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Investigating the Dependence of the Transmitted Heat Output on the Position and Diameter of the Gravity Heat Pipe

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Abstract : Heat transport is one of the most basic needs of the present time. Depending on the distance, appropriate heat transfer systems are chosen. For relatively smaller distances, the use of heat pipes is ideal. They are devices using a phase change of the working substance. They do not contain moving parts, so they are almost trouble-free and maintenance-free. Due to their simple construction and function, they are also relatively cheap. This contribution deals with the analysis of the transmission capabilities of the gravity heat pipe depending on its diameter and the angle of rotation from the vertical plane. The material of the heat pipe is copper, and water was used as the working substance.

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1 Introduction

The general principle of heat pipes using gravity is usually classified as a two-phase thermosyphon. It dates back to the steam period. Then Angier March Perkins and his son Loftus Perkins created the "Perkins tube". This was extended to use in locomotive boilers and working furnaces. Capillary heat pipes were first designed by R.S. Gaugler at General Motors in 1942, who patented the idea but did not develop it further. A heat pipe is a heat transfer device that combines the principles of thermal conduction and phase change to effectively control heat transfer between two solid interfaces [1,2].

2 Heat Pipe

2.1 The Principle of Operation of the Heat Pipe

There is a liquid in the evaporative part of the heat pipe. It is in contact with a thermally conductive solid surface. By absorbing heat from this surface, it turns into steam. The vapor then passes along the tube to the condensing section, where it condenses back to a liquid and at the same time transfers latent heat. The liquid is then returned to the vapor section by capillary forces, centrifugal force or gravity and the cycle repeats. (Fig.1) Due to the very high coefficients of heat transfer during boiling and condensation, heat pipes are highly efficient heat conductors [3].

2.2 Heat pipe construction

A heat pipe consists of a closed tube made of a material that is compatible with the working fluid, such as copper and water working fluid or aluminum and ammonia tubes. A vacuum was used to remove air from the manufactured tube. The heat pipe was partially filled with working fluid and then sealed. The working fluid is chosen so that the heat pipe contains the working substance in both the gas and liquid phases within the range of operating temperatures. Working fluids are selected according to the temperatures at which the heat pipe must be in operation [4,5].

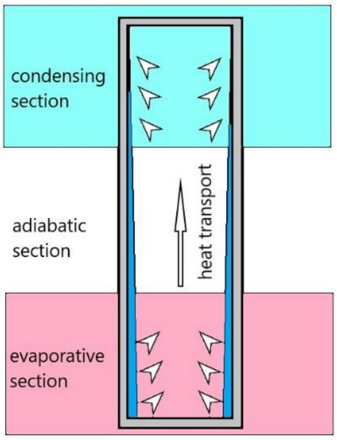

Figure 1 The principle of operation of the heat pipe

The advantage of heat pipes compared to other heat removal mechanisms is their high efficiency in heat transport. Heat pipes contain no mechanical moving parts and usually require no maintenance. The advantage of heat pipes is the quick onset of heat transfer, geometric shape, weight. Heat pipes are used to cool electronic devices and are increasingly used in computing. Another possibility of using heat pipes is in solar collectors, where a heat exchanger is arranged in the condensing part, which is heated directly by heat pipes [6,7].

3 Experimental Measurement

The calorimetric method of measuring with water was chosen for the experimental measurement. Copper gravity heat pipes with the same length of 50 cm were used for measurement. The heat pipes were of different diameters (DN12, DN15, DN18, DN22 and DN28). The working medium in the experimental measurements was distilled water, and the angle of inclination of the heat pipe was varied. For the sake of comparison, the heat pipes were produced with the same filling pressure of 800 Pa. The AMR WinControl program from the AHLBORN company was used to record the measured values. The measurement consisted of heating the evaporation section with a circulating medium with an inlet temperature of 80°C. Cooling of the condensing part was ensured by a circulating medium with an inlet temperature of 20°C. During the experiment, the water flow rate to the condenser was recorded.

Copper tubes of 50 cm length, copper end plugs and copper capillaries for filling were used for the experimental measurement. (Fig. 2). The working medium of the experimental measurements was distilled water. The amount of the working medium was chosen to be 25% of the volume of the heat pipe.

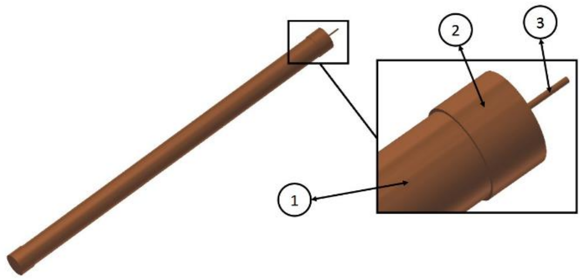

Figure 2 The experimental heat pipe consisted of 1 - a copper tube, 2 - a copper plug, 3 - copper capillaries

The calorimetric method was chosen to determine the transferred heat output. Since heat pipes transfer heat and form an isolated system subject to the law of conservation of energy, the calorimetric equation (1) can be used to obtain the results [8]. The law of conservation of energy states that all heat released from one body is transferred to another body [9]. We can assume that there is no change in the amount of energy, thermal energy cannot be changed into, for example, mechanical energy, and substances are chemically inert, they do not generate heat from chemical reactions:

$$\dot{Q} = \dot{m}.c.\Delta t \qquad (1)$$

where $\dot{Q}$ is the heat flow [W], $\dot{m}$ represents the mass flow [kg.s^{-1}], c represents the specific heat capacity of water at 20°C = 4183 [J.kg^{-1}.K^{-1}] and Δt represents the temperature gradient [K].

