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Natural Convection of Alumina-Distilled Water Nanofluid in Cylindrical Enclosure: An Experimental Study

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Abstract – *Temperature distribution of nanofluids has been investigated experimentally using thermography method and it is shown that suspended small amount of Al_2O_3 nanoparticles into distilled water were capable of lowering surface temperature of cylindrical enclosure. Also, for low concentration of nanoparticle, homogenising is the most preferable equipment used to produce homogenous and stable nanofluid. However, deterioration result was observed at high volume concentration.*

Keywords: Nanoparticle, Nanofluid, Natural convection, Thermography

1.0 INTRODUCTION

In modern technology, removing of heat away from miniature device or industrial equipment become a crucial task as conventional heat transfer media like air, water, ethylene glycol and mineral oil are not capable to cope with hi-tech technology due to poor transport properties of thermal conductivity in comparison with solids [3,11,13,14]. Therefore, suspension of nanometre-sized (1-100 nm) non-metallic, metallic, oxide, polymeric and nanotube particles into conventional liquid is being subject of interest globally as the founders of nanofluid system has reported an enhancement of 60% in thermal conductivity by dispersing only 5% volume fraction of nanoparticles [5]. Since then, a lot of researches have been report by many theorists and experimentalists on enhancement of thermal conductivity of various nanofluids. Corcione 2011 [4] theoretically found that there is enhancement of heat transfer in an enclosed natural convection for three different kind of nanoparticle materials (Cu, Al_2O_3 and TiO_2) in two different based fluids (water and ethylene glycol). He also found that temperature differences for the onset of convection is always larger for nanofluids than that of pure based fluid, in which indicated that nanofluid solution is more stable and the degree of stability increased with increasing nanoparticle volume fraction. By using two-phase lattice Boltzmann method, Ahmed and Eslamian [2] reported that the enhancement in heat transfer coefficient of nanofluid is about 13% higher than pure fluid in a heated square enclosure. In another study, Sharma et al. [12] experimentally reported on the increased of thermal conductivity of silver nanofluids up to 18% and after 30 days of preparation, the thermal conductivity was decreased from 18% to 14%.

Despite numerous studies claim that using nanofluids could significantly enhance heat transfer in the system, some experimentalists also reported on deterioration results in heat transfer of

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nanofluids. Experimental study on natural convection of titanium oxide nanofluids done by Wen and Ding 2006 [15] revealed that the presence of nanoparticle in fluid system decreases heat transfer coefficient and the maximum decrease was observed around 30%. While, for Rayleigh-Bernard convection, [1] reported on deterioration results in heat transfer at high Rayleigh number and the results were worsening as volume fraction of nanoparticles were increasing. The enhancement in heat transfer was only observed at low Rayleigh number. In addition, extensive reviews done by [10], [6,9] concluded that most of numerical studies showed that employed nanofluids had remarkable enhancement in heat transfer while some experimental studies reveal that suspended nanoparticles could deteriorated heat transfer process.

Therefore, the need for continuing studies on the effect of suspending nanoparticles into based liquid on surface temperature of system is necessary. So in this paper, we present investigation on natural convection in cylindrical enclosure contains Al_2O_3 nanofluids suspended in distilled water.

2.0 METHODOLOGY

Aluminium oxide-Based Nanoparticle. A stable nanofluids were prepared by suspending dry aluminium oxide with weight concentration of 0.5%, 1.0%, 1.5% and 2.0% into distilled water. No surfactant/dispersant was used during preparation process. The commercial Al_2O_3 nanopowder was supplied by Mk-Nano with declared diameter of 30 nm, mass purity of 80% and density value of 3.7 g/cm^3. For this study, two different types of mechanical input have been used to prepare a homogenous and stable solution of nanofluid, which are mechanical stirrer and high-shear homogenizer. The stirrer (RW 20, IKA) was operated at speed 450 rpm. While the homogenizer (Ultra-Turrax T25, IKA) operated at speed up to 24 000rpm and thus providing shear rate up to 40 000 s-1 [15]. The duration of mixing nanoparticles in based fluid is 30 minutes. Dynamic viscosity data were determined using rotational viscometer (Cole Parmer). Temperature profile of natural convection nanofluid have been experimentally determined using a thermal imager (Fluke Ti200). During experiment, a cylindrical enclosure contain of Al_2O_3 nanofluid was heated at the bottom and the top surface was exposed to the atmosphere.

