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EXPERIMENTAL INVESTIGATION OF FLOW-BOILING HEAT TRANSFER USING NANO-REFRIGERANT

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ABSTRACT

Thermal systems such as refrigerators and air conditioners consume large amount of electric power, thus several ways of developing energy efficient refrigeration and air conditioning systems with environmentally friendly refrigerants need to be investigated. On the other hand, the rapid advances in nanotechnology have led to emerge a new generation of heat transfer fluids called nanofluids in which addition of nanoparticles to base fluids changes their heat transfer characteristics. In the present study, the effect of using aluminum oxide (AL_2O_3)/Polyol Ester oil (POE) nanofluids on the flow boiling heat transfer coefficient of R134a refrigerant was experimentally investigated. The experiments have been performed at different nanoparticles concentration ranged from 0.025 wt.% to 0.125 wt.%, with nanoparticles size of 50-60 nm, and at heat flux ranged from 53 to 88 kWm^{-2}. The experimental results indicated that the addition of POE oil and AL_2O_3 nanoparticles to the base fluid (R-134a) increases the flow boiling heat transfer coefficient. Furthermore, the stability of the prepared nanofluid samples was investigated by both Ultraviolet-Visible (UV-Vis.) spectrophotometer and dynamic light scattering analysis. The high value of Zeta Potential reflected the good stability of the nanofluid which achieved from the effect of sonication of the nanoparticles within the base oil.

KEYWORDS: Al_2O_3, nanofluid, R134a, vapor compression refrigeration cycle, light scattering.

1. INTRODUCTION

Due to the high consumption of electric power in many thermal systems, such as refrigerators and air conditioners, so it becomes an important to improve the

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thermal performance of these systems to face the depletion of energy resources. Heat transfer fluids are of great importance in these systems, and most traditional heat transfer fluids have poor heat transfer coefficient due to their low thermal conductivity. Thus, evaporating heat transfer coefficient of these fluids should be improved, and it is better to involve friendly-refrigerants with respect to environment.

Generally, the refrigerant is a substance that used in a heat pump and refrigeration cycle and undergoes phase transitions from liquid to vapor and vice versa. The most common refrigerants used for such purpose are ammonia, sulfur dioxide, non-halogenated hydrocarbons, and fluorocarbons, but they are being forbidden because of their ozone depletion effects. The ideal refrigerant should have the following characteristics: good thermodynamic properties, i.e., boiling point somewhat below the target temperature, a high heat of vaporization, a moderate density in liquid form, a relatively high density in gaseous form, and a high critical temperature. In addition, they should be noncorrosive to mechanical components, safe and free from toxicity and flammability, and would not cause ozone depletion or any climate change.

HydrofluorocarbonsR134aisthe most widely used alternative refrigerant in the refrigeration systems because of its high global warming up potential [1]. This traditional heat transfer fluid, and others, has inherently poor heat transfer performance due to their low thermal conductivities. Thus, several researches and development activities have been performed to enhance the heat transfer characteristics of the refrigeration systems by improving the thermo-physical properties and the transport properties of fluids used. Since the past decade, the rapid advances in nanotechnology have produced several aspects for the scientists and technologists to look into; thus a new generation of heat transfer fluids called nanofluid has been emerged. In these fluids, dispersing few milligrams of nanoparticles having size of 1-100 nm to base fluids changes their thermo-physical, rheological and tribological properties [2]. Moreover, the addition of nanoparticles to base fluids helps in enhancing the performance of the refrigeration systems. These fascinating enhancements may be attributed to the increase in the interfacial area between the nanoparticles and the base fluid. This in turn, due to the unique properties of nanoparticles; their large surface area to volume ratio, dimension-dependent physical properties, and lower kinetic energy, that make them better and more stably dispersed in base fluids. Thus, nanoparticles have great potential to effectively improve the thermal transport properties of the resulting nanofluids. This is because large solid particles cause severe problems, such as abrasion of the surface, clogging the micro channels, eroding the pipeline and increasing the pressure drop, which substantially limits the practical applications [3].

The term “nanofluid” was first introduced in 1998 [4], and it was prepared by suspending various metals and metal oxides nanoparticles in several fluids resulting in mixtures with promising properties [5-8]. From then, many scientific researchers have interested in improving thermal transport properties of thermal systems fluids by dispersing thermally conductive nanoparticles in these fluids [9-15]. The solid nanoparticles that may be dispersed into the fluids (lubricating oils or refrigerants) to form nanofluids might be metals, metallic oxides, carbon nanotubes, etc [9, 10].This is because these solid materials have much higher thermal conductivities than pure fluids. Therefore, nanofluids exhibit substantially higher thermal conductivities than those of the corresponding base fluids.

The effect of titanium oxide (TiO_2) nanoparticles on the performance ofR600a refrigerant that used in domestic refrigerators has been studied [11, 12], and the results revealed that TiO_2-R600a nano-refrigerants work normally and safely in the refrigerator, and the refrigerator performance was enhanced by reducing the energy consumption. Another study showed the effect of TiO_2nanoparticles when dispersed in R12 refrigerant to be used as working fluid in domestic refrigerator [13].The reported data showed that the freezing capacity and heat transfer coefficient increased by 3.6 %. In addition, the compression work reduced by 11% and performance coefficient increased by 17% due to the dispersion of TiO_2 nanoparticles in the lubricating oil.In addition, the heat transfer and the performance of a domestic refrigerator using Al_2O_3-R134a nano-refrigerant as working fluid was reported to be better than pure lubricant with R134a working fluid, and with 10.30% less energy used at 0.2% volume ratio of the Al_2O_3-R134a nano-refrigerant [14].On other sides, CuO nanoparticles have been widely used with R134a refrigerant because of better environmental and energy performances, and the refrigerants-containing these nanoparticles enhanced the thermal conductivity and eventually the heat transfer coefficients with respect to those of the base fluid [1,3, 9]. The effect of CuO nanoparticles on the performance R134a has been reported, and the evaporated heat transfer using CuO-R134a nano-refrigerant in the vapor compression refrigeration system at different concentration of CuO (0.05-1%) was evaluated. The obtained results showed that the evaporating heat transfer coefficient was increased with increasing CuO concentration to certain extent and then decreased. Moreover, an experimental analysis on the flow boiling heat transfer of R134a based nanofluids containing CuO nanoparticles has been conducted. The obtained data showed excellent dispersion of CuO nanoparticle with R134a and POE oil, and the heat transfer coefficient increased more than 100% over baseline R134a/POE oil results.

