ISSN: 0974-5823 Vol. 7 No. 1 January, 2022

International Journal of Mechanical Engineering

Heat Pipe Heat Exchanger Performance Enhancement Using Nano Fluid and Nano Coated Fins

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ABSTRACT

Air conditioning is one of the most energy-intensive systems which need more attention regarding reduction of energy consumption. For energy-intensive applications, the Heat Pipe Heat Exchanger (HPHE) is seen to be a good and cost-effective alternative. The effect of Nano coating on Fins and Nano-Fluid on the performance of HPHE to improve its operational efficiency was presented in this study. Additionally, its effect on the HPHE effectiveness and the heat recovery ratio at different inlet air temperatures, 30, 35, 40, 45, 50, and 55 °C, have been determined in the evaporator. The heat pipe has been filled with working fluid by approximately 50% of the evaporator volume, which represents the filling ratio. CuO nanoparticles have been used at concentrations of 1wt %, 3wt %, and 5wt %. In this paper, chemical deposition nanocoating technique was used to produce CuO nanocoating layer on Aluminum alloy (AL-1100) surface fins. The results obtained from this study showed an improvement in HPHE effectiveness and heat recovery rate. Moreover, the highest level of effectiveness and maximum heat recovery value were found, at an inlet air temperature of 55 °C with an inlet air velocity of 1 m/s equal to 0.81 and 1472.142 W, respectively.

Keywords: heat pipe, HPHE, heat recovery, effectiveness, Nanocoating.

1.INTRODUCTION

Many applications of the thermosyphon heat pipe heat exchanger (HPHE) have been investigated for energy-saving purposes, such as heat exchangers that serve as a recovery system, solar energy sharing system, electronic part cooling, spacecraft thermal control, rotary blade gas turbine cooling, etc. [1–3]. Nanotechnology has a wide range of applications in all engineering fields. The use of nanomaterials in heat transfer applications, especially in heat exchangers, was limited. The coating processes for silicon (Si) and high thermal-conductivity stainless steel (1800-3000 W/m K) at room temperature using carbohydrates have been investigated by Filatov et al. [4]. Their measurements have been made using CNT-coated hot wire to analyze the heat exchange in a liquid environment. The heat exchange rate was more than five times higher. The substratum was covered with a carbon nanotube (CNT) by Weibel et al. [5] using MPCVD (Microwave Plasma Chemical Vapor Deposition) to coat the substrate with a CNT layer by physical vapor deposition to increase thermal boil speeds with a copper nanoparticle. This test has been done with water as the working fluid under two phase heat transfer conditions. Both micropatterning and CNT coatings were shown to increase the efficiency of heat transfer substantially, while surface superheat decreased by 72% compared to uncoated surfaces. Graphin used to coat surface fins of different shapes cylindrical and square fin and materials copper and aluminum have been investigated by Sabarish et al. [6]. For example, fin quality parameters have been analyzed in experiments. The rate of heat transfer and efficiency for free and forced heat through fins mode of convection transfer as a result, the heat transfer rates have been improved significantly. Seo et al. [7] used several layers of indium tin oxide deposited nanocoating (SWCNT, hybrid graphene) to increase the coefficient for heat transfer and critical heat flow of nuclear coating surfaces. To render film hybrid graph/SWCNTs the SWCNTs have been deposited on the top of the graph sheet. The results showed that the intermediate graphene/SWCNT film deposited on an ITO surface has a great effect on the heat transfer surface of the boiling pool, since the carbon structures were interconnected. The electron beam was used for coating aluminum nanoparticles by Pongiannan et al. [8]. The heat transfer efficiency of an aluminum pin-fin heat sink was investigated using a device under natural conditions of convection. The heat dissipation with and without coating was tested at different controlled temperatures. The nanocoated heat sink estimated that the height of the end could be decreased by 25% and that heat transfer efficiency could still be comparable. The use of nano-coating also increased the coefficient of surface heat transfer due to increased ruggedness. Several studies have been carried out to obtain thermal efficiency to ensure that the heat pipe heat exchangers work efficiently and reliably [9–12]. One of the newly used methods to improve the performance of a heat pipe is to add nanoparticles to the fluid. Thermosyphons and pipes have been performed in several studies utilizing nanofluid [13–16]. The use of a thermosyphon heat exchanger packed with methanol-silver nanofluid has been studied by Firouzfar et al. [17]. In their study, energy saving and performance comparison with pure methanol have been done. Experimental results show that the use of methanol-silver nanofluid in (HPHE) provides energy saving of about 8.8 - 31.5 percent for cooling and 18 - 100 percent for reheating the supply air stream. Kavusi et al. [18] numerically studied the performance of a heat pipe by using various nanofluids (prepared using alumina, copper oxide, and silver nanoparticles). The results obtained show that the use of a nanofluid instead of water contributes to an improved thermal efficiency and a decrease in the heat of the heat pipe wall. Moraveji et al. [19] experimentally investigated the thermal performance of heat pipe by using aluminum oxide nanofluid. Their obtained results showed that the thermal performance is enhanced by reducing the thermal resistance and wall temperature difference.

Despite the fact that many theoretical and experimental studies have been carried out to investigate the thermal performance of heat pipe heat exchanger (HPHE) in the air condition system, there is a scarcity of using nanofluid inside the HPHE. Thus, the main objective of the present study is to analyze the thermal performance of HPHE by using nanofluid as a work fluid and nano coated fins. Furthermore, the influence of it on the effectiveness and heat recovery of air conditioning systems has been investigated. Moreover, the thermal performance of HPHE charged with nanofluid and provide with nano-coated fins has been compared with HPHE charged with nanofluid and provide with fins without nano-coated. Also has been studied the thermal performance of HPHE charged with nanofluid and provide with nano-coated fins compared with HPHE charged with pure water without nano-coated fins.

The remainder of the paper is organized as follows: Section 2 describes the experimental setup, preparation of nanofluids and uncertainty analysis. Section 3 presents and discusses the experimental findings. Section 4 listed the conclusions from this research.