3.0 RESULTS AND DISCUSSION

3.1 Density

Shown in Fig. 1 is density of Al_2O_3 nanofluid for two different preparation methods of stirring and homogenising. The density of nanofluids were increase with increasing Al_2O_3 weight fraction and the density value for both preparation method are identical for all weight fractions.

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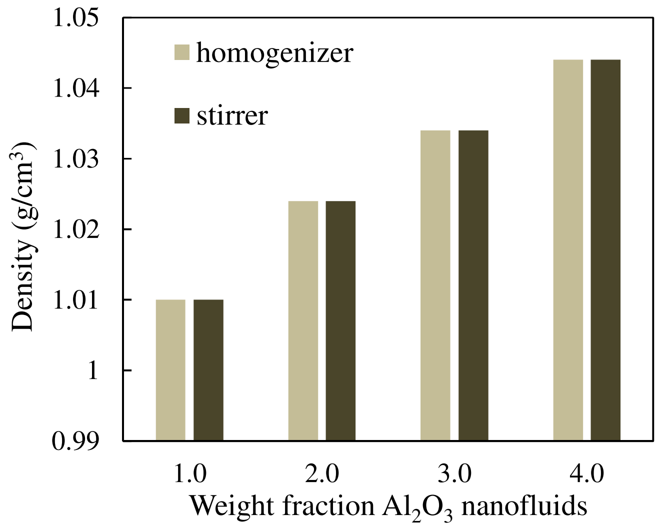

Figure 1: Density of 0.5, 1.0, 1.5 and 2.0% weight fraction Al_2O_3 nanofluids.

3.2 Viscosity

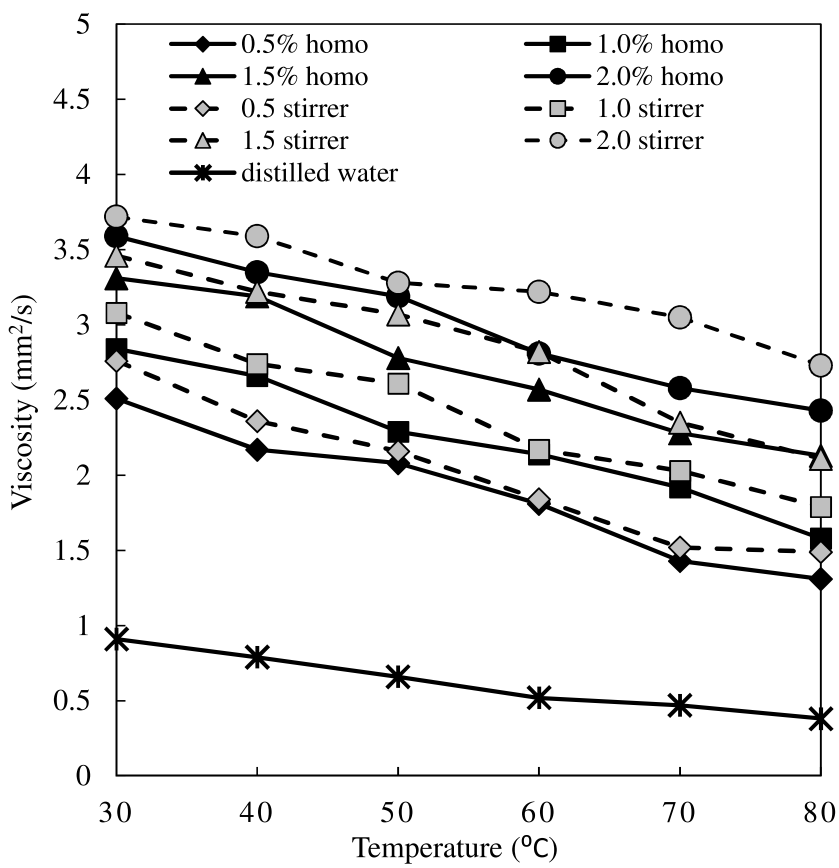

Figure 2: Viscosity of 0.5, 1.0, 1.5 and 2.0% weight fraction Al_2O_3 nanofluids prepare using homogenizer and stirrer.

