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THERMAL PERFORMANCE ENHANCEMENT OF HEAT PIPE HEAT EXCHANGER IN THE AIR-CONDITIONING SYSTEM BY USING NANOFLUID

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ABSTRACT

To reduce the energy consumption in air-conditioning systems without changing the required temperature level in the air-conditioned space, Heat Pipe Heat Exchanger (HPHE) has been experimentally used and tested. The heat pipe has been filled with working fluid by about 50% of the volume of the evaporator which represents the filling ratio. In this research, three mass concentration of nanoparticle from copper oxide (CuO), 1wt%, 3wt% and 5wt% have been used and studied. 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 study revealed that the temperature change of the evaporator and condenser has been increased with increasing the mass concentration of CuO and inlet air temperature which passing through HPHE. Furthermore, the results have been illustrated that the increasing of the inlet air temperature and CuO mass concentration leads to an increase in the effectiveness of the heat pipe. The highest level of effectiveness and maximum heat recovery value, at inlet air temperature 55 °C with inlet air velocity 1m/s have been found equal to 0.59346 and 883.284 Watt, respectively.

Keywords: heat pipe, HPHE, heat recovery, effectiveness, thermosyphon

1. INTRODUCTION

Thermosyphon heat pipe heat exchanger (HPHE) has been investigated for energy-saving purposes in many applications, 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. (Peterson et al. (1994); Faghri et al. (2012); Shabgard et al. (2015); Sobhan et al. (2019); Velardo et al. (2021). The thermosyphon heat exchanger is one of the most productive devices recover lost heat in the world Nouei et al. (2004). Several studies have been carried out to obtain thermal efficiency to ensure that the heat pipe heat exchangers work efficiently and reliably Tan et al. (1990); Peterson et al. (1994); El-Baky et al.(2007); Bahiraei et al. (2016); Cacua et al. (2020)(Yunus and Alsoufi, 2019). 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 Ma et al. (2006); Xue et al. (2006); Kang et al. (2009); Haddad et al. (2014); Han et al. (2015); Han et al. (2018); Yunus et al. (2019). Kang et al. (2006) proved that the use of silver nanoparticles within the grooved heat pipe in distilled water improves its thermal performance. The use of a thermosyphon heat exchanger packed with methanol-silver nanofluid has been studied by Firouzfar et al. (2011). 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. (2017) 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. (2012) experimentally investigated the thermal performance of heat pipe by using aluminum oxide nanofluid. Them 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. Furthermore, the influence of it on the effectiveness and heat recovery of air conditioning systems has been investigated. Moreover, a comparison between the thermal performances of HPHE charged with nanofluid and pure water has been made.

2. EXPERIMENTAL SETUP

2.1 Experimental Design

Figures 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 Heat Pipe Heat Exchanger is thermosyphon heat pipe technology. 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% Barua et al. (2013). 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

$$\varepsilon = \frac{q_{actual}}{q_{max}} \tag{1}$$

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

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

$$\left(T_{e,i} - T_{e,o} \right) > \left(T_{c,o} - T_{c,i} \right) \tag{3}$$

$$C_h \leq C_c \tag{4}$$

where

$$C_h = m_h \, C_{p,h} \tag{5}$$

$$C_c = m_c \, C_{p,c} \tag{6}$$

$$C_{min} = C_h \tag{7}$$

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

$$Q_{act} = m_h \, C_{p,h} \left(T_{e,i} - T_{e,o} \right) \tag{9}$$

$$Q_{max} = m_h \, C_{p,h} \left(T_{e,i} - T_{c,i} \right) \tag{10}$$

$$\varepsilon = \frac{\left(T_{e,i} - T_{e,o} \right)}{\left(T_{e,i} - T_{c,i} \right)} \tag{11}$$
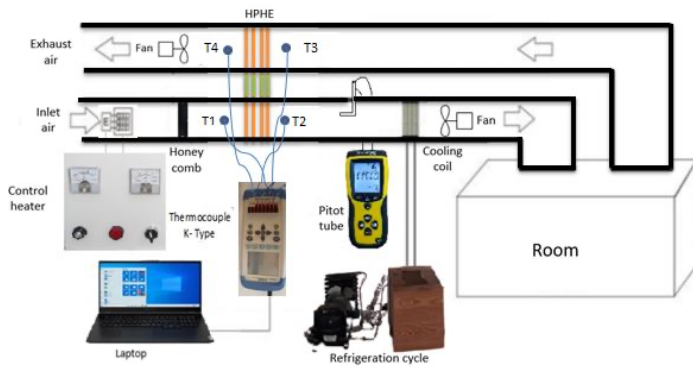
Fig. 1. Schematic diagram of test rig.

