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# Evaluation of Thermal Properties of Copper Heat Pipe Working in Water and Anti-Freezing Liquid at Different Angles and Filling Ratios

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**Abstract:** This research presents the results of laboratory experiments conducted to evaluate the thermal properties of a copper heat pipe operating in water and anti-freezing liquid under various angles and filling ratios. The method of designing experience in experiments is the method of Taguchi. Experiments were conducted in 9 options, and in options 4 and 8, it was determined that the temperature of the condensate-forming part of the heat pipe was 100-120°C. Therefore, in these options, more heat can be accumulated than in other options, and in these options, phase change materials with a high melting temperature can be used as a heat accumulating material.

**Keywords:** heat pipe, slope angle, filling ratio, heat transfer coefficient, heat resistance, Taguchi methods.

## INTRODUCTION

Currently, the energy used for heating and cooling buildings is the main share of all types of energy produced in the world. In 2020, 36% of the total energy produced in the buildings was used for heating and cooling of the buildings, the direct release of $CO_2$ gas into the environment was 15%, and 39% when calculating with the construction of buildings [1]. If the growth of energy consumption continues in this order at 1.5% per year, the demand for energy will increase by 2040 to 37% of the current energy consumption [2]. Therefore, the use of renewable energy sources in the heating and cooling of buildings reduces the demand for traditional energy sources, and the proportional reduction of $CO_2$ emissions into the atmosphere is achieved.

For this, heat pipes can be used to heat the building. Heat pipes operate in two-phase flow over long distances with small and not so large temperature differences. The heat absorbed by the evaporator is transferred to the working fluid by conduction and causes the liquid to vaporize on their evaporating surface, which increases the pressure inside the evaporator and allows the vapor to flow into the condenser. Then the heat is released in the condenser, latent heat is released in the process of steam condensing into liquid. High thermal conductivity in steady state is the main advantage of heat pipes over other traditional devices. Due to the phase change process, very high effective heat transfer rates can be achieved for heat pipes [3]. In order to apply heat pipes to the building, it is necessary to know the optimal selection of its two parameters. The first of these is the filling ratio of the liquid in the evaporator part of the heat pipe, and the second is the angle of curvature of the heat pipe relative to the horizon.

A heat pipe is a two-phase flow passive and reliable heat transfer device used in heating systems. The advantages of heat pipes compared to other traditional methods of heat transfer are summarized in the literature [4] and [5]. Heat pipes are characterized by having much higher thermal conductivity than the best solid conductor by several orders of magnitude due to the latent heat associated with the closed two-phase cycle. Thus, it is able to transfer large amounts of heat over long distances. In addition, heat pipes are characterized by fast heat exposure time, ease of preparation and manufacturing, wide temperature application range, and the ability to control and transport high heat rates at different temperature levels. Finally, due to their inherent high reliability (ability to operate without external power) and minimal maintenance, they are ideal for a variety of applications [6].

The performance of heat pipes depends on its geometric parameters, working fluid, conductivity structure and operating conditions. The working fluid is one of the most important parameters because the heat pipe uses phase change to transport heat. Thus, the choice of working fluid is of great importance to increase the thermal performance of the heat pipe. Conventional working fluids such as water, ethylene glycol and methanol are widely used today [7].

## MATERIALS AND METHODS

**Experimental set-up.** The experiments were conducted on a copper pipe with a length of 550 mm, an outer diameter of 12.8 mm, and an inner diameter of 9.6 mm. The pipe consists of 3 parts, the 1st part is the evaporator, the 2nd part is the adiabatic area, and the 3rd part is the condensation area. The length of the evaporator area is 150 mm, its outer part is wrapped with 230 coils of copper wire with a diameter of 0.5 mm and electrical insulation. Then the total resistance of the wire was equal to

$$R = N\rho\frac{l_0}{S} = 0.78\Omega$$

Here, $\rho$, $l_0$, S, N are copper conductor density, kg/m$^3$, winding length, m, cross-sectional area, m$^2$, and number of windings, respectively.

