Performance Analysis of a Two-Turn Oscillating Heat Pipe under Various Filling Ratios and Power Intensities

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ABSTRACT

In this study, the performance of a two-turn oscillating heat pipe was examined under different filling ratios and power intensities. The heat pipe had an inner diameter of 2 mm and an outer diameter of 4 mm, consisting of three sections: evaporator, adiabatic, and condenser. To evaluate the effect of filling ratio and power on heat transfer, filling ratios of 0%, 30%, and 50% were tested at power levels of 5 and 10 watts. The results showed that increasing the filling ratio led to lower temperatures in the evaporator, adiabatic, and condenser sections, and thermal stability was achieved more quickly. Additionally, increasing the power input caused a rise in the evaporator temperature, but the condenser temperature significantly decreased with higher filling ratios. These findings indicate that optimizing the filling ratio can enhance the performance of heat pipes.

Keywords: *Oscillating heat pipe, Evaporator, Condenser, Heat pipe*

1. *INTRODUCTION*

Heat transfer and cooling of equipment are among the key challenges in modern engineering. Heat pipes are an efficient, simple, and cost-effective method for heat transfer and cooling of devices. These pipes stand out from other methods due to their ability to transfer large amounts of heat over long distances without the need for external power input [1, 2]. The operation of heat pipes is based on a combination of convective and conductive heat transfer, creating a more complex process. In these systems, heat is transferred to one end of the pipe, causing the internal fluid to evaporate and the vapor pressure to increase. This vapor pressure drives the fluid towards the cooler region, where condensation occurs, releasing latent heat and raising the temperature in that area. Due to the high heat transfer efficiency of evaporation and condensation processes, heat pipes are capable of transferring significant amounts of heat. To maintain balance in these processes, the heat transfer surface in both sections of the pipe is adjusted to equalize the rates of evaporation and condensation. Each heat pipe generally consists of three main sections, as shown in Figure 1(a) [3]. Oscillating heat pipes, a more complex variant of this technology, are influenced by various factors such as internal diameter, number of bends, working fluid type, and orientation angle, all of which directly affect their performance. In these pipes, the working fluid moves through specially designed channels, and heat transfer occurs through phase change and fluid displacement. When the evaporator section is exposed to heat, the working fluid evaporates, causing a rise in vapor pressure. This leads to bubble formation and liquid displacement towards the condenser section, as depicted in Figure 1(b) [4].

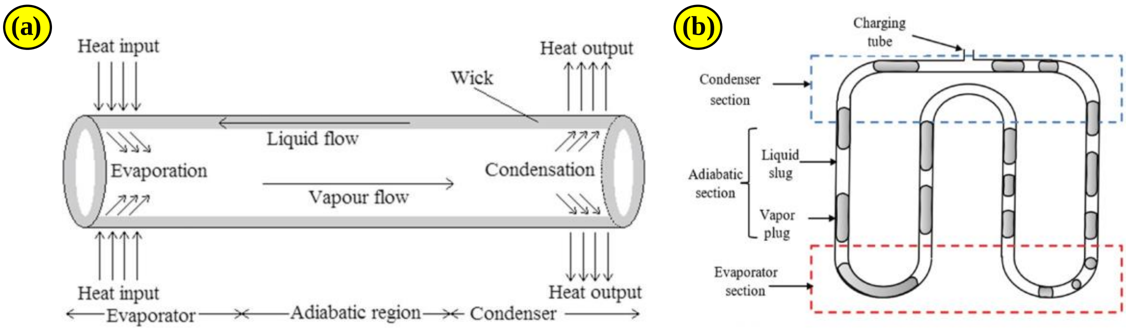

Fig 1: (a) Structure of a heat pipe (b) Schematic of an oscillating heat pipe

The first engineering application of oscillating heat pipes (OHPs) was introduced by Akachi in 1990, who designed 24 prototypes known as rotating heat pipes. These pipes incorporated a one-way valve to ensure unidirectional flow and had a minimum internal diameter of 2 mm, as smaller diameters led to decreased performance. Akachi [5] claimed that these new heat pipes could address the limitations of conventional heat pipes and that working fluids, which were inefficient in traditional designs, would perform better in these innovative models. Following this, Rittidech et al. [6] investigated the effects of various factors such as internal diameter, evaporator length, working fluid type, and the number of turns on the heat flux in oscillating heat pipes. Their findings revealed that increasing the latent heat of evaporation of the working fluid enhances the maximum input power to the evaporator, while extending the evaporator length reduces the critical heat flux. Charoensawan et al. [7] further explored closed-loop copper oscillating heat pipes using water, ethanol, and R-123 as working fluids with two different internal diameters. They discovered that increasing the number of bends beyond a critical value improved the performance of the heat pipes, even when positioned horizontally. In their experiments, they kept the filling ratio constant at 50% and adjusted the temperatures of the evaporator and condenser instead of varying the heat input. In a related study, Tong et al. [8] examined flow conditions in oscillating heat pipes using a pipe with an internal diameter of 1.8 mm. Their research demonstrated that irregular distribution of bubbles and droplets, along with asynchronous boiling, were crucial factors influencing liquid pumping and oscillation within the pipe. Additionally, they found that a minimum heat input was necessary to initiate fluid oscillation in the heat pipe. In this study, the experimental performance of an oscillating heat pipe is investigated at filling ratios of 0%, 30%, and 50%, with input powers of 5 and 10 watts. The thermal behavior of the heat pipe in the evaporator, adiabatic, and condenser sections is examined.