Fig. 2. Photograph of test rig.

value of the HPHE model, equations 1 to 11 have been used (Hung, Teng et al. (2013); Abedalh et al. (2021) .
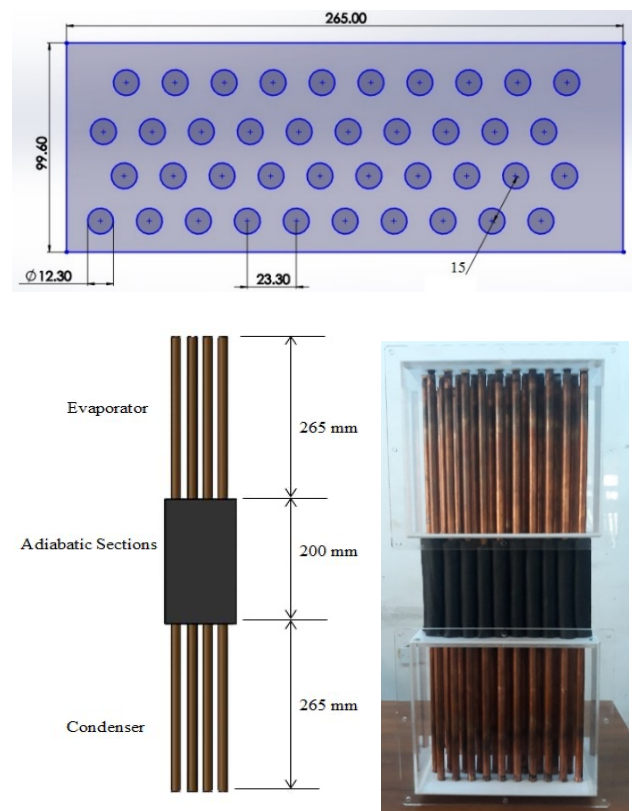
Fig. 3. Schematic diagram and Photograph of the HPHE model.

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) Yau et al. (2015).

$$HR = m_a \; C_p \left(T_{e,i} - T_{e,o}\right) \qquad (12)$$

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 (ΔT_e) and the temperature rise profile in the condenser area (ΔT_c) were the results of this test. In the HPHE evaporator segment, ΔT_e 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 (chool of Mechanical Engineering, KIIT University, Bhubaneswar-751024, Odisha, India and Mukherjee, 2013).

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 (Abedalh, Shaalan and Saleh Yassien, 2021).

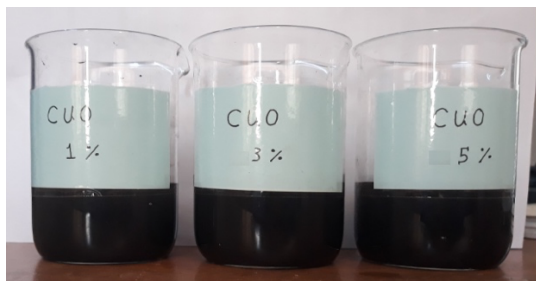**Fig. 4.** Photograph of ultrasonic.

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.