2. EXPERIMENTAL SETUP

2.1 Experimental Design

Fig. 1 and 2 displays the test setup for the air duct system, including the air conditioning system and the test chamber, the thermostat control air heating system, the data acquisition system, the air flow measurement system, the panel box of electricity system, and the HPHE model. Figure 2 shows the HPHE within the air duct system. The HPHE model, an evaporator, is mounted within the lower duct and absorbs heat from the fresh air intake. Inside the upper duct, the condenser portion of the model is cooled by an outlet axial fan. The working principle of this HPHE is thermosyphon heat pipe technology.

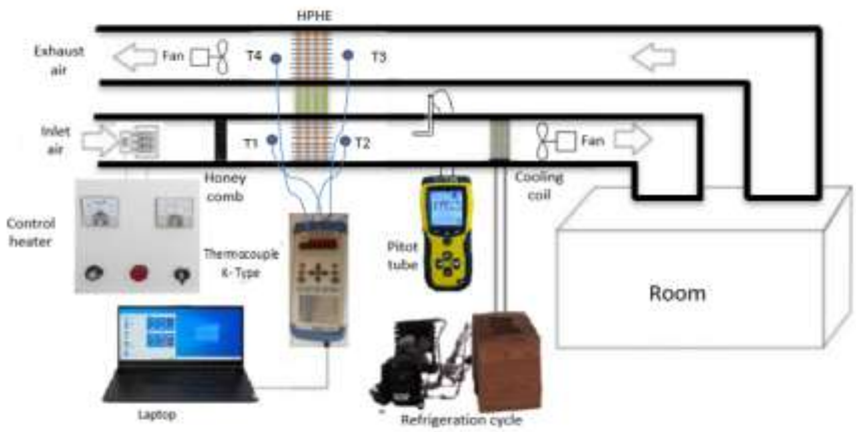

Fig. 1. Schematic diagram of test rig.

Fig. 2. Photograph of test rig.

The purpose of the HPHE placement in the test chamber air conditioning system was to pre-cool the fresh air inlet before entering the cooling coil. An air heating system warmed the fresh air inlet to the air duct system. The heat was created by an air heater with a maximum capacity of 5.35 kW. After the HPHE model, the cooling coil was designed to carry out the cooling process with a particular cooling load, and the room was made of wood with dimension of 830 mm x 415 mm x 500 mm. By changing the variable resistor of the fan speed controller to various velocities (1 to 2 m/s), the air flow velocity of the air duct system has been set and measured by pitot tubing (TROTEC, TA 400). Forty heat pipes, grouped into four rows, have been used in a single HPHE model. In the air system, each design has been tested under variable inlet air temperatures 30, 35, 40, 45, 50, and 55 °C at different air flowrate in the evaporator inlet. Copper tubes with 73 cm in length and 10 mm in diameter have been used as heat pipe. The working fluid has been injected at a 50 per cent filling ratio based on previous studies, it is confirmed that the best filling rate is 50% [20]. 265 mm, 265 mm and 200 mm, respectively, is the length of the evaporator, condenser and adiabatic sections. In the staggered arrangements shown in Fig. 3, each row has 10 heat pipes. Effectiveness is a measure of thermal performance of a heat exchanger. It is defined for a given heat exchanger of any flow arrangement as a ratio of the actual heat transfer rate from the hot fluid to the cold fluid to the maximum possible heat transfer rate qmax thermodynamically permitted. For evaluating the sensible effectiveness value of the HPHE model, equations 1 to 11 have been used [21,22].

$$\varepsilon = \frac{q_{actual}}{q_{max}} \quad (1)$$

An overall energy balance for the two streams of the HPHE model will get:

$$q_{act} = C_h\,(T_{e,i} - T_{e,o}) = C_c\,(T_{c,o} - T_{c,i}) \quad (2)$$

$$(T_{e,i} - T_{e,o}) > (T_{c,o} - T_{c,i}) \quad (3)$$

$$C_h \leq C_c \quad (4)$$

where

$$C_h = m_h\,C_{ph} \quad (5)$$

$$C_c = m_c\,C_{pc} \quad (6)$$

$$C_{min} = C_h \quad (7)$$

$$q_{max} = C_{min}\,(T_{e,i} - T_{c,i}) \quad (8)$$

$$Q_{act} = m_h\,C_{ph}\,(T_{e,i} - T_{e,o}) \quad (9)$$

$$Q_{max} = m_h\,C_{ph}\,(T_{e,i} - T_{c,i}) \quad (10)$$

$$\varepsilon = \frac{(T_{e,i} - T_{e,o})}{(T_{e,i} - T_{c,i})} \quad (11)$$

Heat recovery is the amount of heat that can be transferred from the inlet air before entering the cooling coil, bringing air in the same condition into a chamber while using less electrical energy for the chiller component of the compressor. For that reason, heat recovery is the most significant factor for energy saving in an HVAC device. The recovery of heat is calculated using equation (12) [23].

$$HR = m_a * C_p * (T_{e,i} - T_{e,o}) \quad (12)$$

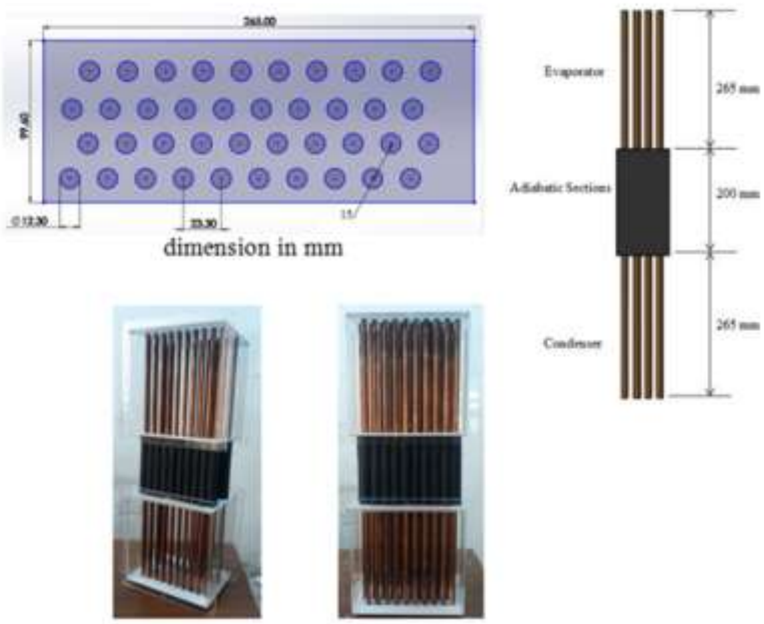

Fig. 3. Schematic diagram and Photograph of the HPHE model.