In the vapor compression refrigeration system, the nanoparticles can be added to the lubricant (compressor oil). When the refrigerant is circulated through the compressor it carries traces of lubricant plus nanoparticles mixture (nano lubricants) so that other parts of the system will have nano lubricant-refrigerant mixture (nano refrigerant).Recently, some investigators have conducted studies on vapor compression refrigeration systems, to study the effect of nanoparticle in the refrigerant/lubricant on its performance. In 2008, it was reported that there is a remarkable reduction in the power consumption and significant improvement in freezing capacity [16], and the improvement in the system performance wasdue to better thermo-physical properties of mineral oil and the presence of nanoparticles in the refrigerant. Another reported study used R134a refrigerant and polyester lubricant mixed with Al_2O_3 nanoparticles to improve the lubrication and heat-transfer performance of a refrigeration system [17]. The results showed that the 60% R134a and 0.1 wt % Al_2O_3 nanoparticles were optimal, and under these conditions, the power consumption was reduced by about 2.4%, and the coefficient of performance was increased by 4.4%.In general, the published data for nanofluids showed that nanofluids possess improved thermal transport properties and it has been experimentally proved that nanofluids have potential as next generation advanced heat transfer fluids.

In addition to improve thermodynamic and mechanical performance of refrigerating machines by using nanofluid, even at relatively low concentrations of nanoparticles, and with a corresponding enhancement of energy efficiency of systems employing such fluids, tribological properties of lubricants can also be improved. Such improvements in tribological properties (lubricity, anti-wear properties, and extreme pressure behavior) will add clear benefits to the life cycle of the refrigeration compressors. The tribological behavior of the POE oil, as a base lubricant, has been improved by adding TiO_2 nanoparticles and single wall carbon nano horns (SWCNH) to the lubricant in presence of R134a as refrigerant [18].

As mentioned above, the unique properties of nanoparticles affect the performance of the nanofluids. However, nanoparticles type, shape size and loading, as well as Zeta Potential and pH of the nanofluids solution are also parameters that may influence the performance of these kinds of fluids.

The objective of the present study is to investigate the evaporating heat transfer coefficient in the vapor compression refrigeration cycle by addition of Al_2O_3 nanoparticles with different concentrations to R134a as a base fluid. The Al_2O_3 has been chosen because it is available in different nano size, and also because of its high thermal conductivity [14, 17]. The preparation and stability of the nanofluids will be also presented here.

2. EXPERIMENTAL SETUP

2.1 Experimental Test Rig

The objective of the present study is to investigate the effect of adding AL_2O_3 nanoparticles to Polyol Ester oil (POE) on the flow boiling heat transfer of R134a. It is conducted for various values of heat flux and nanoparticles concentration to know their effects on the evaporating heat transfer coefficient of the vapor compression refrigeration cycle. An experimental test rig is designed and constructed to fulfill this objective where the experimental measurements are performed. Fig. 1 shows a schematic diagram for the experimental test rig. The experimental test rig consists of a vapor compression refrigeration unit and a water loop. The refrigeration unit mainly consists of a hermetic reciprocating compressor (0.50 HP), air-cooled condenser, capillary tube and tube-in-tube evaporator (test section), in addition to the auxiliaries such as filter dryer, sight glass and shut-off valves. Also, pressure gauges and temperature sensors are placed at assigned locations to measure the pressures and temperatures. Also two service ports are provided at the compressor; one for injecting the nanofluid (POE/Al_2O_3) inside the system and charging the refrigerant, and the other one for draining it.

Full details of the evaporator (test section) are illustrated in Fig. 2. It is a tube-in-tube heat exchanger. The inner tube is 700 mm length straight horizontal tube, made of copper with an outer diameter of 9.52 mm and inner diameter of 7.72 mm. The outer tube is made of copper having an outer diameter of 19.05 mm and inner diameter of 17 mm. The refrigerant flows through the inner tube and the water through the annulus. Also, as shown in Fig. 2, the outer tubes divided to five sections with spacing 25 mm to enable temperature measurements for the outer surface of refrigerant tube, accordingly copper tubes and hoses are used to link the five sections.

On the other hand, the water loop consists of tank with submerged electric heater, pump, water pipes and shut-off valves. Moreover, flowmeter and temperature sensors are installed in the water loop to measure the water flow rate and temperatures. The water flows around the refrigerant tube in a counter direction representing the cooling load on the evaporator. The water is supplied from water tank to the evaporator where it is cooled and giving up its heat to the refrigerant then it is returned back to the water tank to be heated again to the preset temperature. Fig. 3 shows an image for the experimental test rig.

Suitable measuring instruments are used for monitoring temperatures, water volume flow rate and refrigerant pressures. The temperatures are measured by using calibrated digital temperature sensors (embedded temperature panel meter TPM-30). The temperature sensors readings are in the range -50°C to +70°C with a resolution of 0.1°C. They are used to measure the average wall temperature of the refrigerant tube by distributing them at six locations on the outer surface of the refrigerant tube circumference in the test section. They are also used to measure the inlet and exit water temperature of the test section. The water volume flow rate is monitored by using a calibrated rotameter, which have a range from 1 to 7 liters/min with a resolution 0.25liters/min. During the experiments, the water volume flow rate is adjusted at 5liters/min. Moreover, a digital temperature controller (electronic thermostat) is used to control the required temperature inside the water tank during experiments.

