

Study about heat transfer coefficient of water-nanofluid in pulsating heat pipes

*M. Banezhad Jannati**, *H. Goshayeshi*

Department of Mechanical Engineering, Islamic Azad University, Mashhad, Iran

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ABSTRACT: Pulsating heat pipe is an efficient heat exchange device which is being used for cooling and heating recovery. In the present work, we made a closed-loop pulsating heat pipe with six U-turns and we used water in our system. Moreover the use of water-Fe₃O₄ nanofluid was studied with two different filling ratios 40% and 50% and 1% mass concentration. At the end we calculated heat resistance and heat transfer coefficients of water and water-Fe₃O₄ nanofluid in each step and compared the results and showed that 50% filling ratio was the best in our study. And water-Fe₃O₄ nanofluid has better heat transfer coefficient than water.

Keywords: *Filling ratio; Heat resistance coefficient; Heat transfer coefficient; Pulsating heat pipe; water-Fe₃O₄ nanofluid*

INTRODUCTION

Nowadays due to rapid improvement of industry and its direct relation to energy in the world, the necessity of providence in consume of energy is more transparent. Heat transfer is one of the branches that consume energy highly, so looking for a way which could help to reduce it looks vital. On the other hand, heat pipe is an economical instrument that doesn't have any moving part, so it can be a good method for reducing consumption of energy. Heat pipes are three different types:

Simple heat pipe, Thermosyphon and pulsating heat pipe

Simple heat pipe: it is an instrument which transfers heat from one place to the other place. It works like refrigerator but without any consumption of energy. It has three parts namely, evaporator, condenser and adia-

batic part. Heat absorbs in adiabatic part by refrigerant and changes the refrigerant from liquid to gas. Then refrigerant will go to the condenser part. In condenser, heat will be transferred to water or air or any other fluid. It has wicks configuration and works in vacuum. Thermosyphon: This kind of heat pipe is similar to simple heat pipe, but without inner configuration, thus should stay vertically.

Pulsating heat pipe: This system is based on producing bubbles and was introduced by (Akachi, 1990). Bubbles will transfer sensible heat and latent heat concurrently. This is because of capillary tube which differ it from other types of heat pipes. Different kinds of pulsating heat pipes have shown in Fig. 1:

In Fig. 1, at right you could see open-loop type that has named closed-end. At left, there is closed-loop, and

(*) Corresponding Author - e-mail: farshid2090@yahoo.com

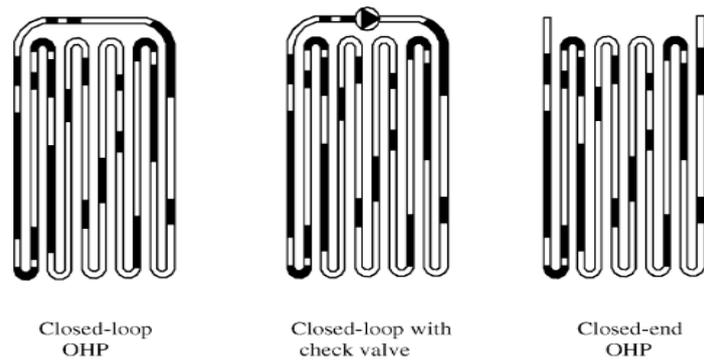


Fig. 1. Different kinds of Pulsating heat pipe

the other one is closed-loop with check valve, which permits the refrigerant to move just in one direction. Important parameters which affect on pulsating heat pipe:

1. The number of U-turns: More U-turns usually make better heat transfer.
2. Filling ratio: The volume of liquid that infused in heat pipe in comparison with total volume of heat pipe.
3. Size of evaporator and condenser.
4. Inclination angle.
5. Refrigerant liquid.

Nanofluids have been tested in pulsating heat pipes these years. They are effective liquids for heat transfer as a result of nanoparticles which they have in solid shape. Metal or oxides of metal nanoparticles that are added into fluids are suitable for this issue as many recent experiments have shown.