The evaporator part is insulated after the wire winding layer. The adiabatic area is 200 mm, in which the outer part of the pipe is insulated from heat. Condensation part is also 200 mm open and exchanges heat with outside air.

During the experiments, in order to change the amount of heat in the evaporator part of the pipe, the current was changed to 4, 5 and 6 amperes, i.e. 12W, 20W and 28W, using the LEYBOLD 521 55 HOCHSTROM NETZGERAT HIGH CURRENT POWER SUPPLY device.

During the experiments, an Arduino board connected to a computer and corresponding DS18B20 sensors were used to record the temperatures. The time step for temperature measurement is 30 seconds.

An overview of the experimental device is shown in Figure 1.

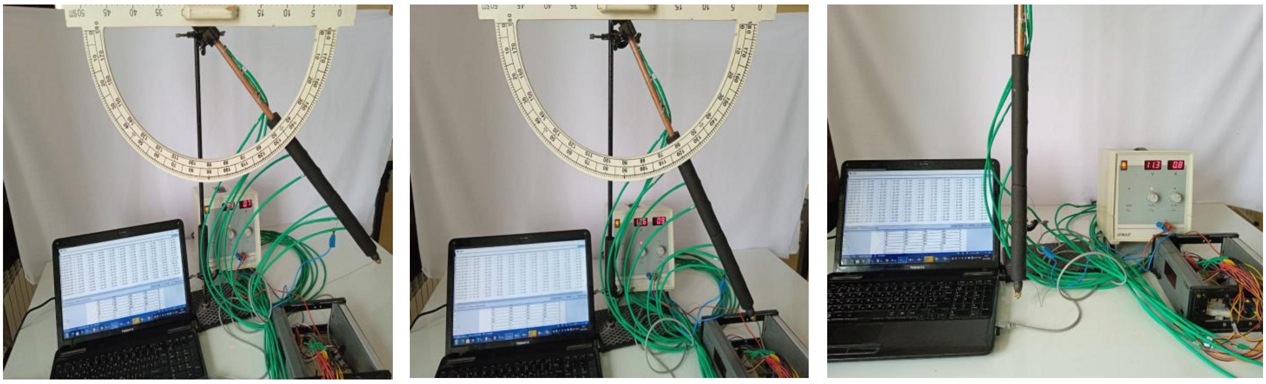

Fig.1. An overview of the experimental device

**Experimental method.** During the experiment, the change of three factors was considered, where each factor has three levels (Table 1). In this case, the total number of experiments will be $3^3 = 27$.

Table 1. Test factors and associated levels

| Levels | Factors | | |
|---|---|---|---|
| | Thermal power, W | Inclination angle, ° | Filling ratio, % |
| 1. | 12 | 45 | 20 |
| 2. | 20 | 60 | 40 |
| 3. | 28 | 90 | 60 |

The Taguchi method can be used to reduce the number of experiments. The Taguchi method does not have a 3x3 layout, so a 4x3 layout is used. Then the total number of necessary experiments will be 9 (Table 2) [4].

Table 2. Options for conducting experiments

| Run | Thermal power, W | Inclination angle, ° | Filling ratio, % |
|---|---|---|---|
| 1. | 12 | 45 | 20 |
| 2. | 12 | 60 | 40 |
| 3. | 12 | 90 | 60 |
| 4. | 20 | 45 | 40 |
| 5. | 20 | 60 | 60 |
| 6. | 20 | 90 | 20 |
| 7. | 28 | 45 | 60 |
| 8. | 28 | 60 | 20 |
| 9. | 28 | 90 | 40 |

In the experiment, water and antifreeze fluid (blue antifreeze fluid prepared on the basis of ASTM D3306 standard) were used as working fluids.

The experiment was conducted in laboratory conditions, and the process was stopped when it reached a stationary state.