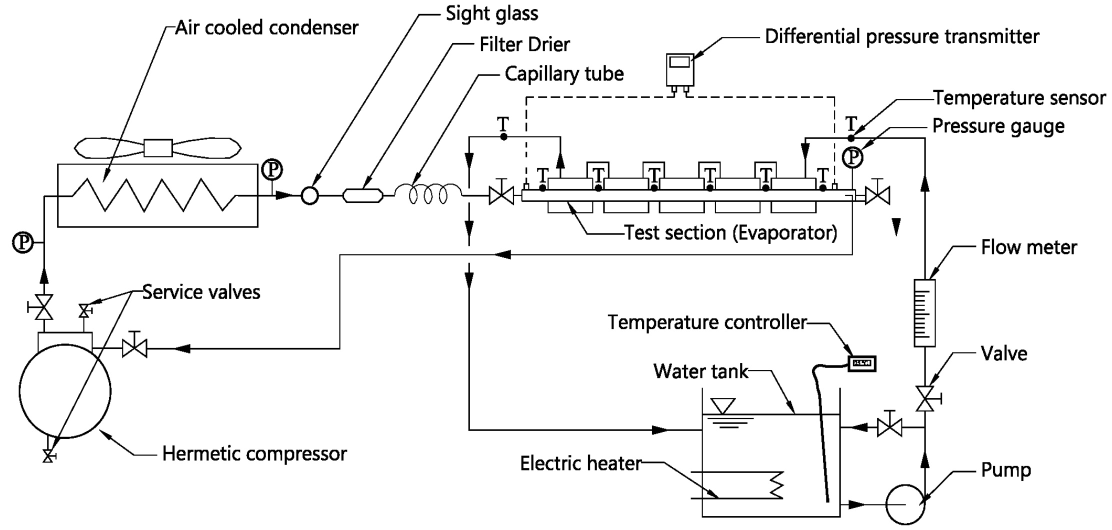

Fig. 1. Schematic diagram of the experimental test rig.

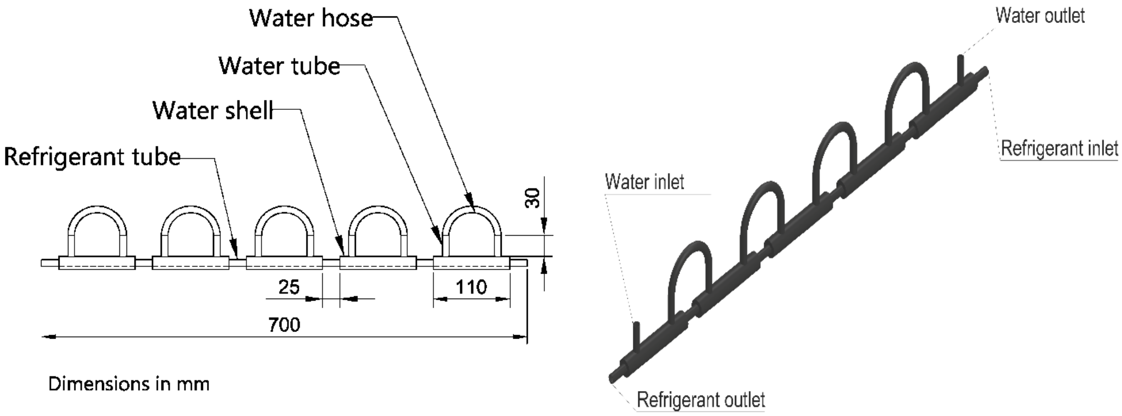

Fig. 2. Test section details.

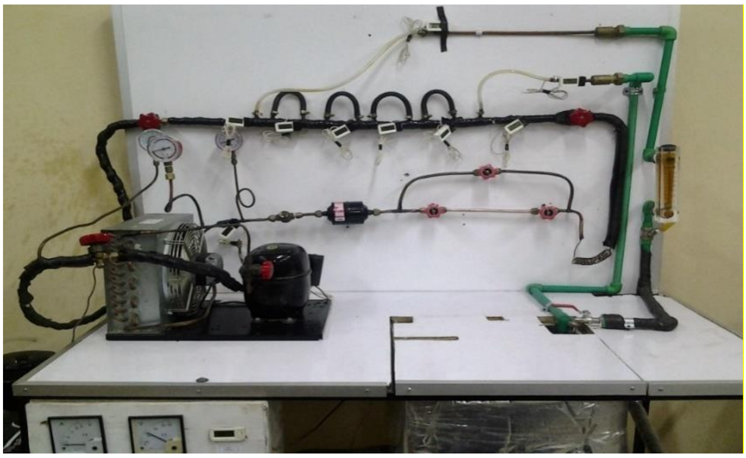

Fig. 3. Photograph of the experimental test rig.

The specifications of the digital temperature controller are: ELIWELL IC 901, 0.5% accuracy, and 1°C set-point differential. Refrigerant pressures are measured in the test apparatus by using three bourdon tube pressure gage, two of them are connected to the high pressure side of the refrigeration cycle, as shown in the Fig. 1. These two gauges have a pressure range from 0 to 500 psi with resolution of 5 psi. The third gauge is connected to the low pressure side of the refrigeration cycle at evaporator exit. This gauge has a pressure range from 0 to 250 psi with resolution of 1 psi. The pressure drop across the evaporator is measured by differential pressure transmitter with maximum working pressure 50 psi.

2.2 Materials

The main materials used in this study were nanoparticles, refrigerant, and polyol ester (POE) that used as lubricating oil. The Al_2O_3 nanoparticles were purchased from MKNANO (M K Impex Corp), with 99 % purity and with average particle size of 50 nm as given by manufacture data sheet, and the refrigerant used was R134a. The lubricating oil used here was the synthetic Emkarate RL 68H purchased from Lubrizol with viscosity and density equal 7.06×10^{-2} $Nm^{-2}.s$ and 0.977 g/mL respectively. This type of lubricating oil is formulated specifically for use in refrigeration and air-conditioning compressors. The combination of low temperature characteristics and thermal stability enable the use of Emkarate RL 68H over a wide operating temperature range.