By adjusting the inlet air temperature and inlet velocity of fresh air, the HPHE module was tested. The temperature drop profile in the evaporator area (ΔTe) and the temperature rise profile in the condenser area (ΔTc) were the results of this test. In the HPHE evaporator segment, ΔTe is the result of the precooling process. The HPHE evaporator absorbs the heat entering this segment from the airflow.

2.2 Preparation of Nanofluids

In the present study, the first-step method has been used for nanofluid preparation. This method involves using nanoparticles and adding a sufficient amount of water to the bottle, then using the ultrasonic vibration homogenizer system to mix the water with the nanoparticles (CuO). The ultrasonic unit shown in Fig. 4 has been filled with water to ensure no damage to the device, as suggested by the supplier's instructions, and then the beaker has been placed inside the bath for 30 to 45 minutes [24]. Three mass fractions (1wt%, 3wt%, and 5wt%) of CuO-water nanofluid have been prepared see Fig. 5. The reason for selecting 1wt%, 3wt%, and 5wt% concentration of nanoparticles higher thermal concentration gives nanofluid concentrations than low concentration. Investigators in this field have shown that the concentration of under 1wt% and above 5wt% will not improve thermal performance. These mass fractions are described as the mass ratio of the nanoparticles to the base fluid [25].

Fig. 4. Photograph of ultrasonic.

Fig. 5. The mass concentrations of CuO nanofluid.

The copper oxide nanoparticles specification is shown in Table 1. These nanoparticles were purchased from skyspring nanomaterials, lnc USA.

Table 1 Specification of Copper oxide Nanoparticle.

Metal oxide Nanoparticle	Average particle size (nm)	Purity	Appearance	Specific surface (m^2/g)	Bulk density (g/cm^3)
CuO	40	99%	Black Nano powder	50	0.7

After completing the mixing processes of the solid nanoparticles with water, the nanofluid has been obtained according to the required mass concentration. Each material has been monitored separately from the other until it reached the separation stage, and the purpose of this monitoring is to demonstrate the stability of the nanofluid to know the duration of separation. Photogrammetry has been performed to test the stability and extent of deposition and separation of nanoparticles, where 200 ml of nanofluid has been placed in the vessel. It was seen that after 3 hours of addition, there was a very slight change in nanofluid stability. However, after 12 hours, it was noticed that the particles suspension became less bright, indicating the deposition of nanofluid particles. After 24 hours the concentration stratification layers were visible clearly as show in Fig. 6.

Fig. 6. Stability test of CuO–water nanofluid (1wt%) as a function of time.

2.3. Nanofluid Thermal Physical Properties

The working fluid used in this study is pure water or a water-CuO nanofluid. The thermo physical properties of nanofluid are calculated by using various correlations at the reference temperature of 300 K, the concentration of nanoparticles influences the working fluid properties. The single-phase model was adopted. Thus, fluid properties must be evaluated by employing relations, available in the literature, in order to compute the thermal and physical properties of the nanofluids [26]. Their values are given in Table 2.

Table 2 Thermo physical properties of nanofluid at 300 K

Fluid	Thermal conductivity (W/m K)	Density kg/m^3	Specific heat (J/kg K)	Viscosity (Kg/m.s)
H_2O	0.6	998.2	4182	0.001003
CuO	76	6302	959.1	----------
H_2O +1wt%CuO	0.6027	1006.58	4150.11	0.0010034
H_2O +3wt%CuO	0.6046	1024.02	4156.23	0.0010042
H_2O +5wt%CuO	0.6146	1042.06	4162.54	0.0010051

Density was evaluated by using the classical formula valid for conventional solid-liquid mixtures, while the specific heat and thermal expansion coefficient were calculated by assuming thermal equilibrium between particles and surrounding fluid [27], for classical two phase mixture as follows:

2.3.1. Thermal Conductivity

Thermal conductivity can be defined as the ability of a material to conduct heat, which is a property of a material. Several classical models proposed by Maxwell (1881), Hamilton and Crosser (1962), Wasp (Wasp), Bruggeman (2009), are available in the literature to predict the effective thermal conductivities of liquid solid suspension. The Maxwell developed a model to predict the effective thermal conductivity of solid-liquid suspension for low volume concentration of spherical micro particles suspensions [28].

$$k_{nf} = k_f \left(\frac{k_p + 2k_f - 2\emptyset(k_f - k_p)}{k_p + 2k_f + \emptyset(k_f - k_p)} \right) \quad (13)$$

2.3.2. Dynamic Viscosity

The effective viscosity is calculated with the Einstein equation (4.2) which is applicable to spherical particles in volume fractions of less than 5.0 vol.% [29].

$$\mu_{nf} = \frac{\mu_f}{(1-\emptyset)^{0.25}} \quad (14)$$

2.3.3. Density

The density correlation equation developed by [30] for nanofluid.

$$\boldsymbol{\rho_n} = (\mathbf{1} - \emptyset)\boldsymbol{\rho_f} + \emptyset\boldsymbol{\rho_p} \quad (15)$$

2.3.4. Specific heat

$$(Cp)_{nf} = \frac{\emptyset\ \rho_p Cp_p + (1 - \emptyset)\rho_f Cp_f}{\rho_{nf}} \quad (16) \quad [31]$$

2.4 Coating Techniques for Fins

2.4.1 Chemical Deposition Method

The method of chemical deposition of membranes is one of the easy ways to build a thin film from any semiconductor by choosing the appropriate chemical reaction and the appropriate proportions of the solutions that contribute to the chemical reaction to produce a thin film [32]. In present study, the chemical deposition method was used to prepare copper oxide CuO films on aluminum fins by mixing saturated solutions of copper chloride and potassium hydroxide.