2. *EXPERIMENTAL SETUP*

In this study, a two-turn oscillating heat pipe with an internal diameter of 2 mm, an external diameter of 4 mm, and a turn height of 300 mm was designed and constructed. As shown in Figure 2, the pipe consists of three sections: the evaporator, adiabatic, and condenser sections, each with a length of 100 mm. The temperature of these three sections was recorded using sensors T1 to T4, as illustrated in Figure 2(a). Deionized water was used as the working fluid in this system. The evaporator, located at the bottom of the pipe, is responsible for absorbing heat and evaporating the fluid. In this section, the fluid reaches its boiling point and evaporates upon receiving heat. The required heat for this section is supplied by a nickel-chromium heating wire wrapped around the copper pipe. To prevent heat loss, the evaporator is insulated with fiberglass, ensuring that all energy is transferred to the fluid, as shown in Figure 2(b). The vapor produced then passes through the adiabatic section, which is 100 mm long, and reaches the condenser. The adiabatic section is insulated to prevent heat loss, and no heat exchange occurs in this region. In the condenser, the vapor releases the absorbed heat from the evaporator to the surroundings and condenses back into liquid form, releasing the latent heat of evaporation in the process. When filling the pipe with the working fluid, it is essential to ensure the system is free of air, as the presence of air can alter the two-phase flow properties. To achieve this, a vacuum pump was used to evacuate the system and reduce the operating pressure, which leads to an increase in the frequency and speed of oscillations. To create a vacuum and ensure proper sealing, the copper pipe joints were connected using silver soldering. Additionally, a pressure gauge was employed to measure the pressure throughout the experiment.