2.3 Preparation of Al_2O_3/Polyol Ester Nanofluid

In this study, Al_2O_3/POE nanofluid was prepared by dispersing a specified amount of Al_2O_3 nanoparticle within a definite amount of POE using magnetic stirrer for 5 minutes. To prevent any clustering of particles in the mixture, and to obtain proper homogenization, the mixture was then sonicated using ultra sonic at room temperature for two hours. This sonication time will enhance the dispersion of nanoparticles within the fluid, and consequently will enhance the stability of the nanofluid as reported in previous work [19, 20].Three different samples with different wt. % of Al_2O_3 /POE oil ranging from 0.025% to 0.125% were prepared. The distribution of the nanoparticles within POE oil is indicated in Fig.4.

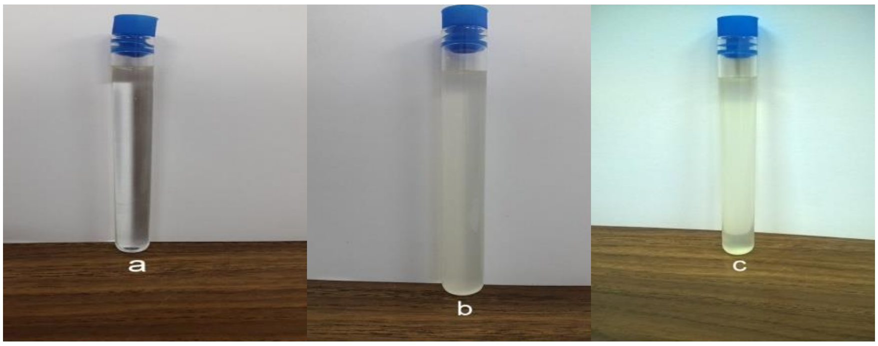

Fig. 4. Distribution of Al_2O_3 nanoparticles within POE oil
a) Pure POE oil, b) POE oil with Al_2O_3nanoparticles after preparation, c) POE oil with Al_2O_3 nanoparticles after 1 week.

3. STABILITY OF NANOFLUID DISPERSION

Although the stability of nanofluid is very important in order for practical application, the data is limited on estimating the stability of nanofluids. The colloidal stability of the dispersions can be estimated quantitatively using Ultraviolet-Visible (UV-Vis.) spectrophotometer [21]. Here, the absorbance of the prepared nanofluid was taken by JASCO V-630 UV–Vis spectrometer at wavelengths ranged from 200 nm to 800 nm and at room temperature. Visual check is also used to investigate the stability of nanofluids by monitoring the dispersion with time. Due to the advanced dispersion technique used in the preparation process, nanofluids can be kept stable for several weeks without visible sediment.

Another method used to investigate the stability of nanofluid and distribution of the nanoparticles within the used POE oil in this study was dynamic light scattering (DLS). Actually, DLS is used to measure the mobility of nanoparticles in nanofluids, and it helps in determining the particle size distributions of these small particles in the solution, which is called “hydrodynamic radius”. Particles distribution is determined from the Brownian motion of suspended particles. This is a critical test to validate the quality of the nanofluids stability via the study of its electrophoresis behavior. According to the stabilization theory, the electrostatic repulsions between the particles increase if Zeta Potential has a high absolute value which then leads to a good stability of the suspensions [22]. Theoretical results have been reported that the anomalous enhancement in thermal conductivity of nanofluids is attributed to Brownian motion [23]. The DLS of the prepared samples was performed by Malvern Zetasizer with base oil as a reference.

4. EXPERIMENTAL PROCEDURES

The experimental procedures are initiated after assembling the test rig. The following steps illustrate the procedures. One of the prepared samples of Al_2O_3/POE nanofluid with a certain concentration is charged into the refrigeration cycle via the service port installed in the compressor. After that, the water tank is filled with water and the electric heater is switched on. After the water reaches the desired temperature, the water is pumped from the tank to the test section (the evaporator) then the compressor is switched on. The aforementioned steps are repeated for different inlet water temperature to the test section to enable working at different heat fluxes. At a certain heat flux, the experimental apparatus is allowed to operate until steady state condition has been reached. It is considered to be achieved when the stable readings of the evaporator wall temperatures, inlet and outlet water temperatures are obtained. Once the steady state has been reached, the measurements of the temperatures, pressures and water volume flow rate are recorded. After completing the experiment, the cycle is switched off to get out the Al_2O_3/POE nanofluid from the compressor via installed service port in the compressor. The above steps are repeated for another concentration of nanofluid.

5. DATA REDUCTION

Excel sheet was prepared to process the experimental data for calculating the average flow boiling heat transfer coefficient as follows:

Water mass flow rate $\dot{m}_w$ is calculated as follow:

$$\dot{m}_w = \rho_w \dot{V}_w \tag{1}$$

where ρ_w is the water density and $\dot{V}_w$ is the water volume flow rate.

Heat flux (q) is calculated based on the heat transfer rate ($\dot{Q}_w$) into the refrigerant from the circulating water as follows;

$$\dot{Q}_w = \dot{m}_w c_w (T_{w,i} - T_{w,o}) \tag{2}$$

$$q = \frac{\dot{Q}_w}{2\pi r_o L} \tag{3}$$

where c_w is specific heat of water, $T_{w,i}$and $T_{w,o}$ are the water temperature at inlet and outlet of the test section, respectively; r_o and L are the outside radius and the length of the test section refrigerant tube, respectively.

