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Experimental investigation on MWCNTs-COOH nano fluid on 3D oscillating heat pipe

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ABSTRACT: The oscillating heat pipe is a new technology that, despite its simple structure, has a very high heat transfer rate. Due to boiling and condensation during operation, the oscillating heat pipe is capable of transferring heat at low temperature without the need for external power, high heat transfer and small volume. The thermal conductivity equivalent to an oscillating heat pipe can reach several hundred times the best conductors such as copper. The present study investigated thermal performance of nano fluid carboxylic multi walled carbon nano tubes (MWCNTs-COOH) with 0.1 wt% based on water with corrugated evaporator in newly designed three dimensional oscillating heat pipe. The results show that using this nano fluid, the thermal resistance has been reduced up to 13%. Also, in filling ratio of 60% compared to 50%, temperature difference between evaporator and condenser has been reduced 8 degree centigrade and the thermal resistance has been reduced up to 6.4%. Corrugating the evaporator leads to mixing and turbulence in the pipe and increases heat transfer. The results showed that thermal resistance decreased with increasing thermal load. It also reduces thermal resistance by reducing the temperature difference between the evaporator and the condenser.

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1- Introduction

Oscillating Heat Pipes (OHPs) are a new generation of heat pipes consisting of a narrow tube with U-shaped bends. First, the air inside it is evacuated and then it is filled by an operating fluid with a suitable filling ratio, the optimal value of which is between 40-60%. Ghashayeshi et al. [1] investigated the effect of magnetic field on the heat transfer rate of an OHP with Fe2O3/Kerosene nanofluid. The results showed an improvement in the thermal performance of the device under the magnetic field. They also found that OHPs made of copper had better thermal performance, especially in higher fluxes and in the presence of a magnetic field than glass pipes [2]. Qu et al. [3] reviewed experimental studies on multilayer three-dimensional OHP. Their results showed that the 3D-OHP had significant advantages over the 2-dimensional OHP due to its multilayer structure. Yu et al. [4] investigated the thermal performance of an OHP with hydroxylated MWNTs nanofluid at various concentration. Experimental results showed that the MWNTs nanofluid PHP exhibits the better start-up characteristics than water as the concentration is below 0.3 wt%. Mobadersani et al. [5], by numerical solution, concluded that the performance of the OHP was reduced by applying a uniform magnetic field.

In this study, a new design of a 3D-OHP made of copper pipe and experiments with water working fluid and nanofluid of carboxylic multi-walled carbon nanotubes (MWCNTs-COOH) with a concentration of 0.1 wt% and temperature, thermal resistance and heat transfer coefficient is measured and investigated.

2- Experimental Setup and Test Procedure

This OHP is closed and three-dimensional with 11 bends in the evaporator part with a new design. The length of each part of the evaporator, adiabatic and condenser is 100 mm, the diameter of the device is 300 mm and the inner diameter of each bend is 40 mm. This device is made of copper pipe with internal and external diameters of 3.4 and 4.8 mm, respectively. Fig. 1 shows the device and its components along with the measuring equipment.

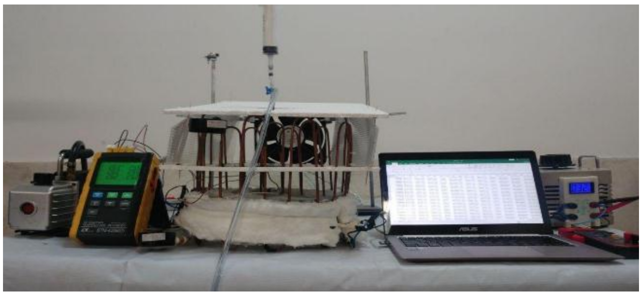

Fig. 1. The new proposed cycle for the power and natural gas production

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An electric plate heater is used to apply heat to the evaporator. The evaporator is insulated from the outside and inside to reduce heat loss. A fan with a wind speed of 8 m/s was used to cool the condenser. Different heat loads are applied by changing the voltage by Varyak device (0-250 Volts). The thermal power applied to the evaporator is calculated from Eq. (1).

$$q = V\,I \tag{1}$$

where V is the voltage applied to the heater and I is the current intensity, which is measured by the digital multimeter. To prepare nanofluids, the MWCNTs Nano particles were added in to the distilled water as the base fluid. In order to stabilize and homogenize the nanofluid, the ultrasonic bath model 5510 BRANSON has been used. After completing the experiments and in order to investigate the effect of curvature on the thermal performance of the 3D-OHP, 4 grooves were created on the evaporator tubes at intervals of 10 mm from each other.

First, the device was evacuated by vacuum pump for 20 minutes at 0.15 bar absolute pressure. Then the vacuum pump path was closed and the injection path opened. Experiments were performed with two Filling Ratios (FR) of 50 and 60% with water and nanofluids with a concentration of 0.1 wt%. Experiments were performed from an input power of 30-300 Watts with an increase of 30 Watts in 15 minutes and the results were recorded. To measure and record the temperature in the evaporator and condenser sections, a BTM-4208SD data logger and a K-type digital thermometer with six temperature sensors are used. Temperatures are recorded in memory every 5 seconds. The average evaporator and condenser temperatures are obtained from Eqs. (2) and (3), respectively. The thermal resistance of the device is calculated according to Eq. (4).

$$T_e = \frac{T_{e1} + T_{e2} + T_{e3}}{3} \tag{2}$$

$$T_c = \frac{T_{c1} + T_{c2} + T_{c3}}{3} \tag{3}$$

$$R = \frac{T_e - T_c}{q} \tag{4}$$

where R is the thermal resistance in K/W, T_e the average temperature of the evaporator, T_c the average temperature of the condenser and q is the rate of heat input in W.