$CuCl_2 + 3KOH + H_2O \rightarrow 2KCl_2 + 2H_2O + CuO + KOH$

2.4.1.1 Chemical Deposition Method Procedures

In the present investigation the steps of chemical deposition method as first Preparation Aqueous Solution: In chemical bath technique was prepare copper oxide Nano coating by using mixed three different ratio (0.35) gm from copper chloride ($CuCl_2$) with the amount constant of potassium hydroxide (KOH) and distilled water H2O (1gm, and 20ml), respectively. The potassium hydroxide (KOH) solution is prepared by placing 1 gram of potassium hydroxide in 20 ml of distilled water and shaking the solution and leaving it for an hour so that it is homogeneous as show in Fig.7. a. The copper chloride (CuCl2) solution is prepared by placing 0.35 gram of copper chloride in 20 ml of distilled water and shaking the solution and leaving it for an hour so that it becomes homogeneous as show in Fig.7. b. The fins are cleaned before the coating process with multiple cleaning powders, then washed with distilled water, then washed with hot methanol to get rid of the fatty substances attached to them, then they are washed with distilled water again and left to dry by immersing them in acetone as show in Fig.7. c. The fins are placed in a baker containing 10 ml of distilled water, then 20 ml of potassium hydroxide solution are added to it, then we add 20 ml of copper chloride and leave the mixture for 24 hours in order to form a precipitate of copper oxide CuO as show in figure Fig.7. d. Several instruments were used to characterize the nanocoating of Aluminum fin such as Atomic Force Microscopy (AFM), X-Ray Diffraction (XRD) and Scan Electron Microscopy (SEM).

2.5 Uncertainty analysis

The accuracy of obtaining experimental results depends upon two factors, the accuracy of measurements and the design details of test rig, and human being errors. Hence, to calculate the error in the obtained results, the procedure of the method presented by [33] is used to find the experimental error. This method is based on a careful specification of the uncertainties in the various primary experimental measurements. The maximum uncertainties of the measured and evaluated performance have been obtained by using the following equation.

$$\frac{wR}{R} = \left[\left(\frac{\partial R}{\partial v1} \cdot \frac{W1}{R}\right)^2 + \left(\frac{\partial R}{\partial v2} \cdot \frac{W2}{R}\right)^2 + \ldots + \left(\frac{\partial R}{\partial vn} \cdot \frac{Wn}{R}\right)^2\right]^{0.5} \quad (17)$$

where R, wR , v1, v2, …, vn and W1, W2, …, Wn are the given function total uncertainty. In the present study, the main variables which may cause the experimental errors are the temperature and velocity. The uncertainties of these variables are (± 0.33°C and ± 0.001 m/s) for temperature and velocity respectively.

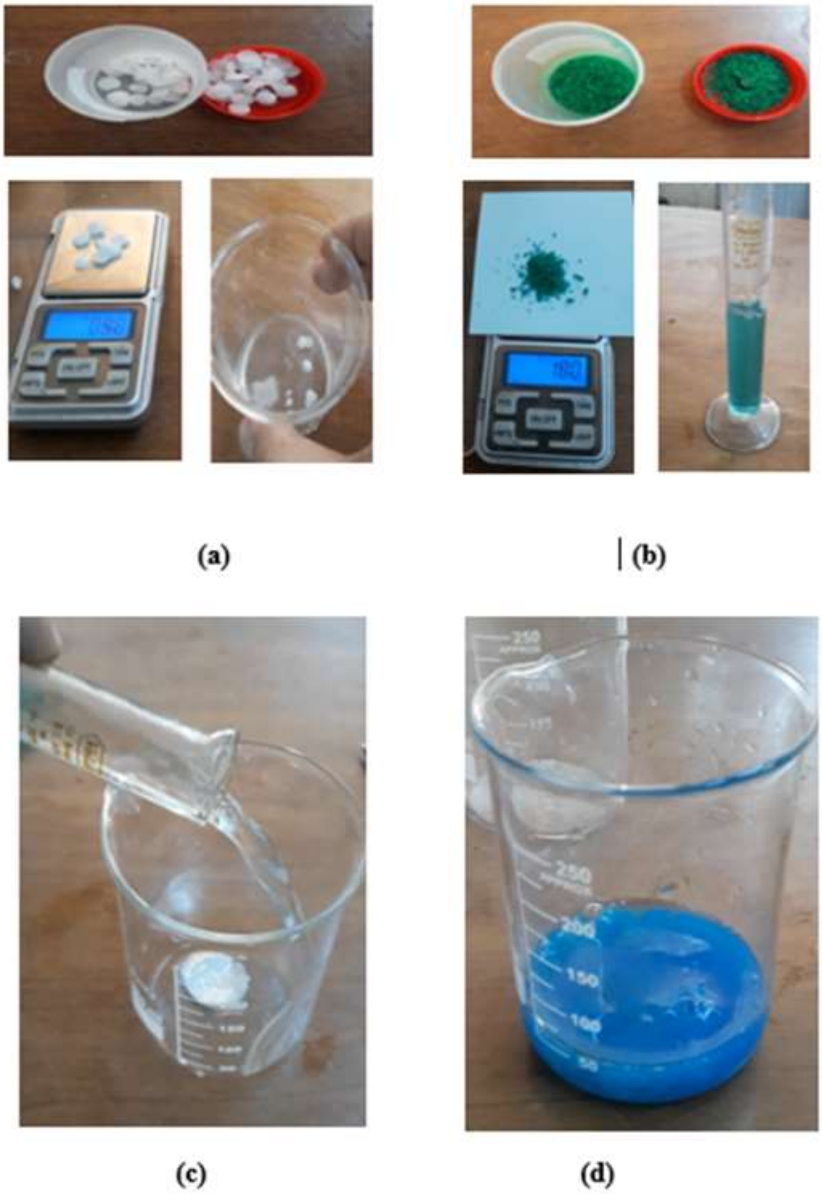

Fig. 7. Prepare copper oxide Nano coating. (a) Prepare (KOH) solution, (b) Prepare ($CuCl_2$) solution, (c) Fins immersed in the H_2O, (d) Mixture ($CuCl_2$) + (KOH)+H_2O

3. RESULTS AND DISCUSSION

3.1 Nanocoated Aluminum Fins Characterization

From Fig. 8 showed the AFM test for nanocoating aluminum fin by copper oxide and chemical deposition nanocoating technique with 0.35gm concentration copper chloride ($CuCl_2$), where the light-colored areas are tops of nanoparticles while the dark areas of the scan area indicate the shallowest parts. The polycrystalline nature of coating CuO is clearly also obtain from Fig. 8 indicated the nanoparticles dimeter of nanocoating layer was 100 nm.