The average wall temperature $T_{wall,avg}$at the outer surface of the refrigerant tube in the test section is calculated from the following equation:

$$T_{wall,avg} = \frac{\sum_{j=1}^{6} T_{ev,j}}{6} \tag{4}$$

where $T_{ev,j}$ is the wall temperature at a certain position from predetermined six positions distributed at the outer surface of the test section refrigerant tube.

The averageflow boiling heat transfer coefficient (h) is determined from;

$$\dot{Q}_w = \left(T_{wall,avg} - T_{ref,avg}\right)\left[\frac{1}{h 2\pi r_i L} + \frac{\ln(r_o/r_i)}{2\pi k L}\right]^{-1} \tag{5}$$

which was rearranged to be:

$$h = \frac{kQ_w}{[2\pi r_i kl(T_{wall,avg} - T_{ref,avg}) - Q_w r_i ln(r_o/r_i)]} \quad (6)$$

where k is the thermal conductivity of the copper tube wall; r_i and r_o are the inside and outside radii of the refrigerant tube in the test section, respectively; and $T_{ref,avg}$ is the saturation temperature of the refrigerant in the test section which is evaluated at average evaporator pressure, $P_{avg} = (P_{ev,in} + P_{ev,exit})/2$. The evaporator exit pressure, $P_{ev,exit}$, is measured using the installed pressure gauge, but the evaporator inlet pressure is calculated by adding the pressure drop measured by differential pressure transmitter on the value of evaporator exit pressure.

6. UNCERTAINTY ANALYSIS

In general, the accuracy of the experimental results depends on the accuracy of the individual measuring instruments and techniques. The uncertainty of the parameters is calculated based upon the root sum square combination of the effects of each of the individual inputs as introduced by Kline and McClintock [24]. For example, the uncertainty for the water mass flow rate $\dot{m}_w$was estimated as follows;

$$\frac{\omega_{\dot{m}_w}}{\dot{m}_w} = \pm\frac{1}{\dot{m}_w}\sqrt{\left(\frac{d\dot{m}_w}{\mathrm{d}\dot{V}_w}\omega_{\dot{V}_w}\right)^2} = \pm\frac{1}{\rho_w\dot{V}_w}\sqrt{\left(\rho_w\omega_{\dot{V}_w}\right)^2} = \pm\frac{\omega_{\dot{V}_w}}{\dot{V}_w} = \pm 2.5\%$$

Where, The uncertainty in volume flow rate is equal to one-half of the smallest scale division of the used rotameter (i.e. $\omega_{\dot{V}_w} = \pm 0.25 = \pm 0.125$ liters/min) and the value of the water volume flow rate is fixed at 5 liters/min. For all experimental runs, the average uncertainties in main parameters are summarized in Table (1).

Table 1: Average uncertainties in main parameters.

Parameter	Uncertainty (ω)
$\dot{m}_w$	±2.5%
$\dot{Q}_w$	±6.4%
q	±12.4%
$T_{wall,avg}$	±0.7%
h	±13.7%

7. RESULTS AND DISCUSSION

Nanofluids, when prepared properly, have attracting characteristics that make them ideal for cooling systems. The dispersion of nanoparticles in Polyol Ester oil (POE) can improve the thermal characteristics of refrigerating machines. The stability of that dispersion is determined using UV-Vis Spectrophotometer at different time intervals. The absorbance of the prepared nanofluid is measured at room temperature from 200nm to 800 nm wavelengths, and the peak absorbance of the nanofluid with 0.125 wt% Al_2O_3isfound to be at 368 nm. Based on this absorbance value, the calibration curve of nanofluid concentration at this wavelength is plotted as shown in Fig. 5. Then, the nanofluid samples are kept for several days in a stable and horizontal place, and their concentrations are measured at different time intervals by the aid of the above calibration curve using the UV-Vis spectrophotometer. The data obtained are tabulated in Table (2), from which it is clear that the stability of the nanofluid dispersion is stood for several days.

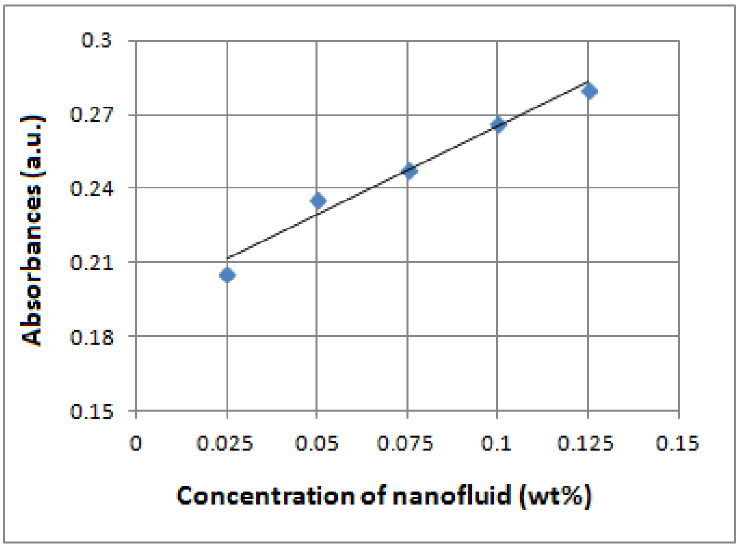

Fig.5.Calibration Curve for the Nanofluid Samples Obtained from UV-Vis Spectrophotometer at Room Temperature.

Table 2. Variation of nanofluid concentration with time

Wt% Initial	Wt% after 1 day	Wt% after 3 day	Wt% after 5 day	Wt% after 7 day
0.025	0.0249	0.0249	0.0248	0.0247
0.075	0.0747	0.0746	0.0745	0.0745
0.125	0.1248	0.1247	0.127	0.1246

The stability of the dispersion of nanoparticles in the POE oil is also investigated by DLS technique, and the particle size distribution is shown in DLS spectrograph, Fig. 6. From this figure, the particle size of Al_2O_3 nanoparticles distributed around 50-70 nm, and the value of Zeta Potential is 61 which reveals that the stability and the distribution of the Al_2O_3 nanoparticles within the POE oil are excellent. Zeta potential is the potential difference between the dispersion phase and the stationary layer of fluid attached to the nanoparticle. It reflects the degree of repulsion between the similarly charged particles in dispersion, thus fluid with high zeta potential (negative or positive) is electrically stable toward coagulation or flocculation [25].

