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# Enhancement of Heat Transfer Characteristics of Nucleate Pool Boiling by Addition of Nano-Metal Particles to The Refrigerant 134a.

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**Abstract**— Experimental study investigated the effect of addition cooper oxide CuO on the refrigerant R-134a, in nucleate pool boiling heat transfer coefficient, (HTC). The experiments were carried out a flat heating surface with mirror surface roughness (Ra), 0.042µm. CuO particles concentrations were used 0.005, 0.01, 0.03 and 0.05 % by volume. The applied heat flux, arranged from 15 to150 kw/m2 and different operating boiling pressure. The results showed that, the heat transfer coefficient increases with increasing CuO particles concentrations from 0.005 to 0.03 %. At high heat flux of 150 kw/m2 the enhancements up to 82 % with increasing nanoparticles concentration to 0.03 % by volume. When increased the CuO nanoparticles volume concentration up to 0.05 % the heat transfer coefficient decreased due to the large quantity of deposition of nanoparticles on heating surface.

**Keywords**: Nanorefrigerant, Heat transfer coefficient, Pool boiling of nanofluids, Heat flux, CuO and R-134a.

**NOMENCLATURES**

| | |
|---|---|
| *A* | Surface Area (*m*$^2$) |
| *C* | Specific heat (*J/kg K*) |
| *I* | Electrical current (*A*) |
| *K* | Thermal conductivity (*W/m K*) |
| *L* | Length (*m*) |
| *M* | Molecular mass (*kg/k mol*) |
| *R*a | Arithmetical mean of roughness profile (*µm*) |
| *Rp* | Maximum roughness peak height (*µm*) |
| *Rq* | Root mean square roughness average (*µm*) |
| *Rv* | Maximum roughness valley depth (*µm*) |
| *Rz* | Irregularities roughness height of ten points (*µm*) |
| *T* | Temperature *(°k*) |
| *V* | Voltage (*V*) |
| *d* | Diameter (*m*) |
| *h* | Heat transfer coefficient (*W/m*$^2$ *K*) |
| *m·* | Mass flow rate (*kg/s*) |
| *p* | Pressure (*Pa*) |
| *q* | Heat flux, (*W*) |

**GREEK LETTER**

| | |
|---|---|
| Δ | Difference. |
| ϕ | Volume concentration. % |
| ξ | Enhancement percentage %. |
| ρ | Density (kg/m3) |
| µ | Viscosity. (Pa.s) |

**ABBREVIATIONS**

| | |
|---|---|
| HTC | Heat transfer coefficient. |
| $Al_2O_3$ | Aluminum oxide. |
| CuO | Cooper oxide. |
| CHF | Critical heat flux |
| CNTs | Carbon nano tubes. |

**SUBSCRIPTS**

| | |
|---|---|
| Vol. | Volume. |
| avg | Average |
| bf | Base fluid |
| nf | Nano fluid |
| np | Nano particles |
| s | Surface |
| sat. | Saturation |
| w | Water |
| * | Normalized |
| c | Critical. |

## 1 Introduction

Nucleate boiling region is a one of the most efficient heat transfer modes, which had been applied in various engineering fields such as nuclear energy, electric power generation, electronic chips cooling and air conditioning plant. Nanofluids are colloidal suspensions of nanoparticles, with diameter from 1 to 100 nm, in a base fluid such as water, oils, ethylene glycol or a refrigerant. These nanofluids are promising way of enhancing heat transfer due to increasing the thermal conductivity of base fluid properties. In the present study, CuO was used as a nanoparticle with diameter 40 nm. The properties of nano refrigerants are given in table (1).

Table 1. The properties of CuO nanoparticles, refrigerant R134a. (liquid phase).

| | Molecular weight (*kg/kmol*) | Density (*kg/m³*) | Thermal conductivity (*W/m. K*) | Specific heat (*J/kg. K*) | Viscosity (*Pa. s*) |
|---|---|---|---|---|---|
| CuO ($D_p$ = 40 *nm*) | 79.00 | 6310 | 44 | 880 | - |
| R134a (T = 25°C) | 102.00 | 1199.7 | 0.0833 | 1427 | 0.0002012 |