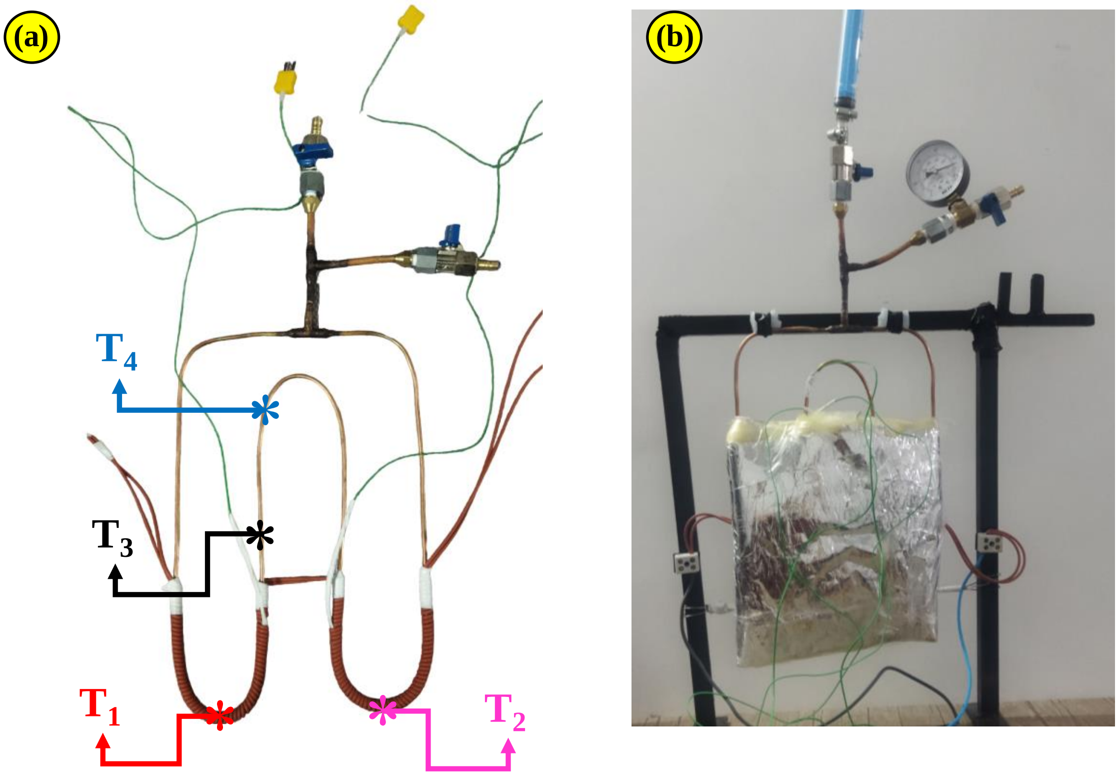

Fig 2: (a) Actual view of the system and the placement of sensors (b) View of the insulated system

3. *RESULTS AND DISSCUTION*

In this section, the performance of the heat pipe at different filling ratios and power intensities is investigated. Initially, to evaluate the heat transfer performance of the copper pipe, a filling ratio of zero percent was examined. As shown in Figures 3a and 3b, this test was conducted over 90 minutes at an ambient temperature of 30°C. The results of the 5-watt test indicated that the evaporator temperature stabilized at around 72°C after approximately 40 minutes, while the condenser temperature stabilized at around 44°C after 45 minutes. However, with an increase in power to 10 watts, the evaporator temperature stabilized at around 100°C after 30 minutes, whereas the condenser temperature reached approximately 68°C after one hour and remained stable. These results demonstrate that with an increase in power input, the temperatures of both the evaporator and the condenser rise, but the time required for the condenser to stabilize is longer compared to the evaporator.

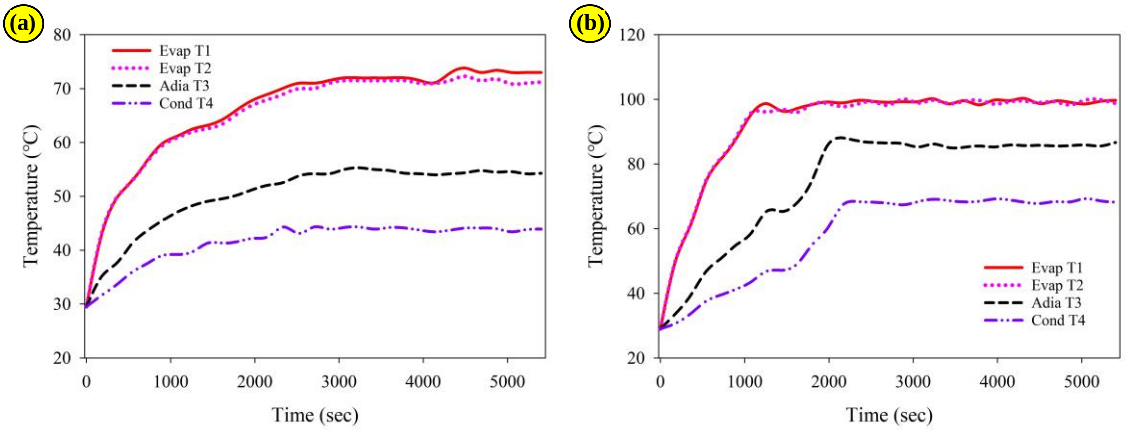

Fig 3: (a) Temperature vs. time at 5W power, zero filling ratio. (b) Temperature vs. time at 10W power, zero filling ratio.

As shown in Figure 4, after examining the temperature variations in empty pipes, the temperature changes at filling ratios of 30% and 50% were also evaluated. According to the results in Figure 4(a), for a power input of 5 watts and a 30% filling ratio, the evaporator temperature increased to 72°C, similar to the empty pipe, and then stabilized. However, the evaporator temperature at this filling ratio stabilized 10 minutes earlier than at a zero percent filling ratio. The condenser temperature at a 30% filling ratio stabilized at 40°C after 40 minutes, which is 4°C lower than the zero percent filling ratio. Additionally, the adiabatic section's temperature decreased by 4°C, dropping from 55°C at zero percent to 51°C at a 30% filling ratio. With an increase in power to 10 watts at a 30% filling ratio (Figure 4(b)), the evaporator and condenser temperatures stabilized after 30 minutes at 104°C and 49°C, respectively. The condenser temperature decreased by 19°C compared to the zero percent filling ratio, while the evaporator temperature increased by only 4°C. As shown in Figure 4(c), with a filling ratio of 50% and a power input of 5 watts, the evaporator temperature stabilized at 69°C after 50 minutes, while the adiabatic and condenser temperatures stabilized 20 minutes earlier at 47°C and 37°C, respectively. Then, as seen in Figure 4(d), with an increase in power to 10 watts, the evaporator temperature rose to 102°C during the first 30 minutes, while the adiabatic and condenser sections increased to 65°C and 45°C, respectively, over the same period. Overall, the results indicate that increasing the filling ratio at constant power intensities enhances heat transfer and reduces the temperatures in all three sections of the heat pipe: the evaporator, adiabatic, and condenser regions.