A measuring device (Fig. 3) was built for the experimental measurement. It consists of 1-protractor, 2-flow meter, 3-measuring the outlet temperature, 4-measuring the inlet temperature, 5-cooling part, 6-heating part, 7- cooled water source, 8 – source of heating water.

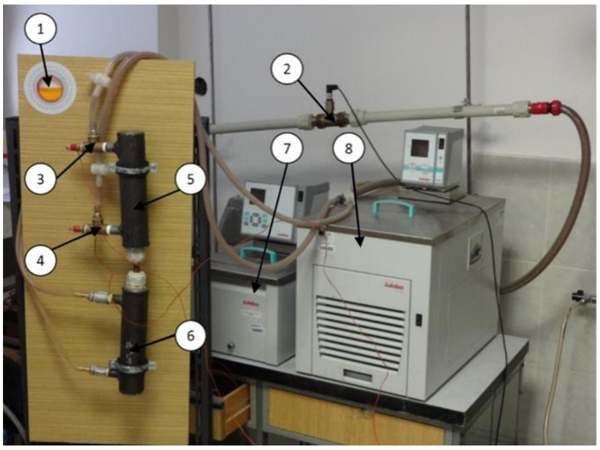

Figure 3 Experimental measuring device

4 Evaluation of the Measurement of Thermal Power Transmitted by a Heat Pipe

The experimental measurement confirms the assumptions that the largest diameter and different working position change the most the thermal power transmitted by the heat pipe. The main goal of the experiment was to find the ideal working position and ideal tube diameter. The heat pipe with a cross-section of 1 cm^2 transferred the greatest heat output. All heat pipes were filled to 25% of their internal volume. To determine the heat output, the mass flow rate and the inlet and outlet temperature of the cooling circuit were recorded.

Table 1 Temperature difference for different angle of rotation and different diameter of the heat pipe [K]

Angle of rotation (°)	DN 12	DN 15	DN 18	DN 22	DN 28
0	0.45	1.2	1.76	2	2.27
15	0.45	1.41	1.75	2.15	2.06
30	0.47	1.53	1.80	2.12	2.17
45	0.51	1.62	1.80	2.09	2.16
60	0.52	2.10	1.98	2.16	2.27
75	0.51	0.88	1.86	2.23	2.18

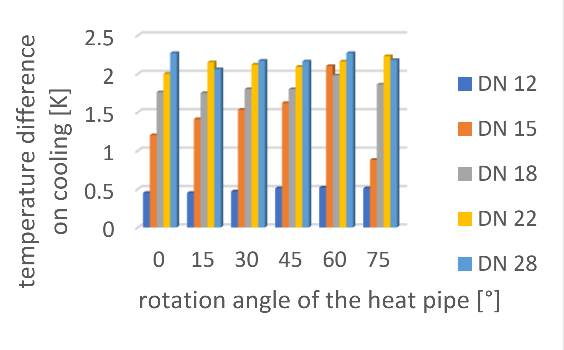

Figure 4 Graph of dependence of the angle of rotation, the diameter of the tube and temperature difference

Based on the results from the graph, the smallest difference in temperature difference is for the DN 28 heat pipe, depending on the diameter of the heat pipe and the angle of rotation during the measurement.

Table 2 The difference in flow volume for different angles of rotation and different diameters of the heat pipe [kg.s^{-1}].

Angle of rotation (°)	DN 12	DN 15	DN 18	DN 22	DN 28
0	0.0635	0.058	0.06	0.062	0.064
15	0.0635	0.054	0.06	0.062	0.064
30	0.0635	0.05	0.06	0.062	0.064
45	0.0635	0.05	0.06	0.062	0.064
60	0.0635	0.034	0.06	0.062	0.064
75	0.0635	0.063	0.06	0.062	0.064

Tab. 2 shows the average value of the mass flow, which was the same during the entire measurement.

To evaluate the measurement, relation (1) was used, where the specific heat capacity of water at 20°C was c = 4183J.kg^{-1}.K^{-1}.