Such nanofluids are known to exhibit a significant increase in thermal conductivity over that of the base fluids Choi [1], and Eastman et al. [2]. Early studied of nanofluids had mainly focused on thermal conductivity enhancement and the parameters that govern this behavior. The Influence of adding $Al_2O_3$ nanoparticles diluted binary water-glycerol mixtures with different volumetric concentrations to enhance the nucleate pool boiling was studied by Soltani et al. [3]. The results indicated that the pool boiling heat transfer coefficient increases up to 25 %. The same behavior of enhancement appears by Soltani et al. [4]. where, they studied increasing Nucleate pool boiling heat transfer coefficients of $Al_2O_3$-water and $TiO_2$-water nanofluids at different volumetric concentrations. Their results showed that, for stainless steel and brass heating surface tubes, the presence of nanoparticles significantly enhanced the pool boiling heat transfer coefficients, on the other hand, heat transfer coefficients deteriorated around the copper heating surface tube due to its higher thermal conductivity in comparison with the other tubes. Enhancement of pool boiling heat transfer coefficients of $Al_2O_3$–water nanofluids with different concentration above a plain plate heating surface was studied by, Bang and Chang. [5]. Its results showed that, the heat transfer coefficient was increased with increasing nano particles concentration up certain value. Using gold nanoparticles on pool boiling heat transfer of water at atmospheric operation pressure was studied by Witharana. [6]. The results showed that the enhancement up to 64 %.  Pool boiling heat transfer coefficients of $Al_2O_3$– water nanofluids with 0.32 wt.%, 0.71 wt.%, 0.95 wt.% and 1.25 wt.% concentrations on a polished stainless steel flat heating surface studied by Wen and Ding. [7]. The results indicated that the enhancement increases with increasing particle concentration. the boiling heat transfer coefficient was reached to 40 %. The Pool boiling heat transfer coefficients of $Al_2O_3$–water nanofluids with deferent concentrations on a flat plate heater was tested by Shi et al. [8]. The results were found that the nanoparticles enhanced boiling heat transfer performance with lower concentration. The effect of addition nanofluid at different roughness of heating surfaces on nucleate pool boiling heat transfer of $TiO_2$-water nanofluids was studied experimentally by Suriyawong, and Wongwises [9]. The enhancement in heat transfer coefficient up to 27% was observed rather than pure water. on the other hand, a significant increase of critical heat flux (CHF) was observed even at very low particle concentrations You and Kim [10]. and Vassallo et al. [11]. Many researchers studied the enhancement of boiling heat transfer performance of refrigeration system by adding nano particles on refrigerant base fluid. Boiling heat transfer coefficient of $TiO_2$ –R141b nanofluids with deferent volume concentrations was studied by Trisaksri and Wongwises [12].  The results revealed that the heat transfer coefficient decreases with the increase of $TiO_2$ concentrations.  A Plain copper tube heating surface for nucleate pool boiling heat transfer of gold Au-R141b nanofluids at deferent concentrations was studied by Yang and Liu. [13]. The results showed that, the heat transfer coefficient was increased by 30% more than those without nanoparticles. The enhancement of nucleate boiling heat transfer of three base fluid halocarbon

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refrigerants (R-123, R-134a and R -22) by adding carbon nanotubes (CNTs) were studied by Park and Jung [14, 15]. The results showed that, the enhancement in nucleate boiling heat transfer coefficients for all refrigerants compared with pure base refrigerant. Investigated Boiling heat transfer performance of Cu-R113 nanofluids by Peng et al. [16]. The results revealed that the presence of surfactant enhances the boiling heat transfer performance of refrigerant-based nanofluid on most conditions but deteriorates the boiling heat transfer performance at high surfactant concentrations.

Pool boiling heat transfer characteristics of the $Al_2O_3$-R141b nanofluids at deferent volume concentrations with and without surfactant SDBS was studied by Tang et al. [17]. The results showed that the suspended δ-$Al_2O_3$ nanoparticles enhanced the pool boiling heat transfer.

As described above, there are many previous studies presented boiling heat transfer characteristics. However, the pool boiling of refrigerant-based nanofluids is not high lightened in the literature. In addition, many numerous conflicting results and trends were presented. Therefore, one can suggest the items that motivate the aim of the present work to highlight the nucleate pool boiling of nano-fluid which consists of R134a with Copper oxide using a circular Copper heating surface. the suggested case was to be investigated experimentally at different values of concentration, boiling pressures, heat flues.