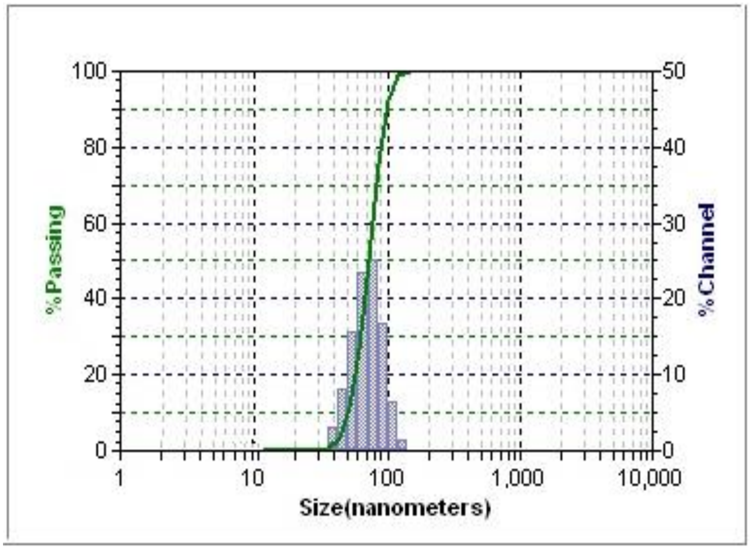

Fig. 6. DLS spectrograph of Al_2O_3/POE nanofluid.

Stability of nanofluids is very important requirement for the proper utilization of the potential of nanofluids. From data obtained from UV-Vis spectrometer and

DLS technique, the stability of the prepared nanofluids was good and this was achieved by using the two-steps preparation method that involves mixing the nanoparticles with the host fluid with magnetic stirring followed by ultrasonication or stirring for two hours in order to reduce particles agglomeration. Previous studies showed that as increasing the sonication time, the dispersion of nanoparticles within the fluid will be enhanced [19]. In our study, this was achieved due to the preparation of nanofluid with very low concentration (from 0.025 wt. % to 0.125 wt.%) at which the chance of sedimentation or settling of nanoparticles is not big [26]. The other reason of achieving the good stability of the prepared nanofluid is the viscosity of lubricating oil used which was 7.06 x 10^{-2} Nm^{-2}.s. In general, viscous liquids produce stable nanofluids due to low settling velocities. As one would expect, without constant mixing, the probability of nanoparticle settling is greater for a low viscosity fluid than for a fluid with a large viscosity. For this reason, lubricants with dispersed nanoparticles, i.e., nano lubricants, can offer the possibility of improving the suspension of the nanoparticles due to the favorable viscosity of lubricants. On other hand, the viscosity of lubricant increases with mixing it with nano additives [27, 28].

Experimental studies are conducted here to evaluate the flow boiling heat transfer coefficient of the vapor compression system with lubricant containing nanoparticles (POE/Al_2O_3). The data obtained from charging the setup, Fig. 7 and Fig. 8 show that R134a refrigerant and POE oil mixed with Al_2O_3 nanoparticles work normally, and the flow boiling heat transfer coefficient increases with increasing the Al_2O_3 concentration and heat flux. It is noted that the flow boiling heat transfer coefficient increases by 42% at both high nanoparticles concentration of 0.125 wt.% and heat flux of 88 kWm^{-2}.

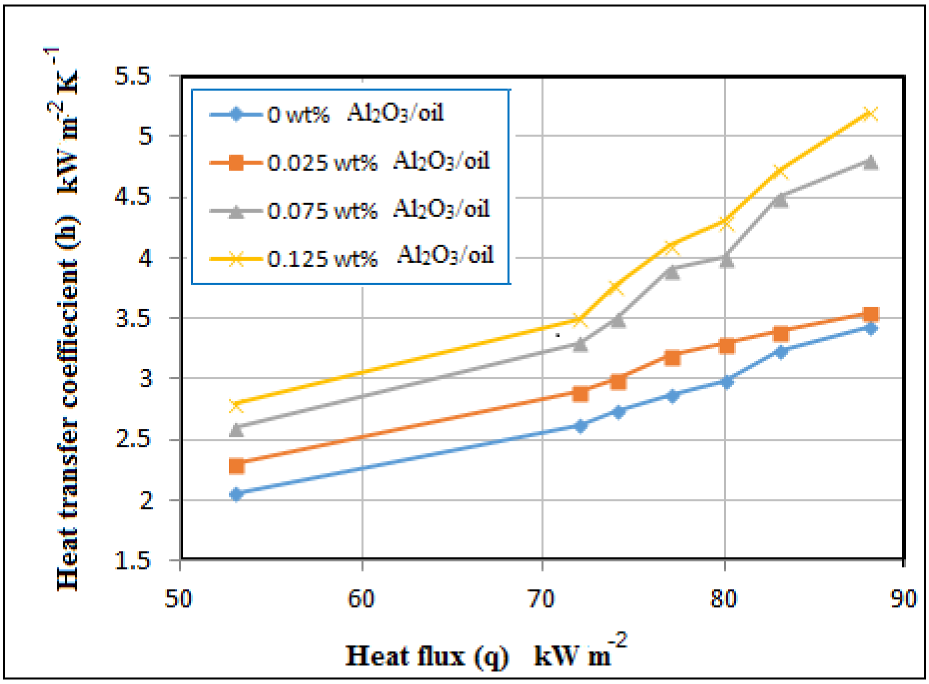

Fig. 7.Variation of heat transfer coefficient with heat flux of nanofluid at different Al_2O_3 wt%.