**RESULTS AND DISCUSSION**

The results of the experiment conducted in water and anti-freezing liquid are presented in Fig. 2 and Fig. 3. During the experiments, the temperature of the environment (laboratory room) was kept unchanged at 30°C. The prepared heat pipe is 150 mm in the evaporator part, every 40 mm (40 mm, 80 mm and 120 mm) from the base, and the adiabatic part is 200 mm long, every 50 mm (200 mm, 250 mm, 300 mm), it has a length of 200 mm in the condensation part, and thermometers are placed every 50 mm (400 mm, 450 mm, 500 mm).

Ds18b20 thermometers were used as thermometers, integrated with a computer through an ARDUINO board and software.

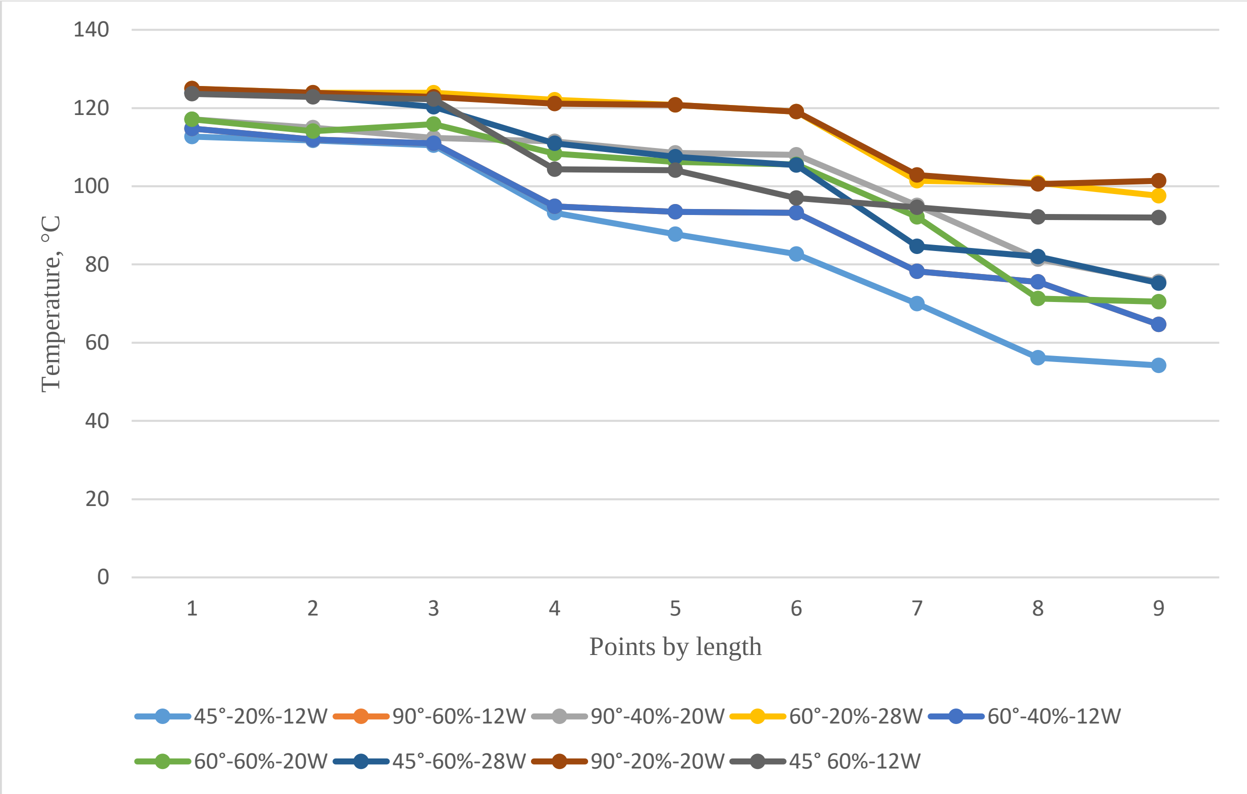


**Fig.2. The results of the experiment with water in the heat pipe (according to the experiment options).**

When water is used as the working fluid in the heat pipe, the highest temperature in the condensation part of the pipe corresponds to option 6 (90° relative to the horizon, 20% of the evaporator part is filled with liquid, heated with 20 W of electricity).