## 2 EXPERIMENTAL APPARATUS.

The design of the test rig and selection of measuring devices were done to facilitate the monitoring of the tested parameters to get the heat transfer coefficient with and without nano particles additions. It also facilitates the ease of assembly of the test rig attachments, photograph the bubble nucleation over the heating surface, the measuring of the height of refrigerant liquid above the heater, the raising up of the vapor, and condensate downward flow by gravity. The test rig includes three sections; bottom section, intermediate section and top section. The bottom section was used to carry the condenser and the compressor of an auxiliary cooling water cycle. Also, a water pump was fixed inside the bottom section of the steel structure frame. The top section has another condenser, water tank with an immersed evaporator and electric heater. The intermediate section has the evaporator tank, the fan, the air heater, the water coil, and the lighting. figure (1) Shown the layout of the experimental apparatus.



| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | Condenser coil | 2 | Pressure gauge | 3 | Pressure cutout | 4 | Control panel |
| 5 | Selector switch | 6 | Slight glass | 7 | Digital temp- indicator | 8 | Vacuum pump |
| 9 | Condensing unit | 10 | Water pump | 11 | Side view glass | 12 | Hand valve |
| 13 | Heating surface | 14 | Pre-cooling coil | 15 | Air heater | 16 | Fan |
| 17 | Chilled evaporator | 18 | Water heater | | | | |

Figure (1) The layout of the experimental apparatus.

The evaporator designed to operate on at high operating pressure. The evaporator fabricated from high carbon steel pipe with inner diameter 175 mm, a height 350 mm and thickness of 12 mm. For visual observations of the bubble formation and photographing fixed tow glass windows with 65 mm diameter at a level of 75 mm from the base evaporator tank. The boiling heating surface is a cylindrical copper block with 40 mm diameter and 103 mm length, immersed in refrigerant liquid inside evaporator tank. A resistance cartridge heater is inserted into the cooper block sleeve to generate heat flux from DC electrical power supply. A digital temperature indicator with 0.1 oC Accuracy was used to Records the measured temperature. In the steady state; one can find the heat removal by the condenser equals the heat addition by the heater. The pressure gauge was fitted in circuit to measure the operating pressures. Measure the water flow rate was used the Rota with a repeatability error of about 0.5%. fitted in the system pressure cut out, bush button key, relays and thermostats for safety the electrical and control system. The refrigerant vapor will condense and backed to evaporator tank by gravity. Figure (2) shown the heating surface details.

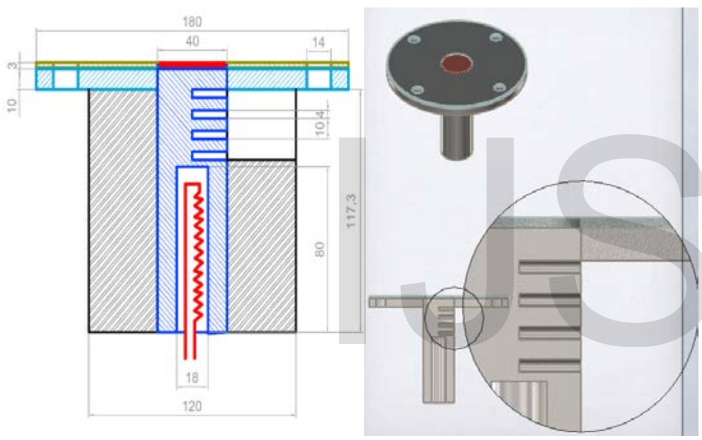


Figure (2) the heating surface details.

The experimental data were recorded at the steady state which its criteria are variations in the saturation temperature of ±0.1 °C. The summary of the experimental runs was provided in table (2).

Table (2) The summary of the experimental work.

| Fluid | Surface roughens, Ra(μm) | Heat flux(kW/m2) | Normalized pressure | concentration, Ø (%) |
|---|---|---|---|---|
| Puer-134a | 0.042 (mirror) | 15, 45, 75, 110 and150 | 0.01, 0.28, 0.37 and 0.52 | … |
| CuO-R134a | 0.042 (mirror) | 15, 45, 75, 110 and150 | 0.01, 0.28, 0.37 and 0.52 | 0.005, 0.01, 0.03 and 0.05 |

The roughness parameters for the tested heating surfaces are given in table (3).

Table (3) The roughness parameters for the heating surface.

| Surface roughness | Ra, μm | Rq, μm | Ry, μm | Rz, μm | Rp, μm |
|---|---|---|---|---|---|
| roughens (mirror) | 0.042 | 0.025 | 0.27 | 0.13 | 0.101 |

The roughness (Ra) of mirror surface as provided by Mitutoy [18]. The surface roughness measured by tracer of profile meter. The preparation of nano-fluids is important because nano particles had special requirements such as even suspension, stable suspension, durable suspension, low agglomeration of particles, Narayan. et. al. [19]. In the present study; using copper oxide nano-particles, with average diameter 40 nm with Refrigerant -134a as a base fluid. The scan of CuO nano particles obtained from the TEM is shown in figure (3).