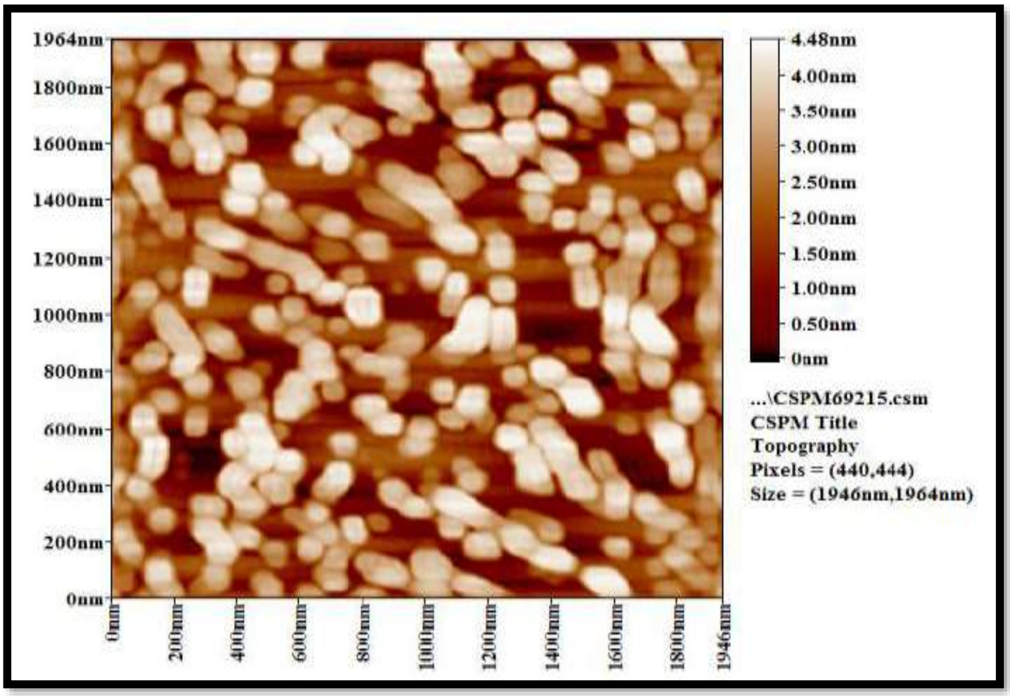

Fig. 8. Two-dimension atomic force microscopy by chemical deposition nanocoating technique with copper oxide nanocoating at concentration 0.35gm ($CuCl_2$)

It is the main technique for analyzing crystalline materials, as it provides information about the crystal structures, phases, and preferred directions of crystals and the rest of the structural parameters of materials such as crystallite size for nanomaterials, ordinary materials, and crystal lattice constants. Figure (9) showed the x-ray diffraction patterns of CuO thin films the range of the diffraction angle (2θ°) was (20° - 80°). According to this figure the presence of sharp peaks was shown and reveals that the deposition CuO thin films with Three highly intense diffraction peaks observed at angles 73.1°, 49° and 42°. The intensity of XRD peaks was related to many factors, which include crystallization quality, density, and thickness of thin films.

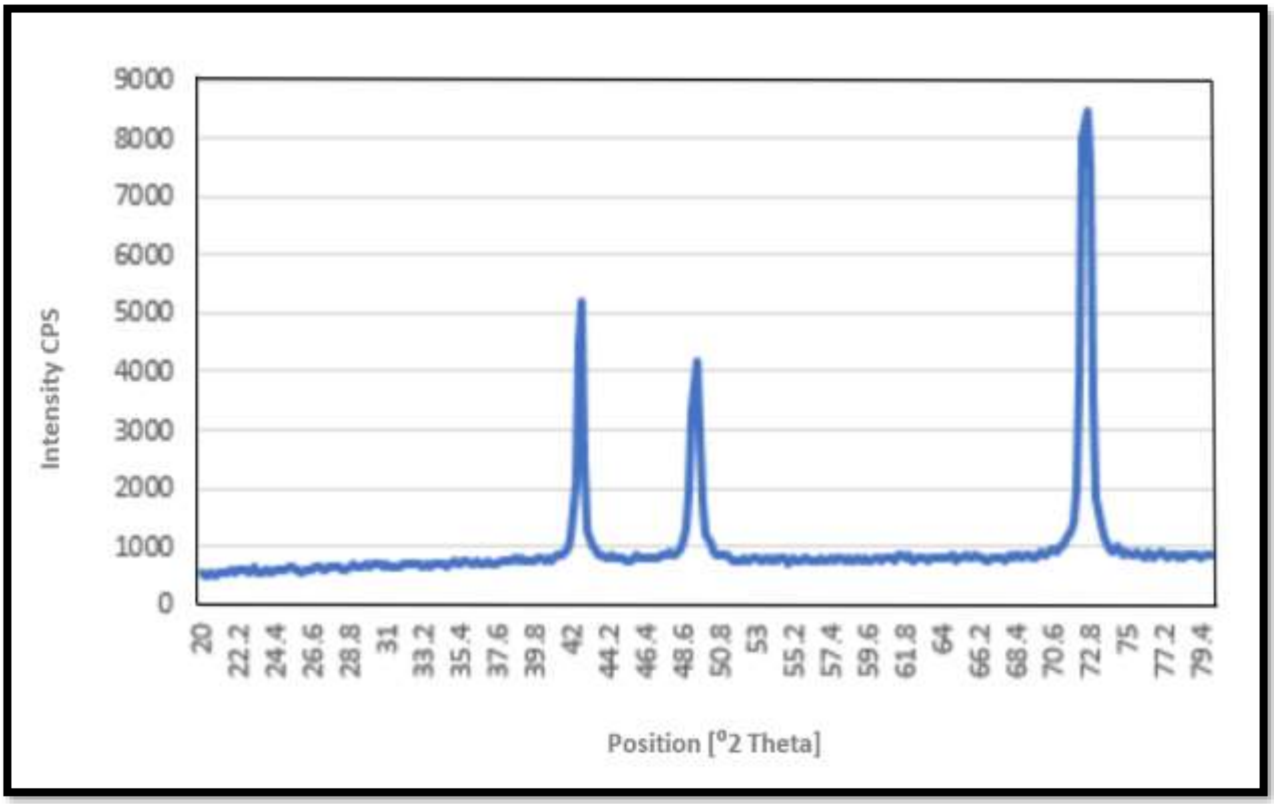

Fig.9. X-ray Diffraction (XRD) test by chemical deposition nanocoating technique with copper oxide nanocoating at concentration 0.35gm ($CuCl_2$)