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Figure 2 shown a viscosity of 0, 0.5, 1.0 and 2.0% weight fraction Al_2O_3 nanofluids prepared using mechanical stirrer and homogenizer. For both methods, the viscosities are increase with increasing temperature and volume fractions and also larger than based fluid of distilled water. However, viscosity of nanofluids prepared using stirrer were higher than that of homogenizer for all weight fractions.

3.3 Surface Tmprature

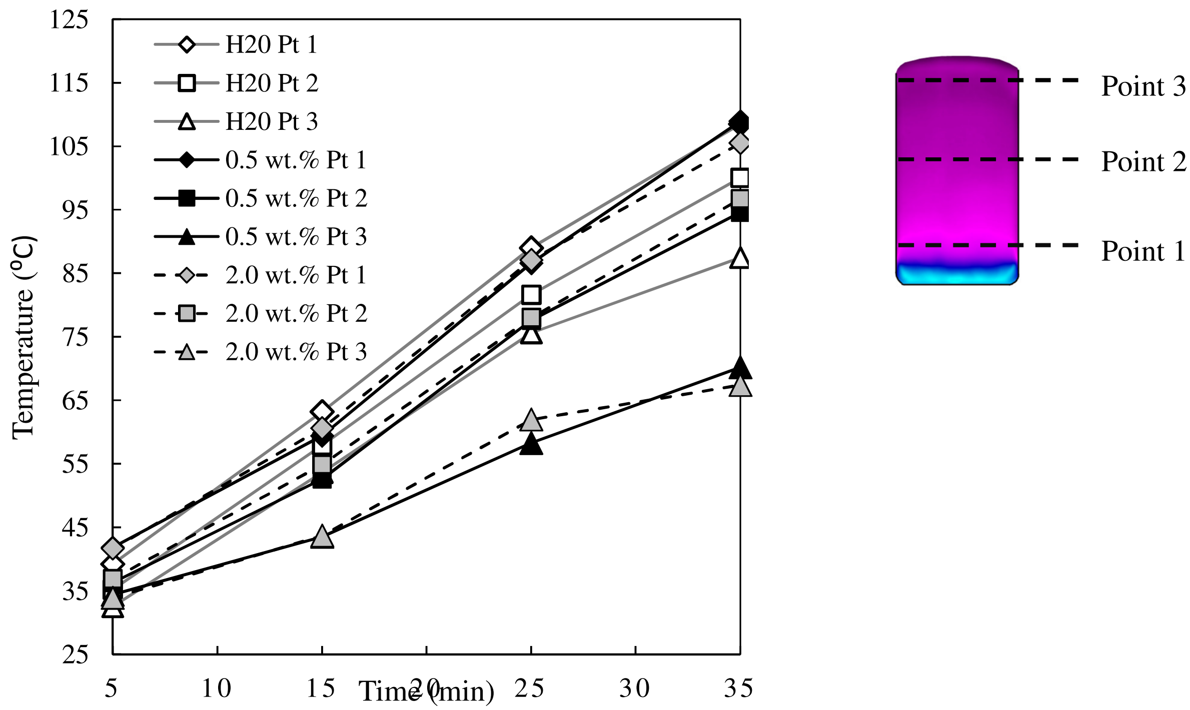

Figure 3: Surface temperature of distilled water and nanofluids prepared using homogenizer at different point from heat source.

Surface temperature (T_s) of the cylindrical enclosure contains of Al_2O_3 nanofluids prepared using high-pressure homogenizer and stirrer are presented in Figure 3 and Figure 4. As seen in both figures, Ts of a system contain nanofluids are slightly lower than that of pure based fluid of distilled water, in which indicated that bulk temperature of nanofluids are a way lower compare to the bulk temperature of distilled water. Also report by [15] that Ts is always higher then temperature of bulk fluid in a system. As reported by many researchers addition of nano-sized particles in based fluid promising in enhancement of thermal conductivity of the fluid system. So, as this transport property of heat transfer media was enhanced, the capability of transferring heat away from the system could be ameliorated.