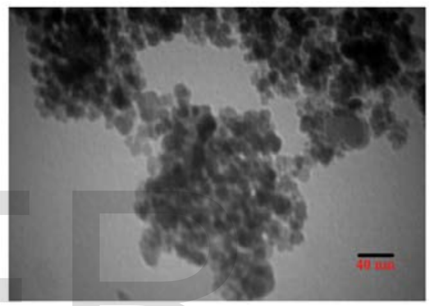


Figure (4) The TEM photographs of CuO nanoparticles.

Nano fluid was prepared using vibration mode about 6 hours to stabilize the dispersion of the nano particles. CuO particles concentrations ware used; 0.005, 0.01, 0.03 and 0.05 % by volume. The particle volume fraction (ϕ) was defined as:

$$\phi = \frac{\text{Volume of nanoparticles}}{\text{Volume of nanoparticles} + \text{Volume of refrigerant}} = \frac{\frac{m_{nanoparticles}}{\rho_{nanoparticles}}}{\frac{m_{nanoparticles}}{\rho_{nanoparticles}} + \frac{m_{refrigerant}}{\rho_{refrigerant}}} \qquad (1)$$

The thermal conductivity (knf) of the nano refrigerant can be calculated by using the equation provided by Hamilton and Crosser [20] as follows:

$$k_{nf} = k_{bf} \times \left[\frac{k_{np} + (n-1)k_{bf} - (n-1)\varphi(k_{bf} - k_{np})}{k_{np} + (n-1)k_{bf} + (k_{bf} - k_{np})\varphi}\right] \qquad (2)$$

The viscosity and the specific heat of nano refrigerant can be calculated using the equations provided by Mahbubul et al. [21] as follows:

$$C_{p,nf} = \emptyset\, C_{p,np} + (1-\emptyset)C_{p,bf} \qquad (3)$$

$$\mu_{nf} = \mu_{bf} \times \frac{1}{(1-\emptyset)^{0.25}} \qquad (4)$$

The properties of new nano refrigerant heat capacity, thermal conductivity, and viscosity are given in table (4).

Table (4) The property of CuO–R-134a nano fluids.

| Property | Ø=0.005 | Ø=0.01 | Ø=0.03 | Ø=0.05 |
|---|---|---|---|---|
| K (W/m2k) | 0.084976 | 0.086687 | 0.09389 | 0.10173 |
| Cp (kJ/kg k) | 1.35316 | 1.34832 | 1.32896 | 1.3096 |
| μnf/ μbf | 1.00001 | 1.0025 | 1.0076 | 1.0129 |

## 3 DATA REDUCTION.

the experimental runs were recorded during the test runs. Experimental runs were carried out using a flat circular horizontal heater. The heat flux, q can be calculated as follows:

$$q = \frac{I \times V}{A} \quad \frac{W}{m2} \tag{5}$$

The heat transfer coefficient, h can be calculated as follows:

$$h = \frac{q}{A \times (T_s - T_{sat})} = \frac{4\,(i \times v)}{\pi \times d^2 \times (\Delta T)} \tag{6}$$

## 4 UNCERTAINTY CACULATION

The uncertainty in heat transfer coefficient is as follows as provided by Holman [22]:

$$\Delta h = \sqrt{\left[\frac{\partial h}{\partial v}\delta v\right]^2 + \left[\frac{\partial h}{\partial i}\delta i\right]^2 + \left[\frac{\partial h}{\partial d}\delta d\right]^2 + \left[\frac{\partial h}{\partial T}\delta T\right]^2} \tag{7}$$

The recorded experimental data from one experiment are:

$v = 192\ V$ $\quad \delta v = 0.1\ V$

$i = 0.68\ A$ $\quad \delta i = 0.01\ A$

$d = 40\ mm$ $\quad \delta d = 0.1 mm = 0.0001 m$ and

$Ts = 59.4\ ^oC$ $\quad Tsat = 53.8\ ^oC$ $\quad \delta T = 0.1\ ^oC$

$$\Delta h = \sqrt{[11.1]^2 + [272.84]^2 + [-106.41]^2 + [-380]^2} = 479.88\ \frac{w}{m^2\ k} \tag{8}$$

$$h = \frac{4 \times 192 \times 0.78}{\pi \times 0.04^2 \times (75.6 - 70)} = 21282\ \frac{w}{m^2\ k} \tag{9}$$

$$\left[\frac{\Delta h}{h}\right]\% = \frac{479.88}{21282} \times 100 \tag{10}$$

Thus; the uncertainty percentage in calculating heat transfer coefficient from measurements is 2.25%.