Uncertainty is calculated according to the Holman method. Voltage and current uncertainty is ±0.4V and ±0.015A, respectively, and temperature measurement uncertainty in the thermometer is ±1K. The maximum error in measuring the input heat flux is less than 5.7%. Also, the thermal resistance uncertainty is 3.29%.

3- Results and Discussion

The average evaporator and condenser temperatures are plotted over time in Fig. 2. (a) With increasing heat capacity, water after about 120 minutes at 68 °C, the first signs of temperature fluctuations are observed. (b) With nanofluids in FR 50%, the onset of oscillation occurs after about 90 minutes at a temperature of 63 °C. (c) At a filling ratio of 60%, the temperature fluctuation occurs 60 minutes after the start of heating at 52 °C. (d) In a grooved evaporator with a filling ratio of 60%, the oscillations start 40 minutes after heating 47 °C.

Fig. 3 shows the thermal resistance of the device in terms of input power. According to this figure, the thermal resistance of the device with nanofluid has decreased by 13.1% in the filling ratio of 50% compared to water. The thermal resistance of the device with nanofluid with 60% filling ratio has decreased by 6.4% compared to nanofluid with 50% filling ratio. Therefore, increasing the filling ratio reduces the thermal resistance. The thermal resistance at the

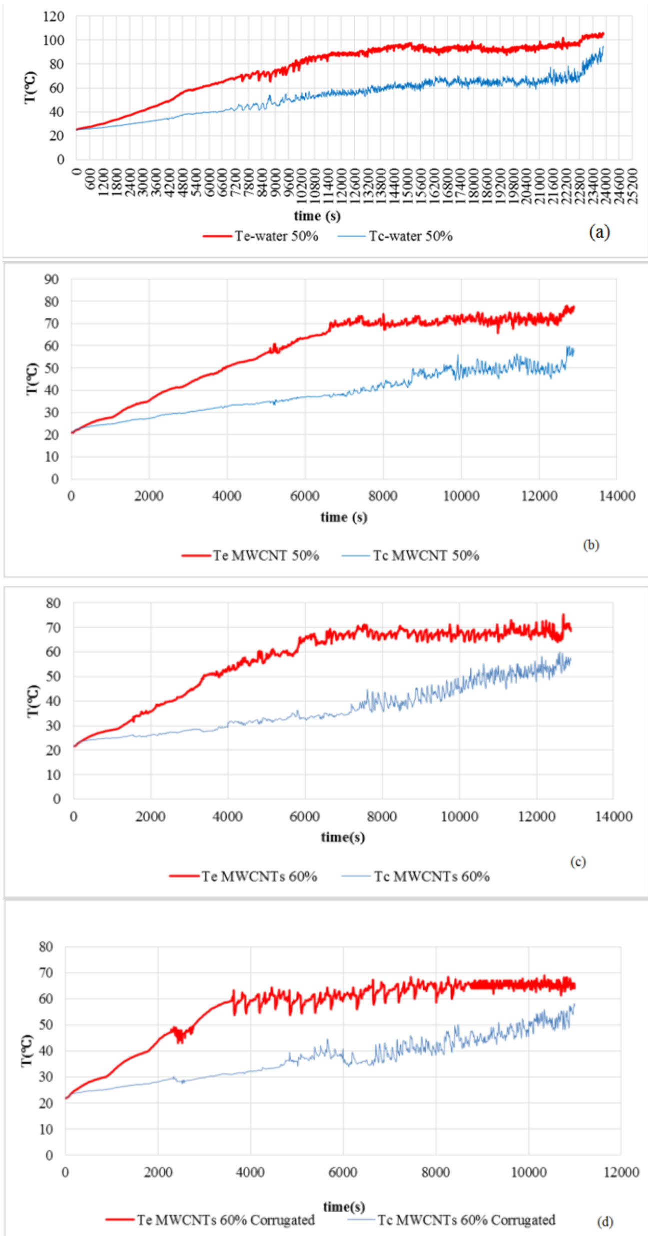

Fig. 2. Evaporator and condenser temperatures over time for operating fluid (a) water with FR 50%, (b) nanofluid with FR 50%, (c) nanofluid with FR 60%, (d) nanofluid with FR 60% with Grooved evaporator tubes

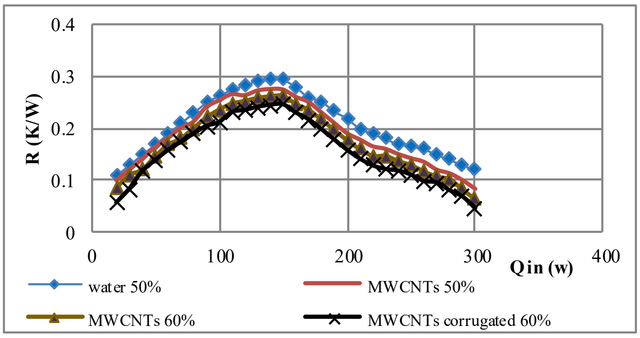

Fig. 3. Thermal resistance in terms of heat output for the operating fluid: water and nanofluid with 50% filling ratio, nanofluid with 50% and 60% filling ratio, nanofluid with grooved and non-grooved evaporator with 60% filling ratio

filling ratio of 60% in the grooved evaporator decreased by 5.3% compared to the non-grooved evaporator and it can be concluded that the grooving of the operator disturbed the flow inside the pipe and increased the heat transfer rate.

4- Conclusions

In this study, water-working fluid with MWCNTs nanofluid with a concentration of 0.1 wt% with a filling ratio of 50 and 60% has been investigated. Normally the best thermal performance of an oscillating heat pipe is in the filling ratio of 40-70%. In this experimental study, it was found that the 60% filling ratio had a better performance. Thermal performance is also improved by grooving the evaporator.

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