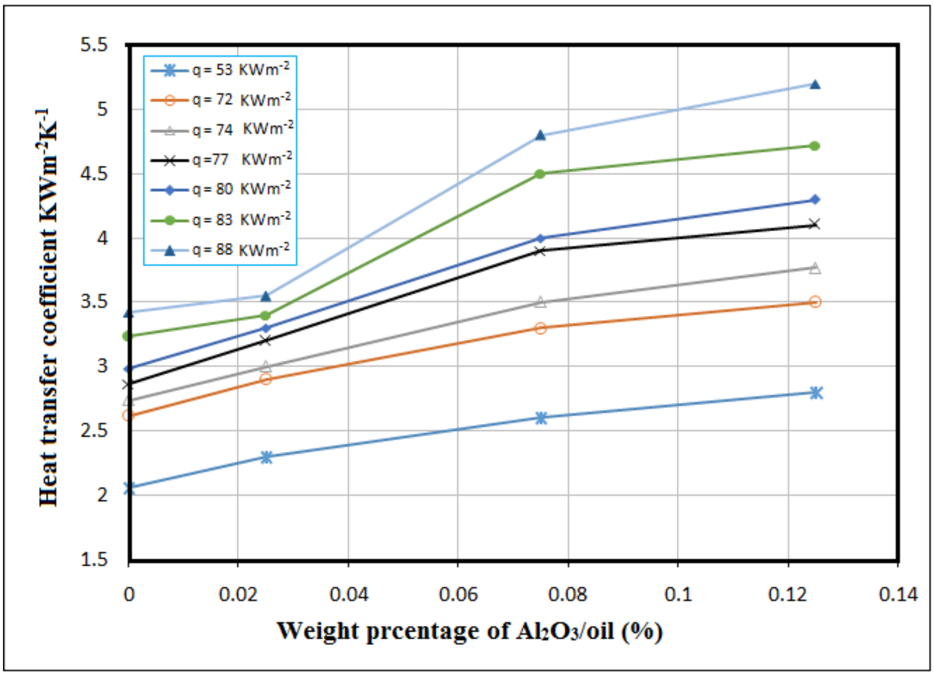

Fig. 8. Variation of heat transfer coefficient with concentration of nanofluid at different heat fluxes.

8. CONCLUSION

Based on the above analysis and discussion of the obtained results, it can be concluded that:

1- The POE oil and R134a refrigerant mixture with alumina nanoparticles worked perfectly, and the nanofluids with different concentrations of nanoparticles have been successfully prepared.
2- The stability of the prepared nanofluids was investigated using UV-Vis. spectrometer and DLS technique, and it was excellent because of the followed way of preparation.
3- The effect of the Al_2O_3 nanoparticles on the flow boiling of R134a was investigated at heat flux ranged from 53 to 88 kWm^{-2}.
4- The flow boiling heat transfer coefficient have been improved and increased by 42% at both high nanofluid (POE/Al_2O_3) concentration of 0.125 wt.% and heat flux of 88 $kW.m^{-2}$.
5- Compressor oils, automatic transmission fluids, fluorocarbons, and other synthetic heat transfer fluids all possess poor heat transfer capabilities, so they could benefit from the high thermal conductivity offered by nanofluid techniques.

REFERENCES

1- Coumaressin, T. and Palaniradja, K., "Performance Analysis of a Refrigeration System Using Nano Fluid", International Journal of Advanced Mechanical Engineering, Vol. 4, pp. 459-470, 2014.
2- Mishra, P.C., Mukherjee, S., Kumar Nayak, S., Panda, A., "A Brief Review on Viscosity of Nano fluids", Journal of International Nano Letters, Vol. 4, pp. 109–120, 2014.
3- Yang, B., and Han, Z. H., "Temperature-dependent thermal conductivity of nanorod-based nanofluids", Applied Physics Letters, Vol. 89(8), p. 083111, 2006.
4- Choi, S.U.S., "Nanofluid Technology: Current Status and Future Research", Korea-U.S. Technical Conference on Strategic Technologies, Vienna, VA, 1998.
5- Eastman, J.A., Choi, S.U.S., Li, S., Thompson, L.J., Lee, S., "Enhanced thermal conductivity through the development of nanofluids", Fall Meeting of the Materials Research Society (MRS), Boston, USA, 1996.

6- Eastman, J.A., Choi, S.U.S., Li, S., Soyez, G., Thompson, L.J., DiMelfi, R.J., "Novel Thermal Properties of Nano Structured Materials", Materials Science Forum, Switzerland, pp. 629-634, 1999.

7- Eastman, J.A., Choi, S.U.S., Li, S., Yu, W., Thompson, L.J., "Anomalously Increased Effective Thermal Conductivities of Ethylene Glycol-Based Nanofluids Containing Copper Nanoparticles", Applied Physics Letters, Vol. 78(6), pp.718-720, 2001.

8- Eastman, J. A., Phillpot, S. R., Choi, S.U.S., Keblinski, P., "Thermal Transport in Nanofluids", Annual Review of Materials Research, Vol. 34(1), pp. 219-246, 2004.

9- Abdel-Hadi, E.A., Taher, S.H., Torki, A. H. M., Hamad, S. S., "Heat Transfer Analysis of Vapor Compression System Using Nano CuO-R134a", International Conference on Advanced Materials Engineering IPCSIT,Vol.15 IACSIT Press, Singapore, 2011.

10- Gupta H.K, Agrawal G.D, Mathur J., "An overview of Nanofluids: A new Media Towards Green Environment", International Journal of Environmental Sciences, Vol. 3, (1), pp. 433-440, 2012.

11- Bi, S., Guo, K., Liu, Z., Wu, J., "Performance of a Domestic Refrigerator Using TiO2-R600a Nano-Refrigerant as Working Fluid", Energy Conversion and Management, Vol. 52, pp. 733–737, 2011

12- Kumar, R. and Sridhar, K., "Heat Transfer Enhancement in Domestic Refrigerator Using Nano Refrigerant as Working Fluid", International Journal of Computer Engineering Research, Vol. 3(4), pp. 42-50, 2013.