## 5 RESULTS AND DISCUSSIONS

The boiling heat transfer characteristics were enhanced by addition of the CuO nanoparticles to the R-134a. the enhancement increases along with the particle concentration up to a concentration percentage. Where the adding nanoparticles quantity increases from 0.005 % to 0.03 % by volume, the heat transfer coefficient of nano-refrigerant had significant increase. This is attributes to the thermal conductivity of nanofluids is higher than that of the conventional heat transfer refrigerant with measurements plotted at figures (4), (5), (6) and (7). The experimental heat transfer coefficient for nano-refrigerant with different (Ø) volume concentrations of nano-particles at different applied heat flux and different operating pressure. The results verified the optimum volume concentration used 0.03 % for all applied heat fluxes and operating pressures. Due to the increase the thermal conductivity of new nano refrigerant.

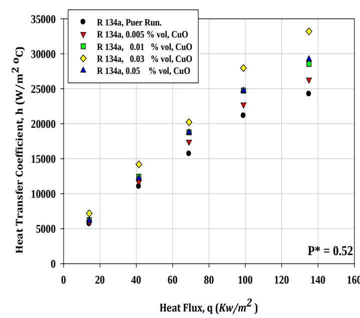


Figure (4) Variation of heat transfer coefficient versus heat flux and concentration for CuO and R-134a nano refrigerant at P*=0.52.

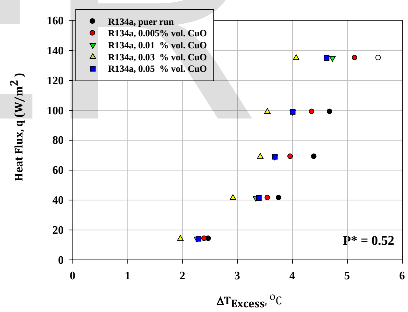


Figure (5) Variation of heat transfer coefficient versus temperature difference and concentration for CuO and R-134a nano refrigerant at P*=0.52.

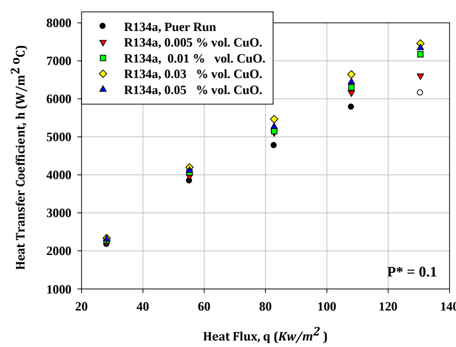


Figure (6) Variation of heat transfer coefficient versus heat flux and concentration for CuO and R-134a nano refrigerant at P*=0.1.

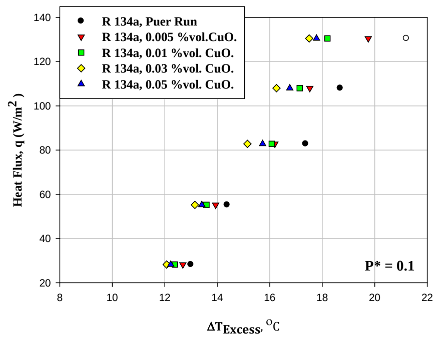


Figure (7) Variation of heat transfer coefficient versus temperature difference and concentration for CuO and R-134a nano refrigerant at P*=0.1

When increased the nanofluids volume concentration up to 0.05%, and 0.1% the heat transfer coefficient decreased due to the nanoparticles deposit on the heating surface which created new locally isolated layer above the heating surface.