Also, as seen in both Figure 3 and Figure 4, the difference in Ts between Al_2O_3 nanofluids and distilled water were very conspicuous especially for a point 3, where it is located slightly far from the heat source and a bit closer to the atmosphere. In addition, the difference in Ts between hot region (Point 1) and warm region (Point 3) for distilled water was smaller, unlikely as demonstrated by 0.5 and 2.0 % weight fraction Al_2O_3 nanofluids.

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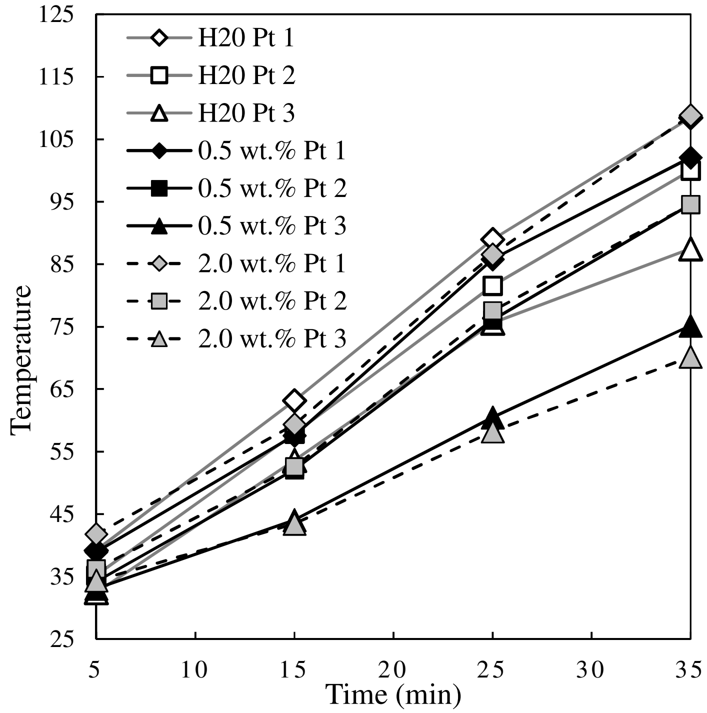

Figure 4: Surface temperature of distilled water and nanofluids prepared using stirrer at different distance from heat source.

However, for both homogenizing and stirring methods, dispersion of large amount of Al_2O_3 nanoparticles (2.0 % weight fraction) into based liquid showed deterioration results in cooling down the system as Ts of 2.0 wt.% were almost similar to Ts of 0.5 wt.%. The trend is somehow contrary to our expectation of enhancing heat transfer by suspending large amount of nanoparticles into based liquid because as reported in many literatures thermal conductivity of nanofluids could be increased by increasing the volume/weight fraction of nanoparticles. Similar results of deterioration in heat transfer were experimentally reported by [1,7,8]. All of them observed the deterioration at high volume fraction of nanoparticles (> 2.0%).

Figure 5 and 6 showed surface temperature of 0.5 and 2.0% weight fraction of Al_2O_3 nanoparticles dispersed in distilled water by using high-pressure homogenizer and mechanical stirrer. As seen in Figure 5, Ts of system contain nanofluids prepared using homogenising method is lower compare to the nanofluid prepared using stirring method. The difference in Ts between those two methods were conspicuously apparent after 15 minutes of constant heating. However, for weight fraction of 2.0%, Ts value for homogenising and stirring method were almost identical throughout the heating process. Failure of homogenizer to produce stable nanofluid solution might be due to the influence of high shear rate on solid-solid and solid-liquid interactions of nanoparticles. Therefore, for a low concentration of nanoparticles, homogenising is most preferable method in dispersing nanoparticles into distilled water whereas at high concentration that method will generate deterioration results.

