transfer improvement. In this context, the pumping power is important parameter for heat transfer of nanofluids. It has proven by many researchers if total pumping power of the heat transfer rig is more than one, using different kinds of nanofluids couldn't considered cost effective according to pumping power. The Figure 5a describes the required pumping power for different (0.1, 0.075, 0.05 and 0.025) wt.% concentrations of ultrasonic assisted ZnO-DW based nanofluids. The rising trend shows that as the amount of ZnO nanoparticles increased in base fluid, the viscosity will increase which needs more pumping power to pump the nanofluids. The 0.1 wt.% concentration of ZnO-DW based nanofluids needs highest pumping power as compare to other three concentrations. The minimum pumping power is required to flow the lowest wt.% concentration due to their low viscosity.

The pressure drop measurement is necessary, in order to use of different nanofluids in engineering industry to augment the performance index of heat transfer improvement(Amiri et al., 2015). The experimentation were conducted to check the pressure drop values for base fluid (distilled water) and different (0.1, 0.075, 0.05 and 0.025) wt.% concentrations of ultrasonic assisted ZnO-DW based nanofluids. The Figure 5b represents the outcomes of pressure drop for base fluid and different concentration of nanofluids against the Reynolds numbers. The pressure drop depends upon the wt.% of ZnO nanoparticles and Reynolds numbers. The leading trend showed, as the flow rate and wt.% increased the pressure drop will increaser accordingly. The maximum pressure drop has been noticed for high concentration at highest Reynolds numbers. The all presented readings in Figure 5b were taken by an OMEGA pressure transducer.

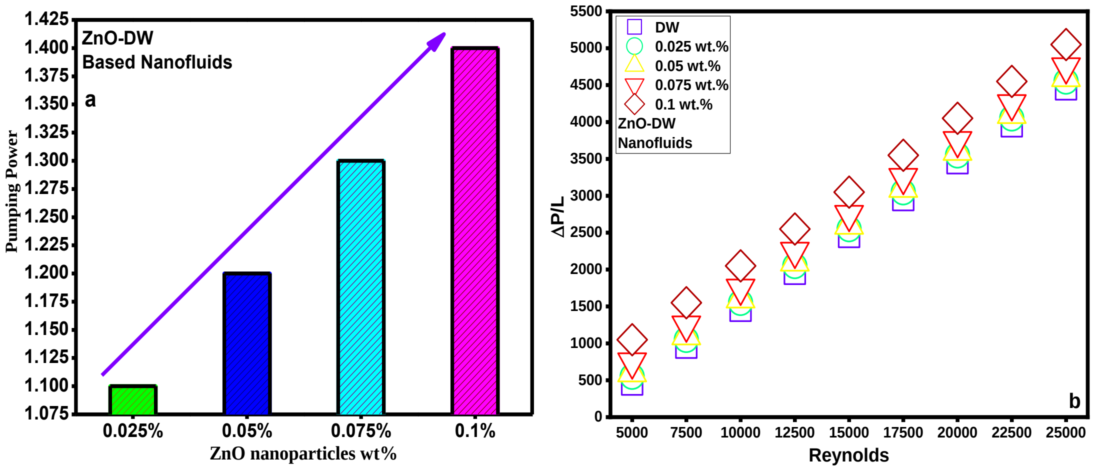


Figure 5 a) Relative pumping power for ZnO-DW based nanofluids and b) Pressure drop variations for different wt.% of the ZnO-DW based nanofluids

4.2 Heat transfer improvement in circular heat exchanger using ZnO nanofluids

To analyze the maximum improvement of convective heat transfer of the sonochemically assisted ZnO-DW based nanofluids with its different (0.1, 0.075, 0.05 and 0.025) wt.% concentrations in the turbulent regimes by using different mathematical equations. The variable flow rates and constant heat flux boundaries were used to measure the heat transfer growth in circular heat exchanger. The maximum Reynolds numbers from 5000 to 25000 have been selected for the heat transfer measurement. The full experimentation was conducted under room temperature environment by using complete heat transfer test rig. To continue the experiment, average heat transfer coefficients have been calculated for each of the ZnO-DW based nanofluids wt.% concentrations against a series of Reynolds from 5000 to 25000. During the experiment, it was observed that the heat transfer were increasing with increase in Reynolds and wt.% of the ultrasonic assisted ZnO nanoparticles. In the Figure 6a at the highest Reynolds and wt.% the maximum heat transfer were recorded. This enhancement credited to maximum presence of ZnO nanoparticles and high Reynolds. While the in case of base fluid (distilled water) the heat transfer improvement was less as compare to nanofluids due to nonexistence of ZnO nanoparticles. The heat transfer coefficient were recorded from 700 W/m^2K to 1470 W/m^2K for 0.1wt.% of the ZnO-DW based nanofluids at maximum Reynolds numbers. Although, the lowermost improvement was notices of 0.025 wt% and base fluid as well.