Nano Metal oxide	Average particle size (nm)	purity	Appearance	Specific surface (m²/g)	Bulk density (g/cm³)
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.
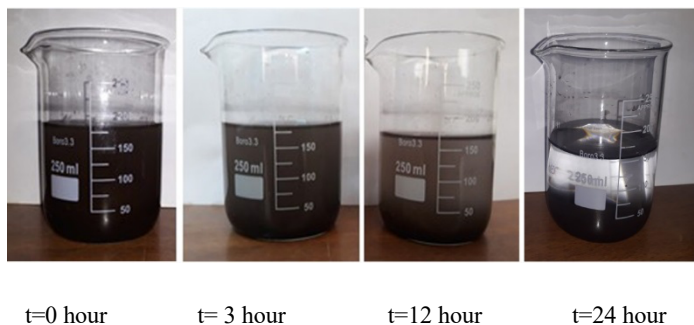
t=0 hour   t= 3 hour   t=12 hour   t=24 hour

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

2.3 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 (Holman, 2012) 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.

$$\frac{wR}{R} = \left[\left(\frac{\partial R}{\partial v1} \cdot \frac{W1}{R}\right)^2 + \left(\frac{\partial R}{\partial v2} \cdot \frac{W2}{R}\right)^2 + \cdots + \left(\frac{\partial R}{\partial vn} \cdot \frac{Wn}{R}\right)^2 \right]^{0.5} \quad (13)$$

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.

3. RESULTS AND DISCUSSION

3.1 The Effects of Nanofluid on The Evaporator and Condenser Temperature Difference

Figures 7 and 8 show the effect of the temperature change in the evaporator and the condenser with the change of the mass concentration of copper oxide (CuO) added to the water inside the heat pipe. It has been found that the increasing of the mass concentration of copper oxide recorded maximum difference between the temperatures of the air entering and leaving the evaporator and the condenser. Additionally, it has been observed that the difference in the temperature of the evaporator in the case of using pure water only as a working fluid inside the heat pipe, at inlet air temperature 55 °C and a constant air velocity of 1 m/s, the value of the difference in the temperature of the evaporator and the condenser is 9.2 °C and 9 °C, respectively. While the value of the difference in the temperature of the evaporator and the condenser becomes 11.6 °C and 11.08 °C, respectively when the use of 5% as the mass concentration of CuO.
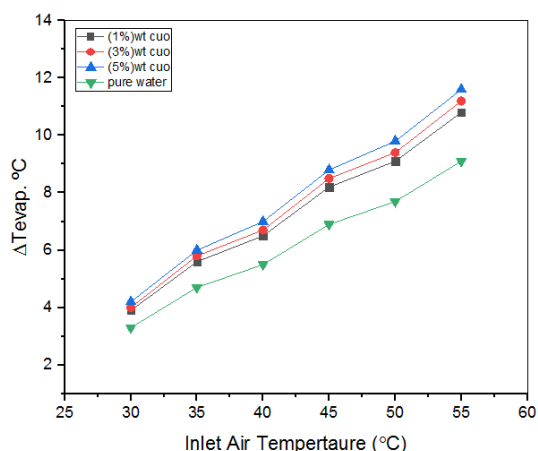

Fig. 7. Heat flux VS temperature differences in the evaporator at velocity=1m/s, 4-row.

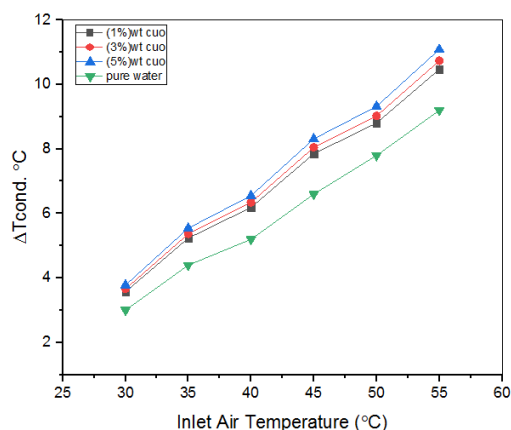**Fig. 8.** Heat flux VS temperature differences in the condenser at velocity=1m/s, 4-row.