LITERATURE REVIEW

In 2011, Yulong, *et al.*, studied the size of Al_2O_3 nanoparticles on a pulsating heat pipe with 5 U-turns. Their base fluid was water. They presented that heat transfer resistance of a pulsating heat pipe is related to filling ratio. They also showed that the best filling ratio for their experiments was 50%.

In 2015, Bhagat and Watt studied an experimental investigation of Methanol in a closed-loop pulsating heat pipe at variable water bath temperatures. They founded that when the temperature of water bath increases, there is increase in evaporator and condenser temperatures. The temperature of condenser increase

more rapidly when the temperature of water bath increases above 58°C . As the temperature of water bath increases, thermal resistance of closed-loop pulsating heat pipe decreases.

In 2013, Verma, *et al.*, studied on thermal performance of a pulsating heat pipe with methanol- DI water. They founded that the minimum start up power for DI water at 50% filling ratio and for methanol 40%. Also, they founded the minimum thermal resistances for distilled water and methanol were at vertical operation, then for 45° inclination and the maximum thermal resistances were for horizontal mode.

In 2013, Pachghare and Mahalle experimentally investigated the closed-loop pulsating heat pipe using methanol, ethanol, acetone and different binary mixtures as working fluid. Tube was from copper with internal diameter 2 mm and external diameter 3.6 mm with filling ratio 50%. His pulsating heat pipe had 10 U-turns and different heat inputs of 10 W to 100 W was supplied, the results showed that from 20 W to 60 W heat input, thermal resistance decreases more rapidly. And above 60 W decreases slowly. The performance was for pure acetone.

In 2014, Gonzalez, *et al.*, studied the effect of silver nanoparticles on closed-loop pulsating heat pipe. It was built with 3 mm diameter tubes. Thermocouples and pressure transducers were installed for fluid and surface temperature and pressure measurements. Operating temperature of the PHP varied from $30\text{--}100^\circ\text{C}$, with power rates of 61 W and 119 W. The fill ratio of 30%, 50%, and 70% were tested. The results showed that the evaporator heat transfer performance was degraded by the addition of nanoparticles due to increased viscosity at high power rate, while the positive

effects of high thermal conductivity and enhanced nucleate boiling worked better at low power rate. In the condenser section, owing to the relatively high liquid content, nanofluid more effectively improved the heat transfer performance. However, since the PHP performance was dominantly affected by evaporator heat transfer performance, the overall benefit of enhanced condenser section performance was greatly limited. It was also observed that the poor heat transfer performance with nanofluid at the evaporator section led to lower operating pressure of PHP.

In 2016, Xingyu Wang and Li Jia studied the effects of different refrigerants on heat transfer performance of pulsating heat pipe. The working temperature of pulsating heat pipe is kept in the range of 20°C-50°C. Thermal resistances of PHP with filling ratio 55% were obviously larger than those with other filling ratios. Thermal resistance of the PHP with R134a is much smaller than that with R404A and R600a. It indicates that the heat transfer ability of R134a is better.

EXPERIMENTAL SET UP

In this paper we made a closed-loop pulsating heat pipe with six U-turns from copper with 4 mm outer diameter and 2.2 mm inner diameter. And then we tested it with different input heats and after that, we added magnetic field which was produced with ferrite magnets. Our filling ratios are 50%, 40% and our fluid is Fe₃O₄-water nanofluid. Condenser part has 524 mm length and 120 mm width. Evaporator has 524 mm length and 110 mm width. We'll take a heater in the evaporator part, which produces 1300 W heat. This heater has shown in Fig. 2:

We used a digital thermometer to measure the temperature of evaporator in 4 points and temperature of condenser in 3 points and temperature of adiabatic part in 4 points. And also we measured temperature of water which flowed in condenser part as a cooler liquid.