Table 3 Transmitted heat power for different angle of rotation and different diameter of heat pipe [W]

Angle of rotation (°)	DN 12	DN 15	DN 18	DN 22	DN 28
0	112.8	291.92	445.12	516.3	604.7
15	120.8	318.27	442.44	556.12	548.08
30	125.1	318.58	454.41	548.74	577.58
45	135.1	333.57	454.37	541.32	575.21
60	138	296.03	500.55	559.53	604.32
75	136.3	230.64	470.27	575.93	578.19

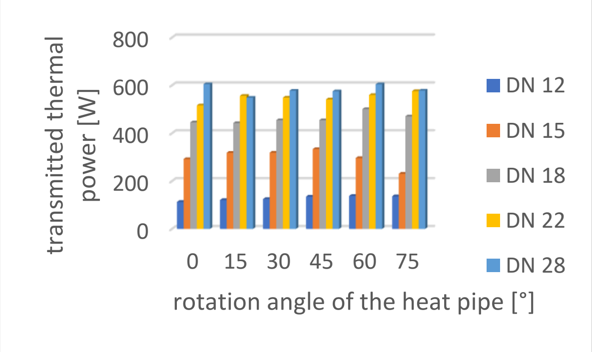

Figure 5 Graph of the dependence of the angle of rotation, the diameter of the tube and the transferred thermal power

In fig. 5 shows the average value of the heat output of the heat pipe when different diameters and working positions were used. The largest diameter was expected to have the greatest heat output. For this reason, the heat output per 1cm^2 was determined.

Table 4 Transmitted heat power per 1cm^2 for different angles of rotation and different diameters of the heat pipe [W.cm^{-2}]

Angle of rotation (°)	DN 12	DN 15	DN 18	DN 22	DN 28
0	99.74	165.20	174.90	135.83	98.2
15	106.8	180.12	173.85	146.31	89.00
30	110.64	180.29	178.55	144.37	93.79
45	119.41	188.78	178.54	142.41	93.41
60	122.03	167.53	196.68	147.20	98.14
75	120.5	130.52	184.78	151.52	93.89

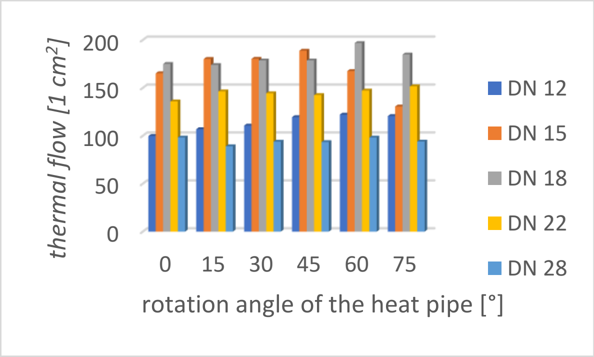

Figure 6 Graph of the dependence of the angle of rotation, the diameter of the tube and the transferred thermal power per 1 cm^2

In fig. 6 shows the difference between the working position and the different pipe diameter.

The best working position for the gravity heat pipe is approximately 60 degrees, and the best results in terms of length and diameter are shown by the heat pipe with a diameter of DN 18, where the maximum transferred heat output per 1 cm^2 was 196.68 W.cm^{-2}.

The heat pipe with a diameter of DN 28 comes out as the worst, where although the total transferred heat output is the largest, but compared to the transferred heat output per 1 cm^2 cross-section, this output is the smallest.

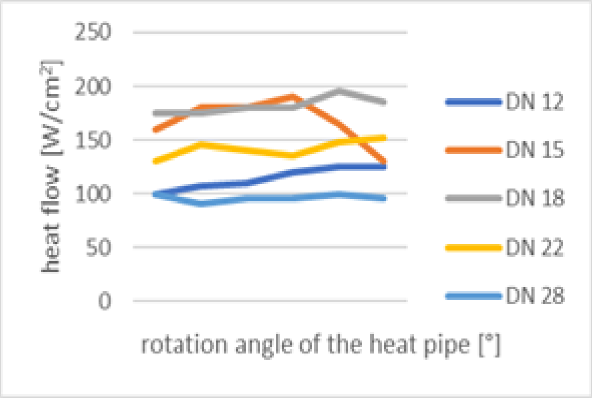

Figure 7 Graph of the increase in heat output per 1cm^2 depending on the angle of rotation and the diameter of the tube

Fig. 7 shows the increase in heat output when the diameter of the tube changes. The graph shows that the best working position for heat pipes is around 45 to 60 degrees, and the best working diameter for gravity heat pipes is a DN15 heat pipe up to a rotation angle of 45° and a DN18 heat pipe at a rotation angle of 60°.

5 Conclusion

During the experimental measurement, the influence of the diameter, type of gravity heat pipe and its working position on the ability to remove heat from the cooled device was determined. During the measurement, it was found that the expansion of the diameter also increases the transmitted power of the gravity heat pipes. The greatest increase in the transferred heat output of 604.7W was achieved by the gravity heat pipe with a diameter of DN28 with a vertical working position, but in comparison of the transferred heat output per 1 cm2 of the cross-sectional area, the highest transferred heat output with a value of 196.68 W was achieved by the gravity heat pipe with a diameter of DN18 with working position 60 degrees.

6 The reference list

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