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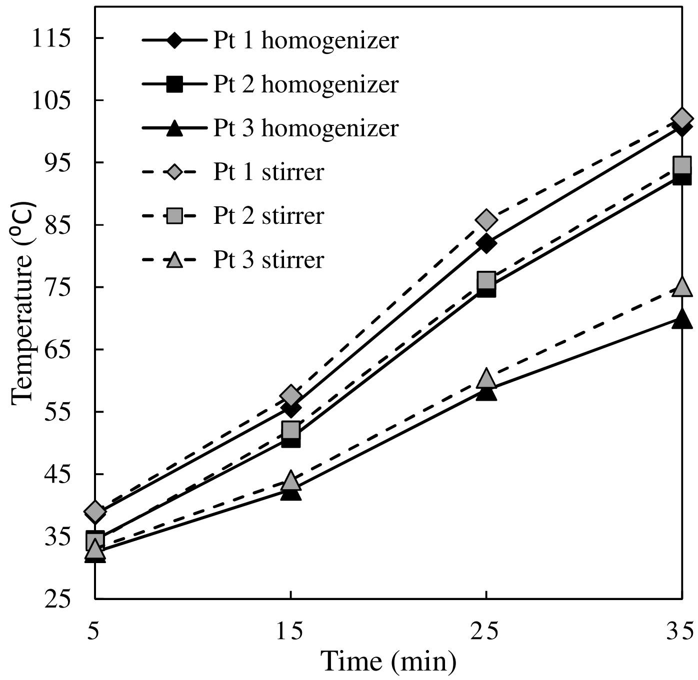

Figure 5: Surface temperature of Al_2O_3 nanofluids at 0.5% weight fraction.

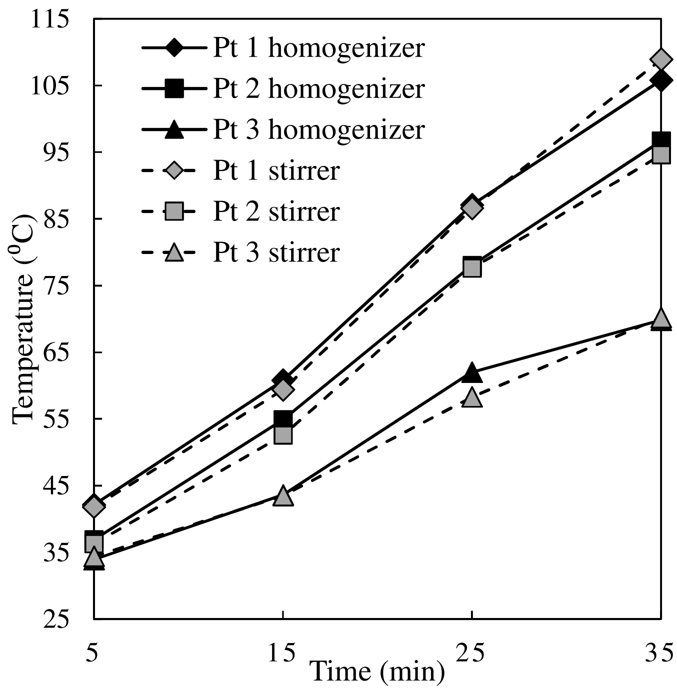

Figure 6: Surface temperature of Al_2O_3 nanofluids at 2.0% weight fraction.

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3.4 Temperature distribution