From Fig. 10 as show the SEM results are shown with magnification 200000× and it is easy to notice that the examined particles consist of a number of smaller objects of 400nm. From maximum resolution image obtain. The nanocoating copper oxide with chemical deposition nanocoating technique with copper oxide nanocoating at concentration 0.35gm ($CuCl_2$) showed good clarity of morphology This was due to a good distribution of dark and bright areas, where bright areas represented Nano-structures' peaks, and the dark areas represented their valleys in between. The average particle size ranged between (90-100nm).

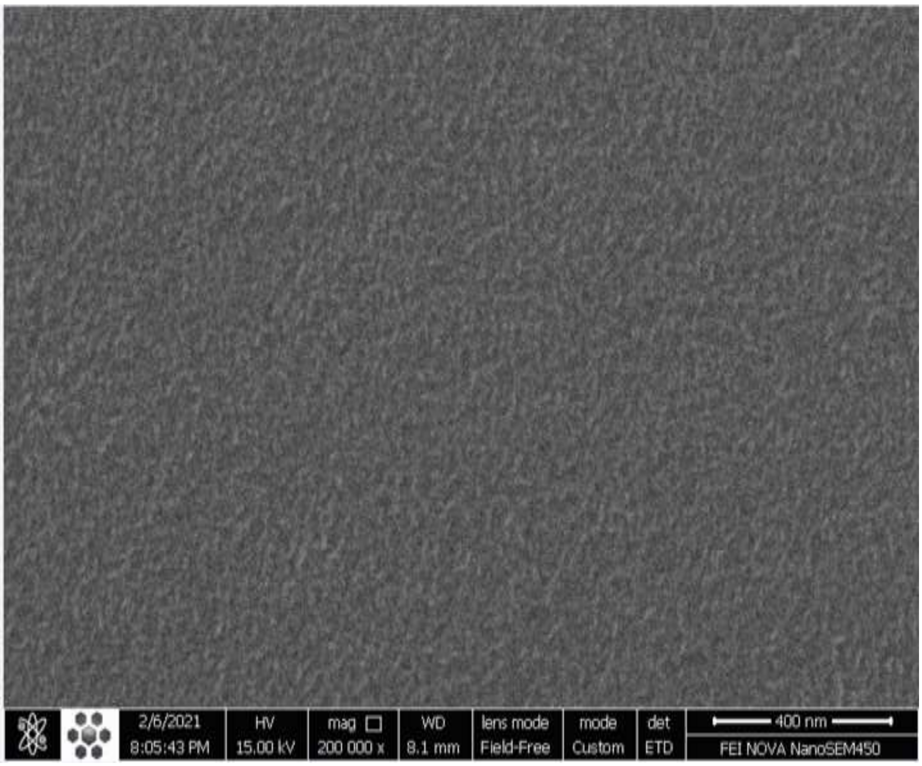

Fig.10. SEM test of copper oxide nanocoating with chemical deposition nanocoating technique with copper oxide nanocoating at concentration 0.35gm ($CuCl_2$)

3.2 Effectiveness of The Heat Pipe Heat Exchanger

Fig. 11 illustrates the effect of using a nanofluid and nanocoating fins on the effectiveness of a HPHE and compare with the HPHE that uses pure water with nanocoating fins. It has been noticed that the effectiveness value will increase as the mass concentration of CuO increased, as the inlet air velocity has been fixed at 1m/s and the effectiveness calculation at inlet air temperature ranges between 30 to 55 °C. From the above, it has been concluded through the obtained readings that the effectiveness is for a HPHE, which is increased whenever the inlet air temperature increased. Moreover, three percentages of the mass concentrations of copper oxide have been used, 1wt%, 3wt% and 5wt% with nano coating fins. It has been recorded that the best effectiveness is obtained when the use of 5wt% as a mass concentration of CuO with nano coating fins, where its value is estimated at 0.81, while the effectiveness value for using pure water as a working fluid with nano coating fins is about 0.588 at the same inlet air temperature and air velocity. Whereas, the improvement in effectiveness that occurred due to the use of nanoparticles of CuO with a mass concentration of 5wt% is about 27.3%.

From Fig.12 shows the effect of the nano-coating of the fins on the effectiveness of HPHE. It has been noticed that the effectiveness value will improve when use nanocoating fins, as the inlet air velocity has been fixed at 1 m/s and the effectiveness calculation at inlet air temperature ranges between 30 to 55 °C compared to cases without nanocoating. Additionally, found from Fig.12 the amount of effectiveness improvement by using 1wt%, 3wt%, and 5wt% of CuO with nanocoating fins ranges about 14.5%, 20.6% and 22.68%, respectively compared with the same mass concentrations of copper oxide without nanocoating fins.