Fig. 2. Heater with 1300 W

Total shape of our system could be seen in Fig. 3:

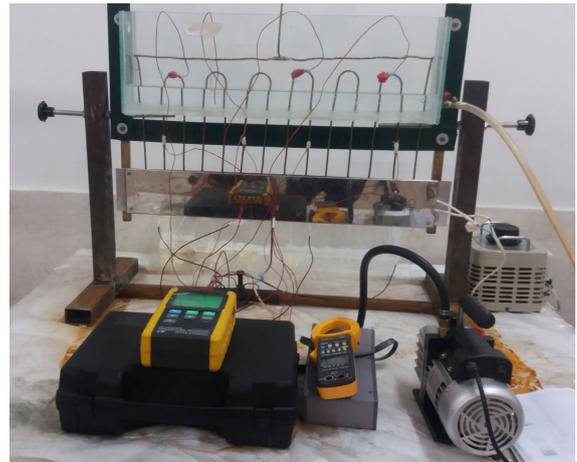


Fig. 3. Our pulsating heat pipe

Our thermometer could be seen in Fig. 4:



Fig. 4. Digital thermometer

We will change the input heat by Variac which changes voltage and has shown in Fig. 5, it can change voltage to 250 V. And so, the input heat changes with Voltage by Formula (1):

$$Q = V \times I \quad (1)$$



Fig. 5. Variac



Fig. 6. Vacuum pump

And I is the electricity current which was measured by an ampere meter in each step. And V is the voltage. For start of our tests we should create vacuum in the tube of our system. For this step we used a vacuum pump. This pump could be seen in Fig. 6:

To create vacuum, we used this pump for 30 minutes. Then we injected nanofluid in our system. When we injected nanofluid, we started the first step by first voltage and measured the current of electricity. Next we changed voltage from 40 V to 50 V, 60 V, 70 V and 80 V. And measured the current of electricity again and calculated the input heat by (1). Then we repeated these steps and recorded the results. We tested with and without magnets.

Temperatures of evaporator, condenser and adiabatic part are mean, and are calculated respectively from (2),(3) and (4):

$$T_e = \frac{T_{e1} + T_{e2} + T_{e3} + T_{e4}}{4} \quad (2)$$

$$T_c = \frac{T_{c1} + T_{c2} + T_{c3}}{3} \quad (3)$$

$$T_a = \frac{T_{a1} + T_{a2} + T_{a3} + T_{a4}}{4} \quad (4)$$

Heat resistance coefficient of pulsating heat pipe is achieved from (5):

$$R = \frac{\Delta T}{Q} \quad (5)$$

Which Q is input heat and ΔT is temperature difference between evaporator and condenser.

Heat transfer coefficient of pulsating heat pipe is achieved from (6):

$$h = \frac{1}{RA} \quad (6)$$

Which A is the whole area of pipe and is gained from (7):

$$A = \pi DL \quad (7)$$

Which D is outer diameter of tube and L is length of tube.

We used water-nanofluid as the working fluid. It is produced by adding nanoparticles to water- nanoparticles which we used have properties that have showed in Table 1:

To stabilize -water, we can use ultrasonic bath or we can use Tetra Methyl Ammonium Hydroxide as a surfactant.

RESULTS

Figs. 7, 8, 9 and 10 show results of our tests:

Table 1. Properties of Fe₃O₄ nanoparticles in our tests

Color= Dark brown	Purity= 99.5%	True density= 4.8-5.1(gr/cm ³)
Morphology= Spherical	Bulk density= 0.84 (gr/cm ³)	Size = 20-30 (nm)