13- Sabareesh, K.R., Gobinath, N. Sajithb, V., Sumitesh, D. Sobhan, C.B., "Application of TiO_2 Nanoparticles as a Lubricant-Additive for Vapour Compression Refrigeration Systems-An Experimental Investigation, International Journal of Refrigeration, Vol. 35(7), pp. 1989-1996, 2012.

14- Kumar, D. S., Elansezhian, R., "Experimental Study on Al_2O_3-R134a Nano Refrigerant in Refrigeration System", International Journal of Modern Engineering Research (IJMER), Vol. 2. (5), pp. 3927-3929, 2012.

15- Henderson K., Park Y., Liu L., Jacobi A., "Experimental Analysis on the Flow Boiling Heat Transfer of R134a Based Nano Fluids in a Horizontal Tube", IJHMT, Vol. 53, pp. 944-951, 2010.

16- Bi, S., Shi, L., Zhang, L., "Application of Nanoparticles in Domestic Refrigerators", Appl. Therm. Eng, Vol. 28, pp. 1834-1843, 2008.

17- Jwo C., Jeng L., Teng T., Chang H., "Effect of Nano Lubricant on the Performance of Hydrocarbon Refrigerant System", Journal of Vacuum. Science and Technology. B, Vol.27, (3), pp. 1473-1477, 2009.

18- Bobbo S., Fedele, L., Fabrizio, M., Barison, S., Battiston, S., "Influence of nanoparticles dispersion in POE oils on lubricity and R134a solubility", International Journal of Refrigeration, Vol. 33, pp. 1180-1186, 2010.

19- Mahbubul, I.M., Shahrul, I.M., Khaleduzzaman, S.S., Saidur, R., Amalina, M.A., Turgut, A., “Experimental investigation on effect of ultrasonication duration on colloidal dispersion and thermophysical properties of alumina–water Nanofluid”, International Journal of Heat and Mass Transfer, Vol. 88, pp. 73-81, 2015.

20-Kumar, K.D., Ayyappa, T., “An Experimental Investigation on Application of Al_2O_3 Nanoparticles as Lubricant Additive in VCRS”, International Journal of Engineering Research and Application, Vol. 6 (10), pp. 32-38, 2016.

21-Jiang, L., Gao, L., and Sun, J., "Production of Aqueous Colloidal Dispersions of Carbon Nanotubes", Journal of Colloid and Interface Science, Vol. 260(1), pp. 89-94, 2003.

22-Goldburg, W. I., "Dynamic Light Scattering", American Journal of Physics, Vol. 67(12), pp. 1152-1160, 1999.

23-Jang, S. P., and Choi, S. U. S., "Role of Brownian Motion in the Enhanced Thermal Conductivity of Nanofluids", Applied Physics Letters, Vol. 84(21), pp. 4316-4318, 2004.

24-Kline,S.J., McClintock, F.A., “Describing uncertainties in single-sample experiments”, journal of Mechanical Engineering, Vol. 75(1), pp. 3-8, 1953.

25-Mukherjee, S., Paria, S., “Preparation and Stability of Nanofluids-A Review”, Journal of Mechanical and Civil Engineering, Vol. 9 (2), pp. 63-69, 2013.

26-Kedzierski, M. A., “The Effect of Lubricant Concentration, Miscibility and Viscosity on R134a Pool Boiling” International journal of Refrigeration, Vol. 24 (4), pp. 348-366, 2001.

27-Ettefaghi, E., Ahmadi, H., Rashidi, A. Mohtasebi, S. S., Alaei, M., “Experimental evaluation of engine oil properties containing copper oxide nanoparticles as a nanoadditive”, International Journal of Industrial Chemistry, Vol. 4, pp. 28, 2013.

28-Nezhaad, G. V., Dorany, A., “Effect of Single-Walled Carbon Nanotube on the Viscosity of Lubricants” Energy Procedia, Vol. 14, pp. 512 – 517, 2012.

دراسة عملية لإنتقال الحرارة أثناء الغليان السرياني بإستخدام موائع نانوية

إن استهلاك كميات كبيرة من الطاقة في العديد من الأنظمة الحرارية مثل الثلاجات و مكيفات الهواء يتطلب الدراسة لتطوير تلك الانظمة كي تعمل بكفاءة و ذلك عن طريق استخدام موائع تبريد صديقة للبيئة. و لقد ادى التقدم السريع في تكنولوجيا الدقائق النانوية الى استحداث جيل جديد من موائع نقل الحرارة تدعى الموائع النانوية، و ذلك من خلال خلط الموائع التقليدية بكميات ضئيلة من الدقائق النانوية المناسبة والتى من شأنها احداث تحسنا ملحوظا فى الخصائص الحرارية والانسيابية لتلك الموائع. و لذلك تتضمن هذه الورقة البحثية دراسة تأثير مزج تركيزات مختلفة من دقائق اكسيد الالومنيوم مع زيت POEعلى معامل انتقال الحرارة للغليان السرياني لنظام تبريد يعمل بفريون R134a. و قد اجريت التجارب عند تركيزات نانونية وزنية تتراوح من0.025% الي0.125% و عند تدفقات حرارية تراوحت بين 53 – 88 كيلو وات/متر مربع. و قد تبين ان اضافة دقائق الالومنيوم الزيت POE احدثت تحسنا في معامل انتقال الحرارةللغليان السرياني، و علاوة على ذلك تم التحقق من استقرار العينات التي تم تحضيرها من خلال مطياف الاشعة الفوق بنفسجية – المرئية و جهاز تحليل الضوء الديناميكي المتناثر و الذي تبين منهما التوزيع الجيد للدقائق النانوية داخل الزيت المستخدم.