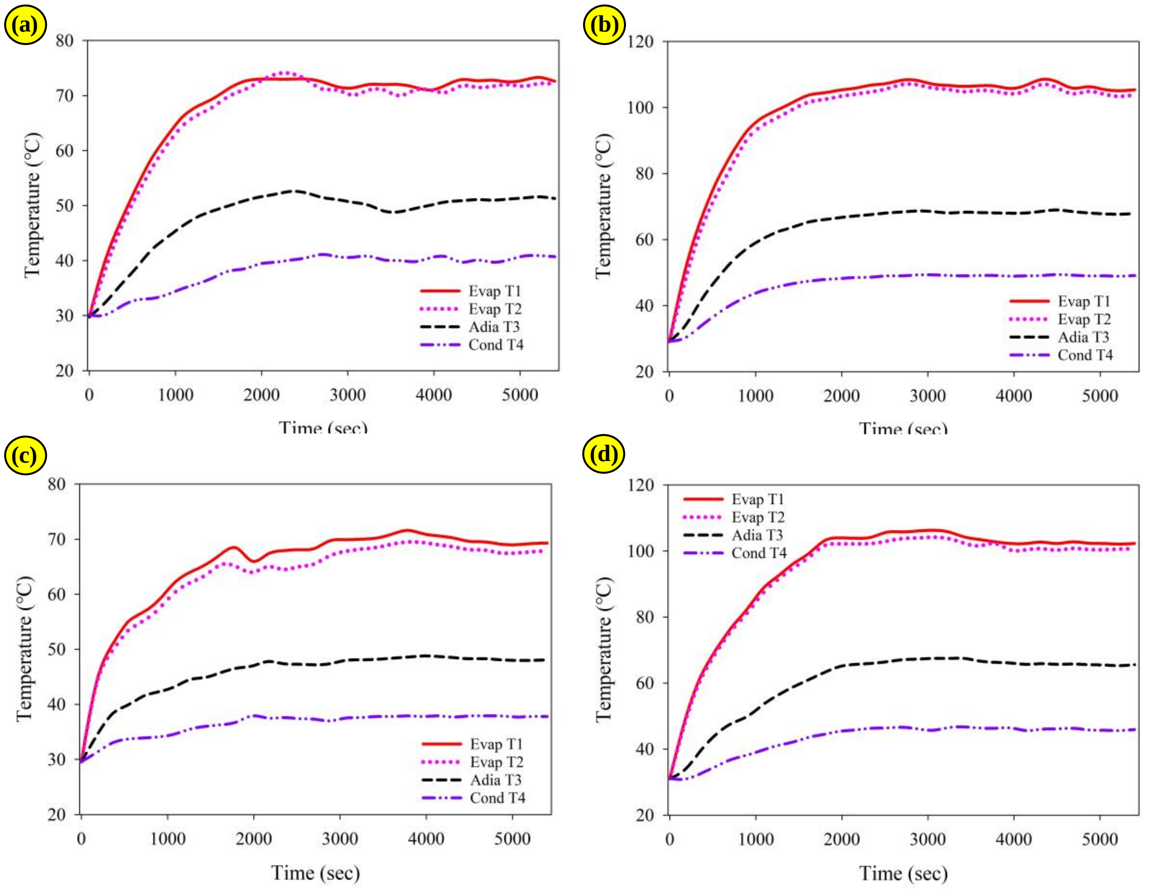

Fig 4: (a) Temperature vs. time at 5W power, 30% filling ratio. (b) Temperature vs. time at 10W power, 30% filling ratio. (c) Temperature vs. time at 5W power, 50% filling ratio. (d) Temperature vs. time at 10W power, 50% filling ratio.

4. *CONCLUSION*

The results of this study demonstrate that the filling ratio plays a crucial role in improving the performance of heat pipes. As the filling ratio increased from 0% to 30% and 50%, the temperatures in various sections of the pipe decreased, resulting in more efficient heat transfer. Moreover, increasing the power input to 10 watts raised the evaporator temperature, but due to the higher filling ratio, the condenser temperature significantly decreased. This reduction in condenser temperature contributes to improved overall system efficiency and enhanced heat dissipation capability. Ultimately, it can be concluded that optimizing both the filling ratio and power input is essential for designing efficient heat pipes for industrial and research applications.

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