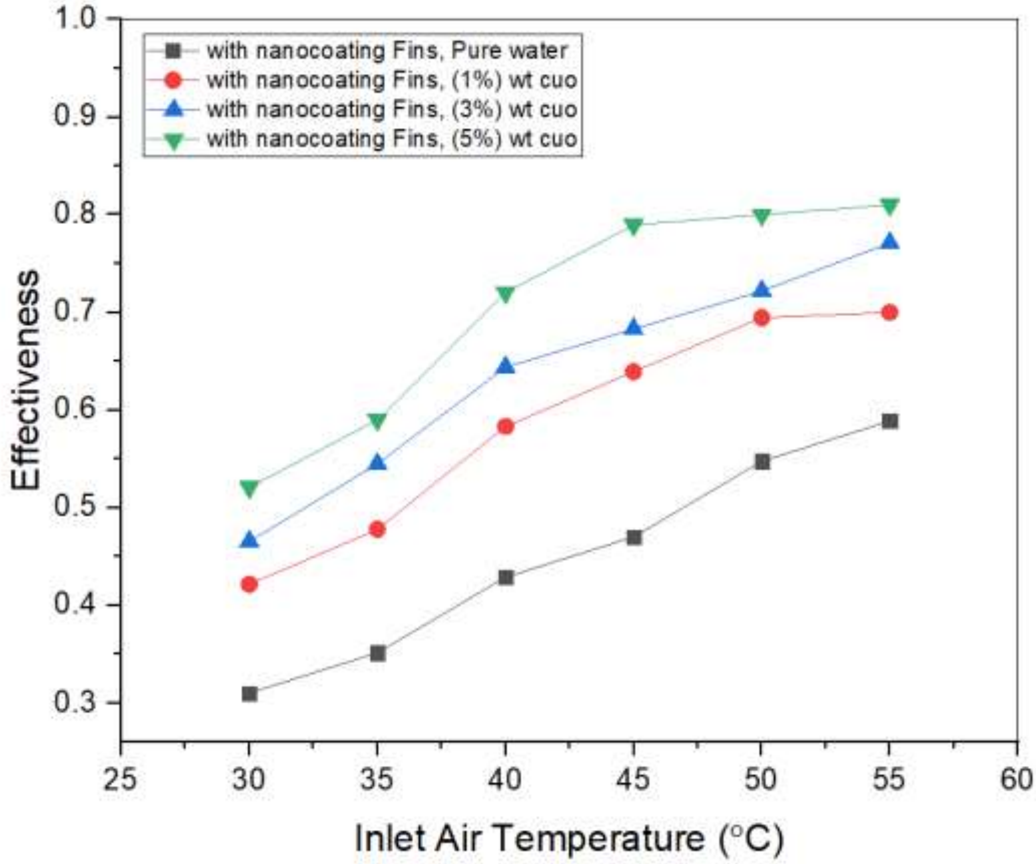

Fig. 11. Effectiveness of HPHE at velocity=1m/s

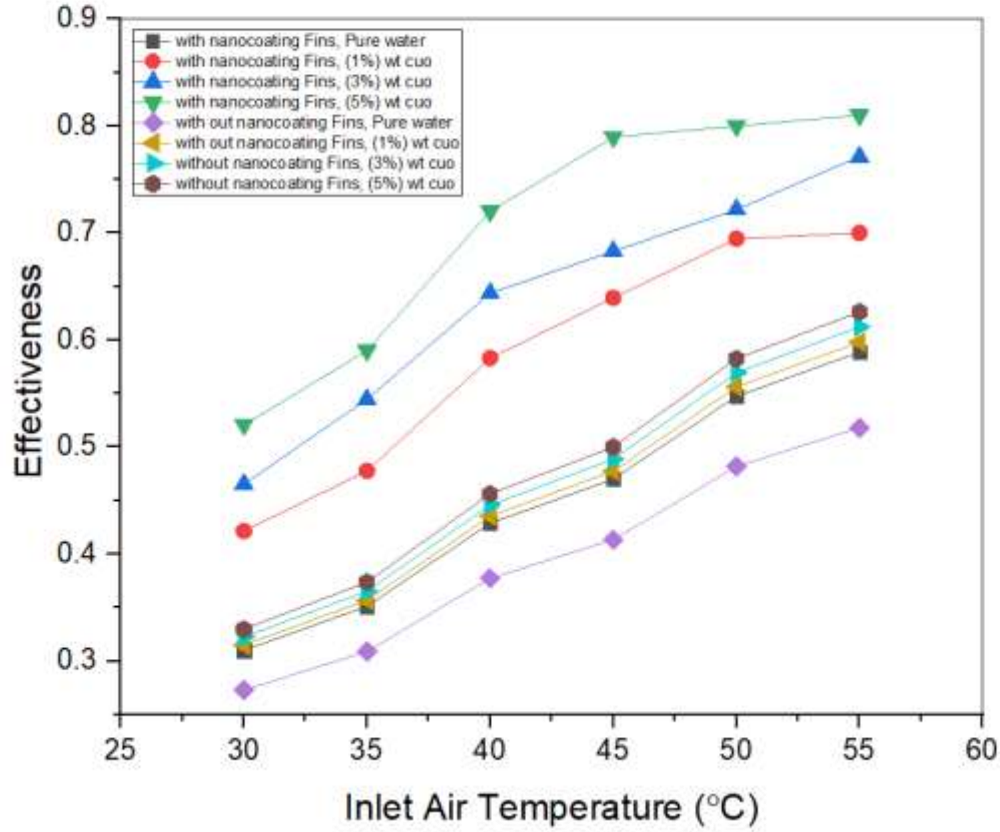

Fig. 12. Comparison between effectiveness of HPHE at velocity=1m/s with and without nanocoating fins

3.3 Heat Recovery of HPHE

In the HPHE application, the process of heat recovery is carried out in the evaporator and condenser. In the present work, a heat recovery has been observed during precooling (HPHE evaporator), so it directly influenced a reduction in the energy consumption of the system. It is possible to achieve the sum of heat recovery in the air conditioning system using HPHE, with several experimental parameters shown in Fig. 13. This result shows the effect of using three percentages of CuO and nano coting fins on the heat recovery. It has also been found that the amount of heat recovery improvement by using 1wt%, 3wt%, and 5wt% of CuO ranges about 13%, 17.3% and 20.6%, respectively compared with pure water. But note it has also been found that the amount of heat recovery improvement by using 1wt%, 3wt%, and 5wt% of CuO with nanocoating fins ranges about 22.7%, 30.166% and 36.6%, respectively compared with the same mass concentrations of copper oxide without nanocoating fins as show in Fig. 14.