3.2 Effectiveness of The Heat Pipe Heat Exchanger

Figure 9 illustrates the effect of using a nanofluid on the effectiveness of a HPHE. 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 1 m/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%. It has been recorded that the best effectiveness is obtained when the use of 5wt% as a mass concentration of CuO, where its value is estimated at 0.59346, while the effectiveness value for pure water is about 0.471 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 20.6%.
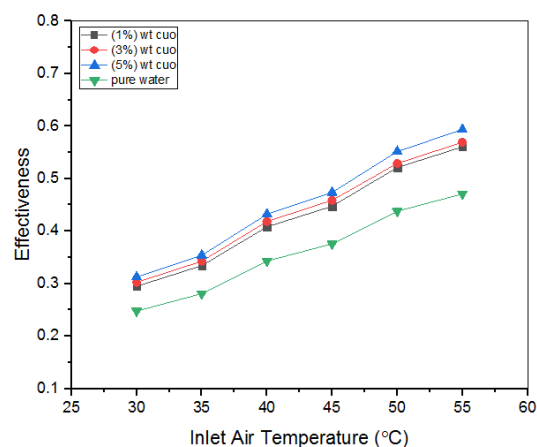

Fig. 9. Effectiveness of HPHE at velocity=1m/s, 4-row.

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. 10. This result shows the effect of using three percentages of CuO 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. In addition, inlet air temperature 55 °C, the results show that the heat recovery has been improved at 5% of mass concentration of CuO with heat recovery of 883.284 Watt, while it is about 701.023 Watt when using pure water at the same conditions.

3.4 The wall temperature distribution versus the length of the heat pipe

Figures11 show the location of the thermocouple along the heat pipe. Additionally, it is also Fig.12 to14 show that the experimental results of the surface temperature distribution along the length of the thermosyphon heat pipe for the various heating powers, which 750, 1500, and 2000 W, when the filling ratio was 50% and the inlet air velocity was 2 m/s and various working fluids water, (1wt %) CuO+H2O, (3wt %) CuO+H2O,

and (5wt %) CuO+H2O. An axial distance of (9 to 27 cm) indicates the evaporator section followed the distance between (27 to 55 cm) present the adiabatic zone, and distance (55 to 73 cm) condenser zone. It can be seen that the average wall temperature and the temperature difference of all three working fluids increased with increasing heating power. For example, when the nanofluid $CuO+H_2O$ with mass fraction (5wt %) was used as a working fluid, the temperature differences between the two ends of the heat pipe at heating powers 750, 1500, and 2000 W were 10.5, 12.33, and 14.5 °C respectively. Additionally, It is also found that the temperature difference between the two ends of heat pipe under heating power 2000W for water, (1wt %) CuO+H2O, (3wt %) CuO+H2O, and (5wt %) CuO+H2O. 16.1, 15.25, 14.75, and 14.4, respectively.
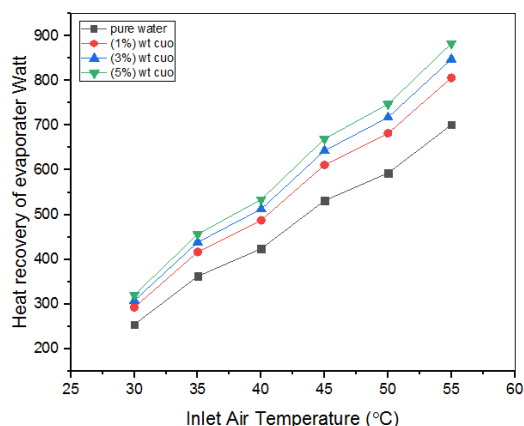

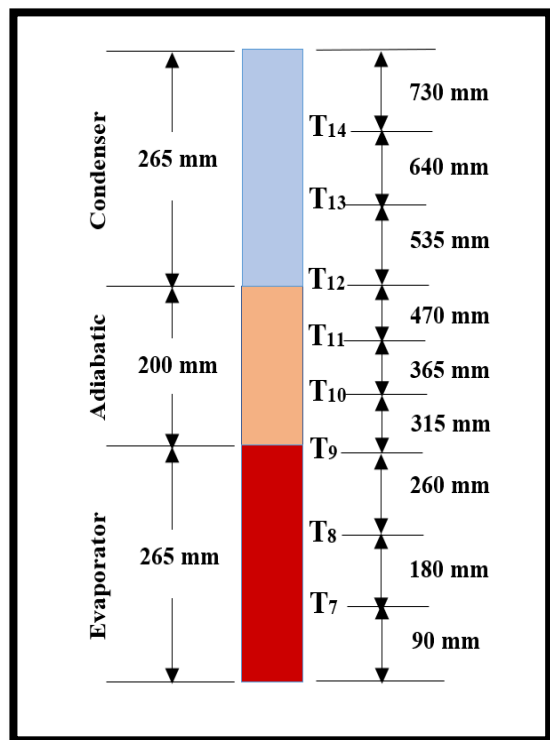**Fig. 10.** Heat recovery of HPHE at velocity=1m/s, 4-row.