$$h = \frac{q''}{Tw - Tb} \quad (1)$$

$$q'' = \frac{Q}{A} \quad (2)$$

$$A = 4\pi d^2 \quad (3)$$

$$Re = \frac{\rho v D}{\mu} \quad (4)$$

Based on average heat transfer (h) the change in average Nusselt numbers were been also calculated by using correlations proposed by (Gnielinski, 1975; Dittus & Boelter, 1985; Petukhov, 1970) are given in Equ 5-6. The Figure 6b describes the outcomes taken by the numeric calculations, the average Nusselt numbers were also increasing with an slight increase in Reynolds numbers and wt.% of the ZnO nanoparticles. The maximum Nusselt increase were topped up for 0.1 wt.% from 10 to 19 at highest value of the Reynolds. All the wt.% concentrations of the ZnO-DW based nanofluids shows improved average Nusselt values with variation in Reynolds as compare to base fluid (distilled water). The ultrasonic assisted ZnO-DW based nanofluids shows positive improvement in heat transfer by using a circular heat exchanger.

$$Nu = h * \frac{D_h}{K} \quad (5)$$

$$Nu = \frac{\left(\frac{f}{8}\right)(Re-1000)Pr}{1++12.7\left(\frac{f}{8}\right)^{0.5}(Pr\,^\wedge 2/3\ -1)} \quad (6)$$

$$Nu = \frac{\left(\frac{f}{8}\right)RePr}{1.07+12.7\left(\frac{f}{8}\right)^{0.5}(Pr^{2/3}-1)} \quad (7)$$

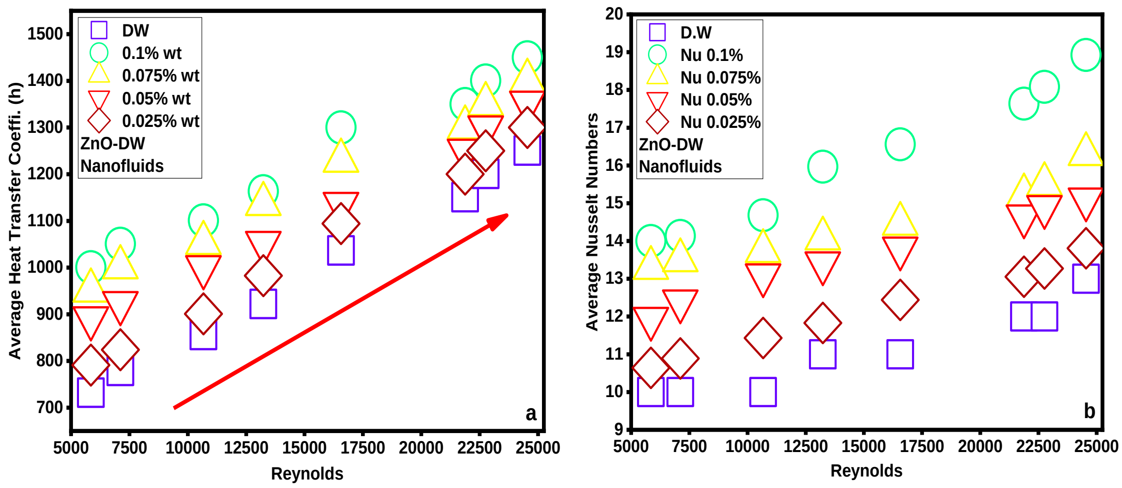


Figure 6 a) Average heat transfer growth, b) Average Nusselt numbers improvement of the ZnO-DW based nanofluids

5 Conclusion

In this research, the investigations were focused on synthesis of ultrasonic assisted ZnO nanoparticles and ZnO-DW based nanofluids for heat transfer improvement in circular tube heat exchanger. The ZnO nanoparticles were synthesized by using sonochemical process, where the zinc acetate and sodium hydroxide were used as raw materials. The XRD, FTIR, UV-vis and FESEM characterizations were performed to confirm the success of ZnO synthesis. The two step nanofluids preparation technique was applied for the preparation of ZnO-DW based nanofluids. The different (0.025, 0.05, 0.075 and 0.1) wt.% concentrations of ZnO-DW based nanofluids were prepared by using high probe sonication technique. Nanofluids at all the concentrations were tested to obtain the thermo physical and hydrodynamic properties and also their effects on heat transfer improvement in a circular heat exchanger. The results revealed enhanced changes in viscosity and density with the increase in wt.% of ZnO nanoparticles, while these changes were reversed with the increase of temperature. The heat transfer results showed a leading improvement with the addition of ultrasonic assisted ZnO nanoparticles in the base fluid. The maximum heat transfer improvement was recorded at the highest 0.1 wt.% concentration of ZnO-DW based nanofluids, where all other concentrations also showed positive improvement in heat transfer as compared to the base fluid. Finally, this study inferred that the addition of ultrasonic assisted nanoparticles in distilled water with uniform and homogeneous dispersion provides the benefits for enhanced heat transfer values. Thus the ZnO-DW water is a suitable combination for heat exchanger liquid specially in some specific environments.

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