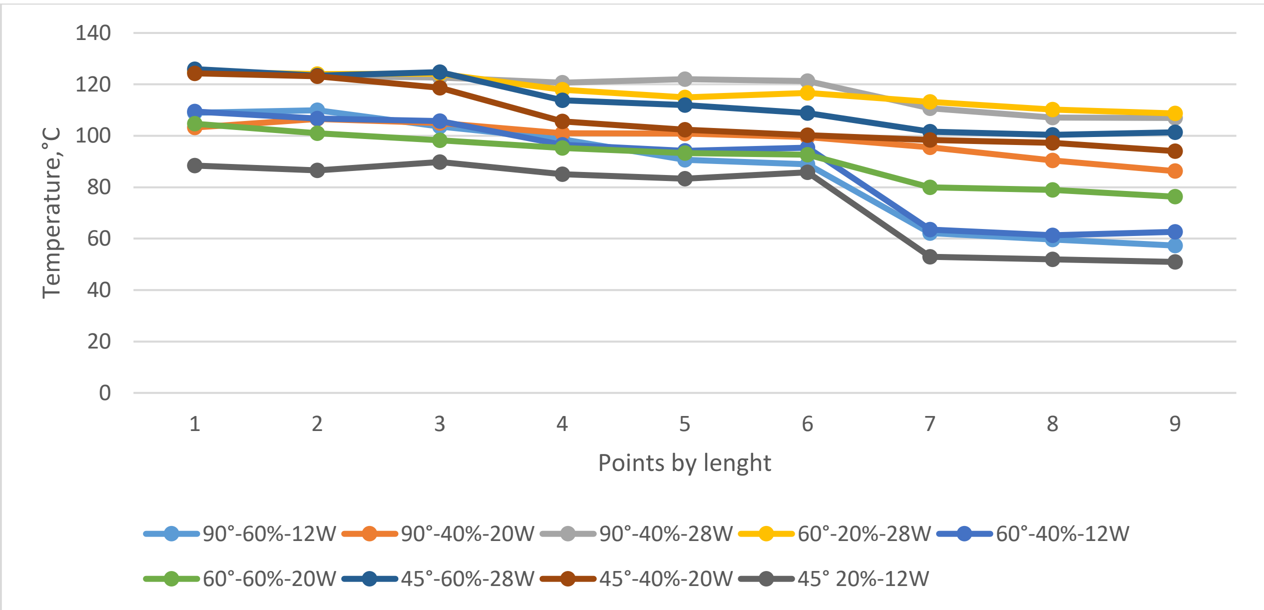


**Fig.3. The results of the experiment with anti-freezing liquid in the heat pipe (according to the experimental options).**

During experiments with anti-freezing liquid, the temperature rise in the condensing part of the heat pipe was recorded in option 8 (60° to the horizon, 20% of the evaporator section is filled with liquid, heated by 28W electricity) in the table of the Taguchi method, the highest indicators compared to other options.

Based on the conducted studies, the interrelationships of transferred useful power and COP (Coefficient of Performance) for cases where the working fluid is water and anti-freezing fluid in various combinations of the heat pipe are presented in Fig. 4 and Fig. 5. As can be seen from the graph of the results of the experiment for the anti-freezing liquid in Fig. 4, the COP of the heat pipe is the largest value when the power supplied from the heater is 12W. 3 experiments were conducted on the basis of 12W power, and among them, it can be seen that the COP of the device was 34.8% when it was installed at an angle of 90° and filled 20% of the evaporator section. In Fig. 5, it is shown that the COP of the device reached a high value when heat was applied to 12W power even in the heat pipe with water as the working fluid. But in this case, when 60% of the evaporator part of the heat pipe placed at an angle of 45° is filled, the COP is 34.8%.