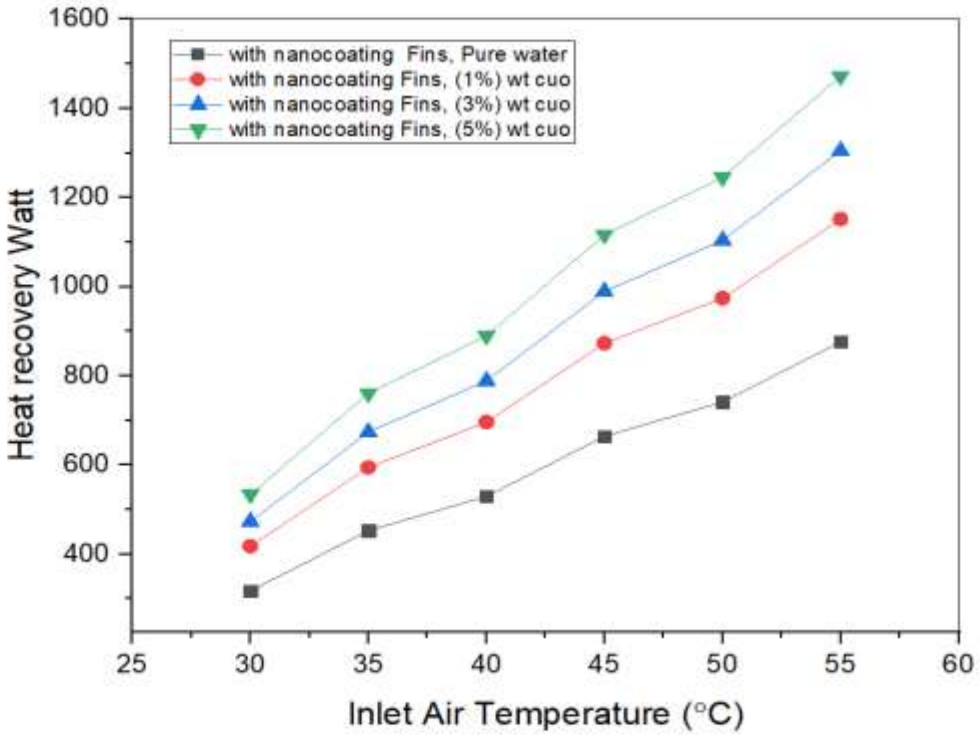

Fig. 13. Heat recovery of HPHE at velocity=1m/s

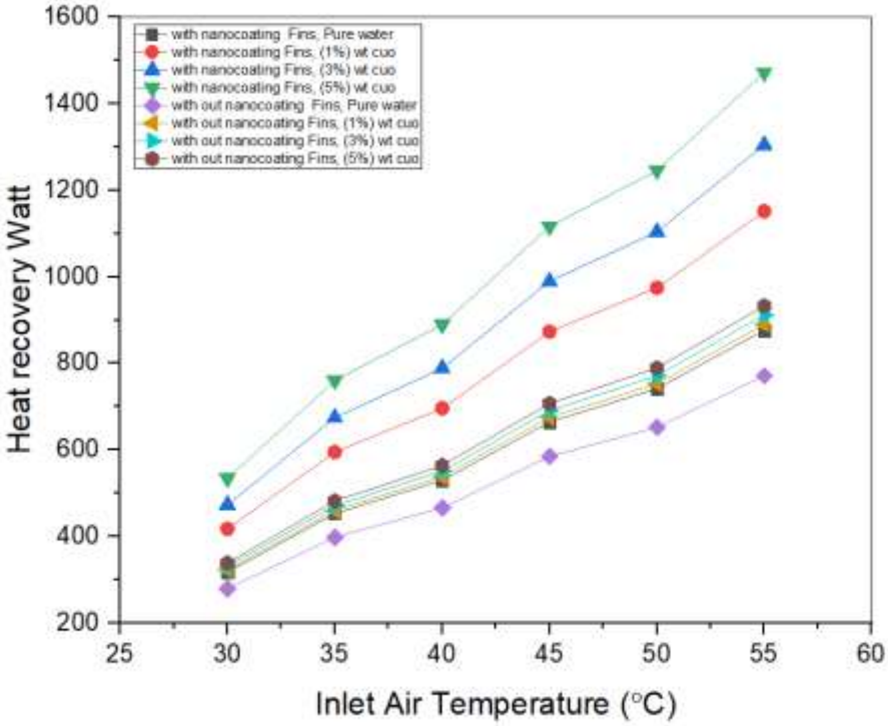

Fig. 14. Comparison between Heat recovery of HPHE at velocity=1m/s with and without nanocoating fins

4. CONCLUSIONS

HPHE has been characterized in this study by varying evaporator inlet air temperature and inlet air velocity to the evaporator. From the results, the following conclusions are made:

1. The effectiveness of the HPHE rises when the inlet air temperature and mass concentration increases.
2. The heat recovery of the HPHE increases when the inlet air temperature and the mass concentration increase.
3. The effectiveness and heat recovery of the HPHE enhancement when used nanocoating fins.
4. The amount of heat recovery improvement by using 1wt%, 3wt%, and 5wt% of CuO with nanocoating fins ranges about 22.7%, 30.166% and 36.6%, respectively compared with the same mass concentrations of copper oxide without nanocoating fins.
5. The amount of effectiveness improvement by using 1wt%, 3wt%, and 5wt% of CuO with nanocoating fins ranges about 14.5%, 20.6% and 22.68%, respectively compared with the same mass concentrations of copper oxide without nanocoating fins.
6. The maximum effectiveness level and heat recovery value, at inlet air temperature 55°C and inlet air velocity 1m/s have been found equal to 0.81 and 1472.142 Watt, respectively.
7. The use of HPHE model in air conditioning system with nanofluid as a working fluid and nanocoating fins, , has been more efficient in energy saving than using pure water as a working fluid and nanocoating fins.

ACKNOWLEDGMENT

We would like to appreciate the Technical Engineering College-Baghdad, Middle Technical University, Iraq for their laboratory support for this work.

NOMENCLATURE

C_p	Specific heat in the ambient air, J/ kg k
m_h	Mass flow rate of hot air, kg/s
m_c	Mass flow rate of cold air, kg/s
Q	Heat transfer rate, Watt
HPHE	Heat Pipe Heat Exchanger
HR	Heat Recovery, Watt
T	Temperature, °C
m_w	Mass flow rate of water, kg/s
Greek letters	
ε	Effectiveness
Subscripts	
act	actual
max	maximum
c	condenser
e	evaporator
i	inlet
o	outlet
h	hot

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