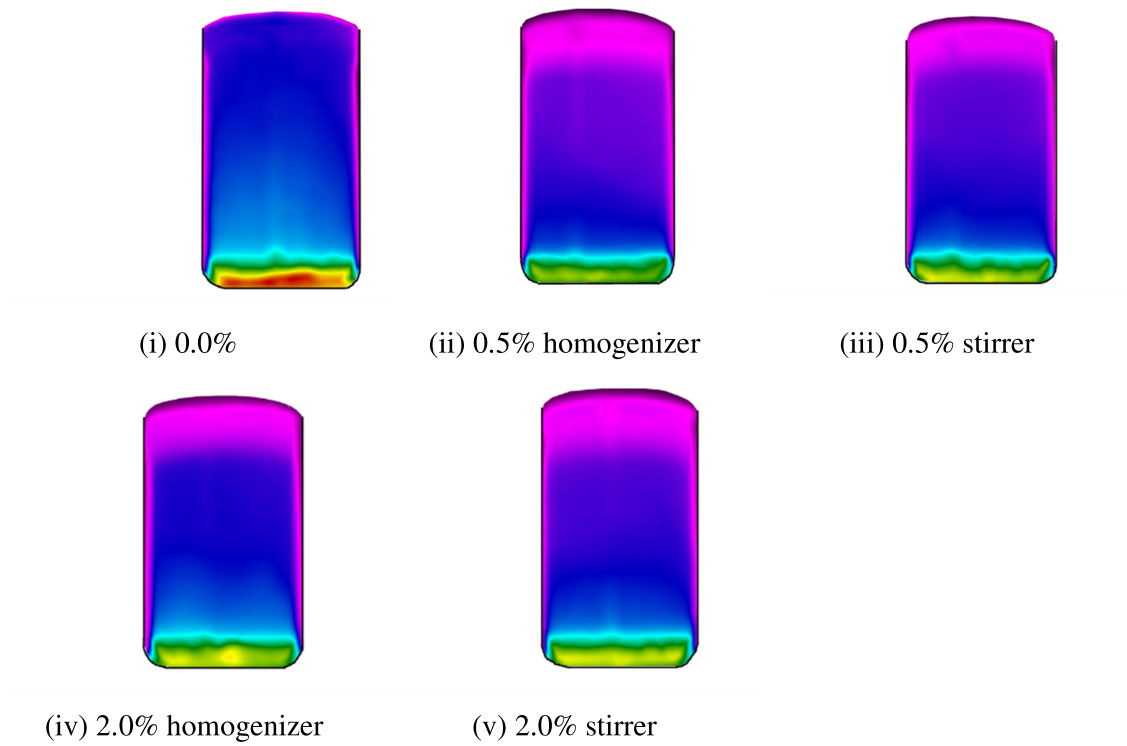

Figure 7: Temperature distribution of pure liquid and nanofluids at 15 minutes.

Figure 7 showed a temperature distribution of distilled water and Al_2O_3 nanofluids at 15 minute of heating process. For pure based liquid, an appearance of red contour at bottom part and distribution of blue contour to all over surface of the system had been proved of fact that surface temperature of system which contain solely distilled water was rose faster compare than nanofluid system. So addition of solid particles into based liquid could retard an increment of temperature due to the improved transport properties of the system. For all nanofluids system, as distance from heat source increased, the Ts is decreasing particularly near the atmosphere. However, regardless of preparation method, the presence of bright yellow contour only in weight fraction of 2.0% was indicated that adding more nanoparticles into based liquid have been fruitless in reducing Ts of system and eventually bulk temperature of liquid. Whereas, at low concentration of 2.0%, temperature distribution for nanofluid prepared using homogenizer and stirrer was almost similar except at bottom area as green contour of stirring solution was brighter than that of homogenizing solution.

At 25 minute of constant heating, green contour dominated the distribution while for nanofluid, the height of boundary of green contour were increased with increasing weight concentration of Al_2O_3 nanoparticles for both preparation method as depicted in Figure 8.