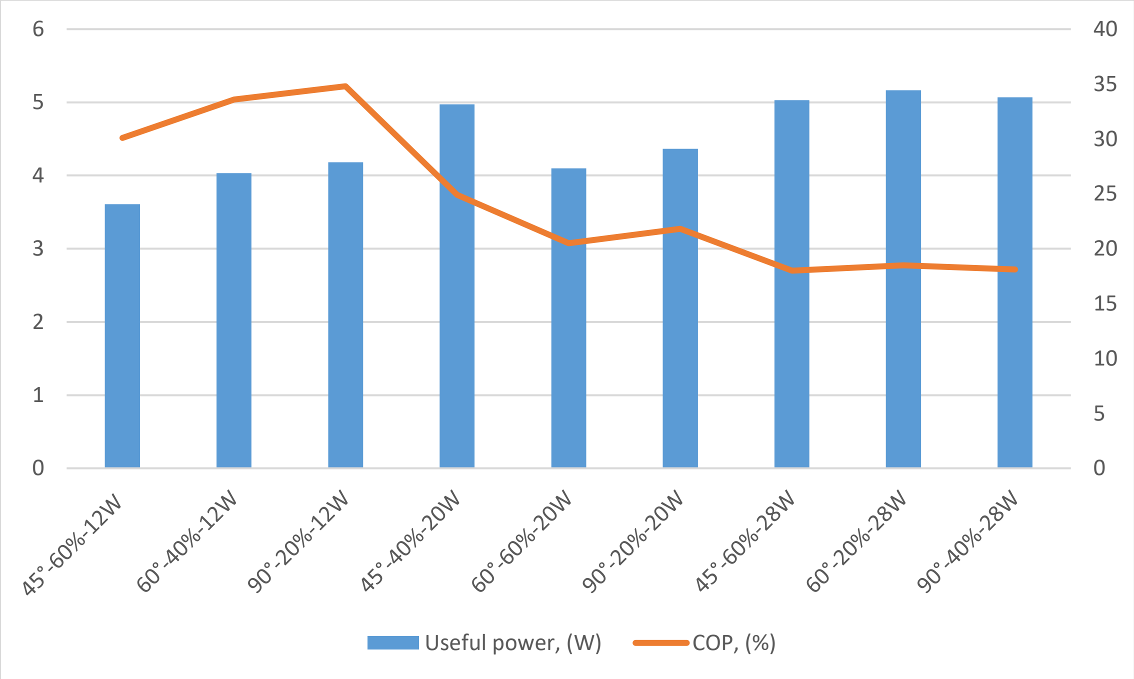


**Fig. 4. Useful power and COP transferred in a heat pipe where the working fluid is a anti-freezing fluid**

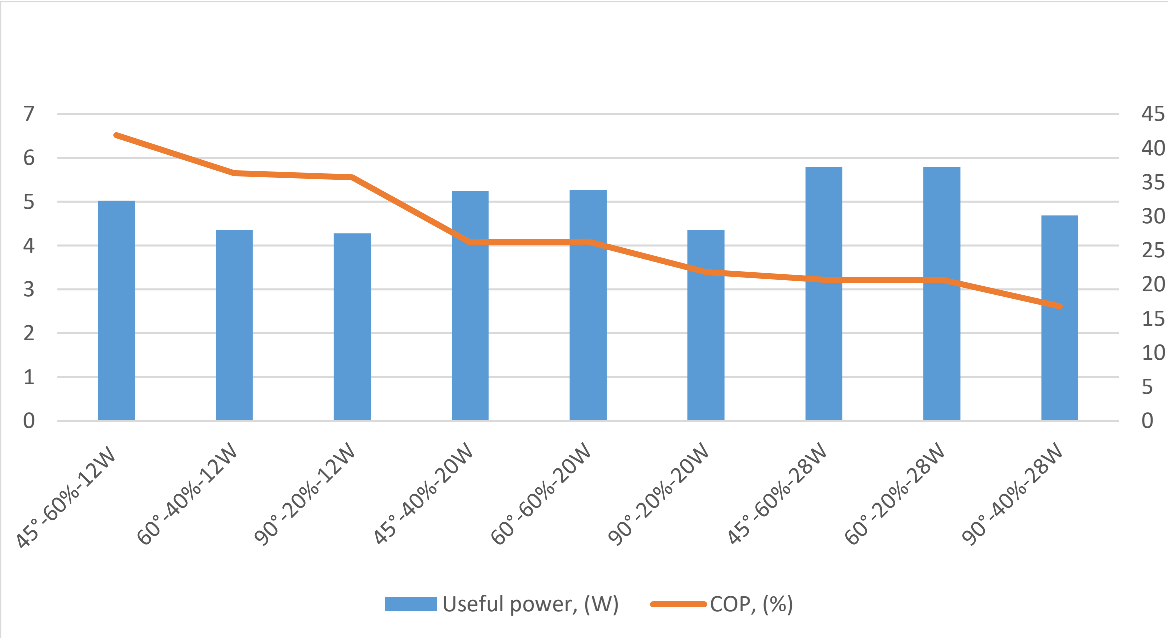


**Fig. 5. Useful power and COP transferred in a heat pipe with water as the working fluid**

From this, it can be concluded that when water is used as a working fluid in the heat pipe, when the amount of water is up to 60% of the evaporator, there is a high probability that the liquid is completely evaporated, and there is no heat-absorbing liquid left. Therefore, the given heat is spent inefficiently. When using anti-freezing liquid, it was observed that evaporation is slightly less than water.

## CONCLUSION

A heat pipe was prepared based on the analysis of the literature on the heat pipe. The Taguchi method (orthogonal experiment) was used in the experiments. Experiments were conducted in 9 options by calculating the combination of factors and levels using the Taguchi method. According to the results, in the experiment with anti-freezing liquid, the temperature in the condenser part of the heat pipe is the highest only in the 8th option, and in the experiments conducted with water, it is the highest in the 6th option, and it is in the range of 100-120°C, respectively.