The enhancement percentage is defined as:

$$\xi = \frac{(h - h_o)}{h_o} \qquad (11)$$

An empirical correlation was deduced to formulate the relation among h and the parameters (p, q, φ and Ra) for pool boiling of nano refrigerant using EUREQA FORMLIZE software within a maximum deviation of about ±10 % as follows, (12), and as shown in figure (8).

$$h^* = \left(2\left(1.01\times10^5 Ra^{(0.037Ra)} - 2.02\times10^6(\emptyset)\right)^{(p^*)}\right)^{\left(\emptyset^{(0.72(p^*))^{(0.55*(q^*))}}\right)} \qquad (12)$$

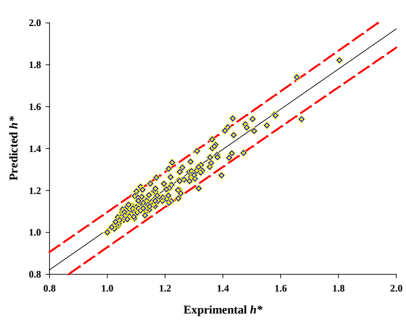


Figure 8 Comparison of the predicted values of the new correlation with the experimental data for R-134a.

## 6 COMPARISONS OF PRESENT RESULTS WITH PUBLISHED CORRELATIONS.

The experimental data we had for pure refrigerant were validated by comparing the obtained data from copper correlation, [23]. at all operation condition as following.

$$h = q^{0.67} \times 55 \times \left[\frac{p}{p_{cr}}\right]^{(0.12-0.2\,log\,R_p)} \times \left[-log\frac{p}{p_{cr}}\right]^{-0.55} \times M^{-0.5} \qquad (13)$$

Validation of the experimental results for mirror surface with copper correlation show in the figure (9).

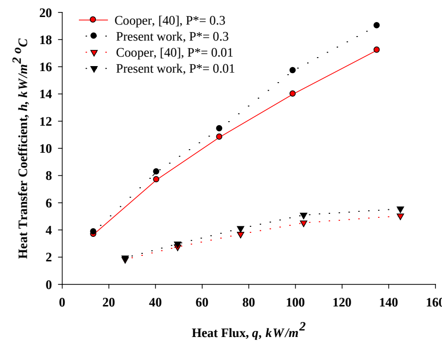


Figure (9) Validation of the experimental results for mirror surface.

The comparison among present work and previous ones is shown in figure (10).

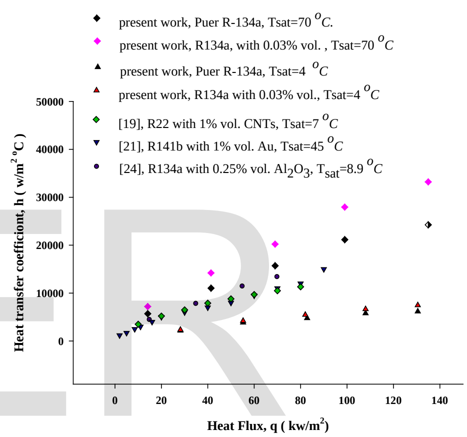


Figure (10) Comparison of present measurements of the heat transfer coefficient with published data.

Tang et al. [15] and [21] tested nano refrigerant R-22 and R-141b with CNTs and aluminum oxide at different volume concentration from 0.001 to 0.1%. It is clear from the comparison that the present work has a slight enhancement rather than that of Tang one. This due to, the present work has considered the so-called optimum concentration which is 0.05%. However, Tang concentration was 0.01%. The more concentration of nano particles, the more enhancement in heat transfer coefficient. Also, the comparison between the present work at 0.05% concentration, 85 °C saturation temperature and the work by Yang and Lui, [24] which uses Gold nano particles at 1.0% concentration, 45 °C saturation temperature shows a very slight enhancement in the present work rather than the Yang work. This is due to the present work were tested at high saturation pressure, as the enhancement has a direct proportional with the applied operating pressure.

## 7 CONCLUSIONS

The present experimental work used passive technic to enhancement nucleate pool boiling by adding CuO nano particles above R-134a at different volume concentration. The experimental investigation using horizontal Copper heating surface. All test runs applied at different critical pressure and heat flux up to 150 kW/m2. The results can be summarized as following.

1. The experimental heat transfer coefficient increased for CuO-134a with increasing the nano particles concentration from 0.005 % Vol. to 0.03 % by volume. With increasing the nano particles concentration up to 0.05 % and 0.1 % by volume. the heat transfer coefficient decreased.
2. At applied high operating normalized pressure 0.52 the enhancement percentage up to 82%.
3. The experimental results data was fitted to the EUR equation program. An empirical correlation predicted the enhancement percentage of, HTC depend on operating conditions (q, p*, Ra, Ø) with a deviation ±10%.

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