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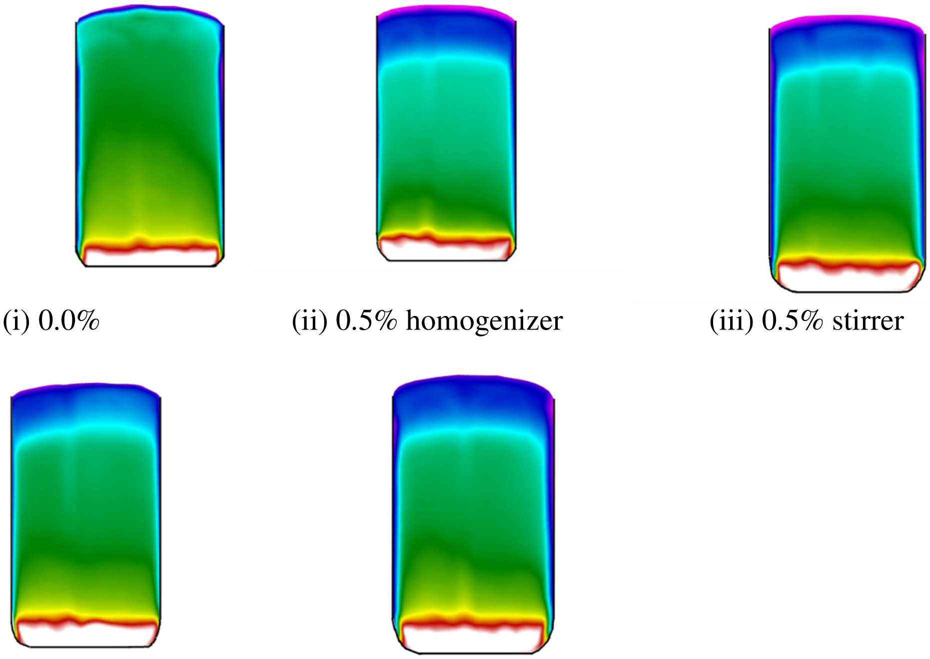
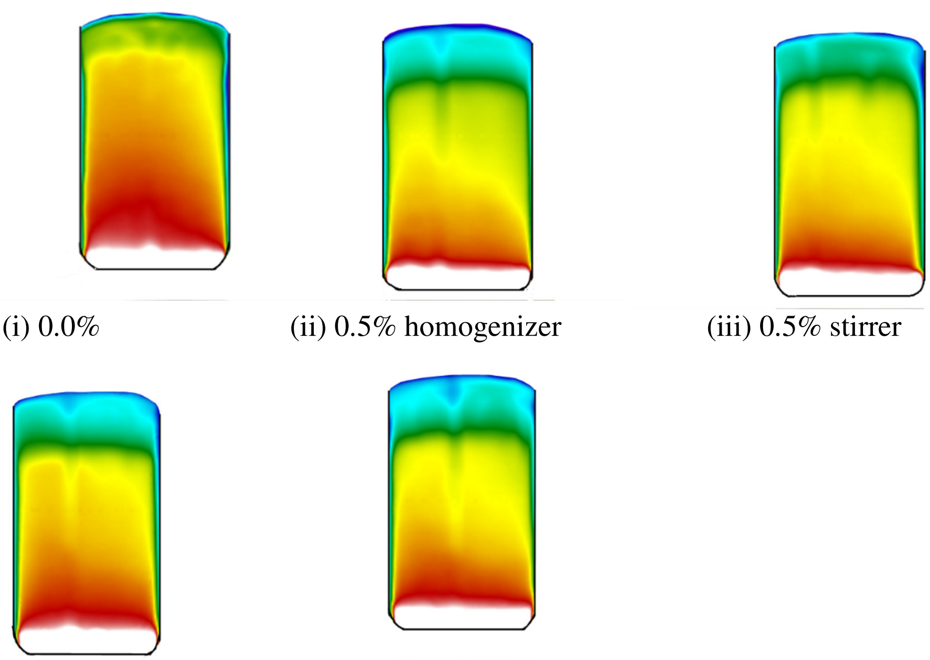


(i) 0.0% (ii) 0.5% homogenizer (iii) 0.5% stirrer

(iv) 2.0% homogenizer (v) 2.0% stirrer

Figure 8: Temperature distribution of pure liquid and nanofluids at 25 minutes.



(i) 0.0% (ii) 0.5% homogenizer (iii) 0.5% stirrer

(iv) 2.0% homogenizer (v) 2.0% stirrer

Figure 9: Temperature distribution of pure liquid and nanofluids at 15 minutes.

As heating process were continued up to 35 minutes (Figure 9), for distilled water, boundary of yellow contour just appeared near the upper surface while for nanofluid, the height of same boundary layer were increased with increasing weight concentration and approaching green boundary layer. Therefore, as presented in the figure above, nanoparticle is capable of enhancing transport properties of the fluid and hence competently cooled down temperature of system.

4.0 CONCLUSSION

Natural convection of cylindrical enclosure contain Al_2O_3 nanofluid was studied, while the effect of different preparation method of nanofluids and the influence of increasing amount of nanoparticles suspended was explored. Infrared thermography have been employed to study temperature distribution in the systems during hating process. Surface temperature of enclosure contains nanofluids are lower than that of distilled water. For preparation method, homogenising method promote better cooling compare than stirring method. However, increased weight concentration of nanoparticles into based liquid resulting in deterioration heat transfer. Viscosity of nanofluids prepared using stirring method are larger than homogenising method.

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