## REFERENCES

1. IEA org [on the internet]. - https://www.iea.org/data-and-statistics/data-tools/energy-statistics-data-browser?country=UZBEKISTAN &energy =Electricity&year=2020 (15.06.2024).
2. H. Goudarzi, A.Mostafaeipour Energy saving evaluation of passive systems for residential buildings in hot and dry regions. Renew. Sustain. Energy Rev. 68, 2017.432–446.
3. R. Wrobel, D. Reay, A feasibility study of heat pipes for thermal management of electrical machines, IEEE Energy Conversion Congress and Exposition (ECCE) (2020) 4230–4237.
4. B. Suman, Modeling, experiment, and fabrication of micro-grooved heat pipes: an update, Appl. Mech. Rev. 60 (2007) 107–119.
5. Y. Yau, M. Ahmadzadehtalatapeh, A review on the application of horizontal heat pipe heat exchangers in air conditioning systems in the tropics, Appl. Therm. Eng. 30 (2010) 77–84.
6. B. Zohuri, Heat Pipe Design and Technology: A Practical Approach, CRC Press, 2011.
7. I.A. Aly Wael, A. Moustafa Elbalshouny, H.M. Abd El-Hameed, M. Fatouh Thermal performance evaluation of a helically-micro-grooved heat pipe working with water and aqueous Al2O3 nanofluid at different inclination angle and filling ratio //Applied Thermal Engineering 110 (2017) 1294–1304
8. Douglas C. Montgomery Design and Analysis of Experiments John Wiley & Sons, Inc. 2013.
9. Jasbir S. Arora Introduction To Optimum Design Academic Press is an imprint of Elsevier 2012