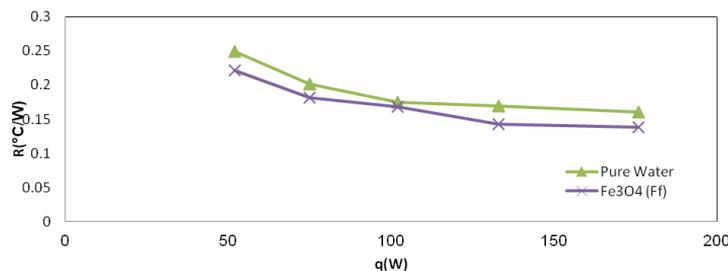


Fig. 7. Compare of heat resistance coefficient of our pulsating heat pipe with input heat, in different conditions by 40% filling ratio

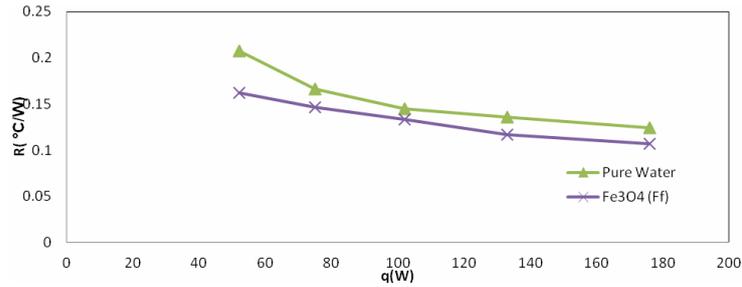


Fig. 8. Compare of heat resistance coefficient of our pulsating heat pipe with input heat, in different conditions by 50% filling ratio

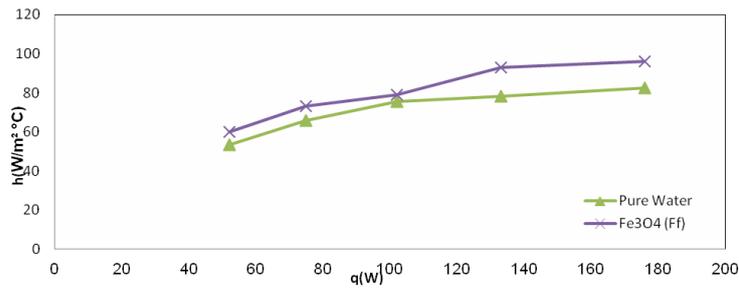


Fig. 9. Compare of heat transfer coefficient of our pulsating heat pipe with input heat, in different conditions by 40% filling ratio

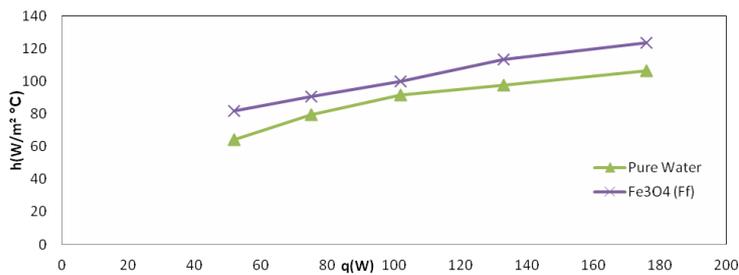


Fig. 10. Compare of heat transfer coefficient of our pulsating heat pipe with input heat, in different conditions by 50% filling ratio

CONCLUSIONS

From the charts it is transparent that using water- Fe_3O_4 nanofluid instead of pure water will decrease heat resistance coefficient of pulsating heat pipe and so will increase its heat transfer coefficient. It is due to metal nanoparticles which have very low heat resistance. And also it is clear that 50% filling ratio has less heat resistance coefficient and more heat transfer coefficient when we compare it with 40% filling ratio. Maybe it is because of more fluid in pulsating heat pipe.

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AUTHOR (S) BIOSKETCHES

Mohammad Banezhad Jannati, M.Sc. Student, Mechanical Engineering, Islamic Azad University, Mashhad, Iran, *Email: farshid2090@yahoo.com*

Hamidreza Goshayeshi, Associated Professor, Department of Mechanical Engineering, Islamic Azad University, Mashhad, Iran