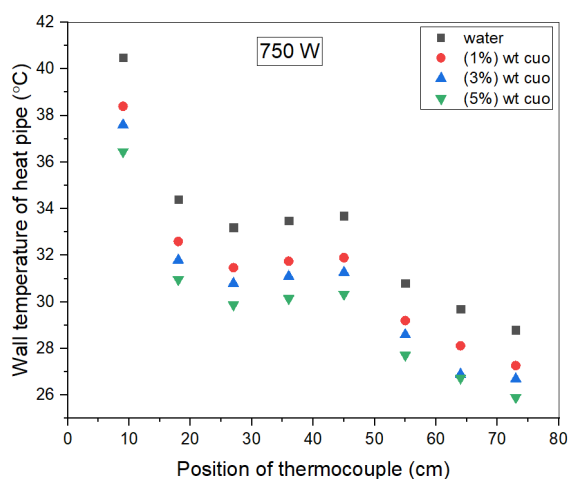**Fig. 11.** Thermocouples locations along the heat pipe.

Fig.12. The temperature distribution on the wall of the heat pipe for 750 Watt heating powers
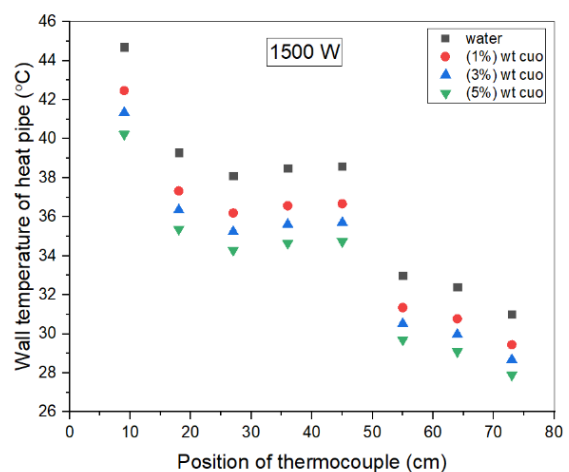

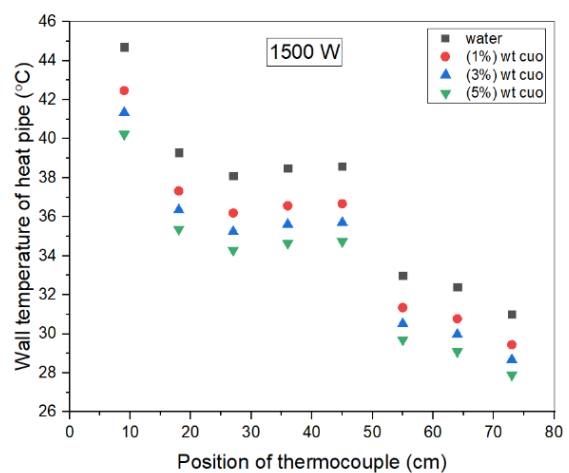**Figure 13.** The temperature distribution on the wall of the heat pipe for 1500-Watt heating powers

Fig. 14. The temperature distribution on the wall of the heat pipe for 2000-Watt heating powers

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 increases.
3. 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 0.59346 and 883.284 Watt, respectively.
4. At inlet air temperature 55 °C, the heat recovery has been 883.284 Watt at 5wt% of mass concentration of CuO while it is about 701.023 Watt when using pure water.
5. The use of HPHE model in air conditioning system with nanofluid, as a working fluid, has been more efficient in energy saving than using pure water.

ACKNOWLEDGMENT

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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