Performance Study of Solar Heat Pipe with Different Working Fluids and Fill Ratios

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Abstract. This paper elaborates on the testing of solar heat pipes using different working fluids, fill ratios and tilt angles. Methanol, Acetone and water are used as working fluids, with fill ratios 25%, 50%, 75% and 100%. Experiments were carried out at 60° and 35° inclinations. Heat pipe condenser section is placed inside a water basin containing 200ml of water. The evaporator section is exposed to sunlight where the working fluid gets heated and it becomes vapour and moves towards the condenser section. In the condenser section the heat is given to the water in the basin and the vapour becomes liquid and comes back to the evaporator section due to gravitational force. Two modes of experiments are carried out: 1) using a parabolic collector and 2) using heat pipe with evacuated tubes. On comparative study, optimum fill ratio is been found to be 25% in every case and acetone exhibited slightly more efficiency than methanol and water. As far as the heat pipe orientation is concerned, 60° inclination of the heat pipe showed better performance than 35°.

1.Introduction

The heat pipe is a highly effective device which can be used to transmit heat. Generally heat pipes are circular in shape due simplicity of manufacturing and design. Heat pipe has mainly three components a container, a wick and some amount of working fluid. Different types of working fluids, such as acetone, methanol, ammonia, sodium or even water can be used in heat pipes based on the required operating temperature. In case of a wickless heat pipe, the main driving force is gravitational force. So for the proper working of the heat pipe the condenser section must be always kept above the evaporator section. For the solar application we use a two phase closed thermosyphon heat pipe as the solar collector. It is a gravity assisted wickless heat pipe as shown in figure.1. In this type of heat pipes it has only two parts the evaporator section and the condenser section. Since the condensate is returned by the gravitational force, the condenser is always kept above the evaporator section. Operation of the thermosyphon heat pipe is sensitive to the fill ratio and the inclination of the heat pipe. Since gravity is the major driving force in a thermosyphon heat pipe, capillary force doesn’t have much effect on the returning of condensate.
Experimental analysis of a solar collector using heat pipes with different concentration of water and ethanol as the working fluid were carried out by [1] et al. He used 25% fill ratio for the experiment and tested for different proportions of water ethanol solution and found 50-50% of the water and ethanol solution proved to be the most efficient. They also conducted experiments with different tilt angles and found 35\(^\circ\) the best one and found that the wick and water flow does not have much effect on the performance of the heat pipe. [2] et al. analysed the heat transfer capacity of horizontal solar heat pipe and concluded that when the fill ratio must be 19 to 22% of the inner diameter of the heat pipe for the best performance. [3] et al. found a new system for desalination by the combination of heat pipe, parabolic collector and evacuated tubes. An aluminum foil is placed between the evacuated tubes and heat pipe and it conducts the heat from evacuated tubes to the heat pipe. They also conducted the experiments with different fluids like oil and water instead oil aluminum foil for filling the space between the heat pipe and the evacuated tubes. They concluded that the system which contains 150ml of water in the basin and filled with oil showed the maximum production rate than the aluminum foil. Performance analysis of a miniature heat pipe for different fill ratios and working fluids were conducted by [4] et al. They used acetone, methanol and water as the working fluids and tested with different fill ratios. They concluded that with acetone 100% fill ratio of the evaporator section showed the best performance. [5] et al. studied about the integrated heat pipe as a solar collector. The heat pipes are inclined 60\(^\circ\) to the horizontal. They found that for a seven hour of solar radiation the temperature in the basin was increased by 25\(^\circ\)C and the collector efficiency reached a 66% by employing new type of solar collector. [6] et al. studied the effect of length to diameter ratio of a heat pipes. He has done experiments with different types of L/d ratios and found that L/d ratio equal to 52.63 found to be the most efficient.

The present study aims to obtain the best suitable combination of solar collectors, working fluids, fill ratios and tilt angles for the purpose of water desalination or water heaters. Methanol, Acetone and water are used as working fluids, with 25%, 50%, 75% and 100% fill ratios. 60\(^\circ\) and 35\(^\circ\) inclination experimentations were carried out.

2. Experimental Setup

The experimental setup was fabricated and tested at Amrita School of Engineering, Bangalore, located 930m above the sea level. For the heat pipes, two copper tubes of diameters 1.9cm and 15cm, length 1.4cm and 75cm were brazed together. The 15cm portion served as the condenser section and the 75cm portion as the evaporator section. The top region of the condenser section was completely brazed to prevent air and fluid leakage. The bottom end of the evaporator section was brazed with a nut, in which the bolt can be tightly fitted for closing of the evaporator section. In order to seal the
heat pipe with working fluid in it, the filled condenser section was first heated using a heating coil, keeping the evaporator section above. Meanwhile, end of the evaporator section was held shut with a thumb. When the vapour of the working fluid produced a pressure on the thumb, the end was tightened firmly with a bolt. Care was taken to avoid any leakage of the working fluid from the heat pipe. The evaporator section of the heat pipe was exposed to the sunlight for the maximum absorption of the heat radiation and the condenser section of the heat pipe was fully immersed in a water basin of 200ml. The water basin covered the condenser section completely and was made of a PVC pipe of diameter larger than the condenser section. Both the heat pipes used in the present study were made this way and are of the thermosyphon type, with no wick and works on gravity force. Because of this, the condenser section must be always kept above the evaporator section for the proper working of the heat pipe. The working fluids used were acetone, methanol and water. Acetone has a boiling point of 56°C and methanol 64°C. Experiments were done with 25%, 50%, 75% and 100% volume of the evaporator filled with the working fluids. The experiments were conducted for a period of two hours, from 12.00pm to 2.00pm during December 2015 to May 2016.

2.1 Fabrication of Parabolic Collector
The heat pipe was first kept in a parabolic collector and tested for different working fluids and fill ratios. The parabolic collector was kept at an angle of 60° inclination to the horizontal, facing the south as shown in figure.2. The temperature of water in the basin was measured using a mercury thermometer. The evaporator section temperature was measured using a K type thermocouple. The experiments were conducted for a period of two hours, from 12.00pm to 2.00pm. A solar flux meter is used to measure the intensity of solar radiation and is measured in W/m².

2.2 Fabrication for Testing of Evacuated Tubes
The evaporator section of the heat pipe was completely kept inside the evacuated tube and the condenser section was kept inside the water basin as shown in figure.3. The evacuated tube is of 150cm length and its inner and outer diameters are 3.7cm and 4.7cm. The outer sides of the twin glass evacuated tubes have a dark colour metal coating for effective absorption of sunlight. Experiments with different fill ratios and working fluids are done in this case also. The evacuated tubes are placed on an iron frame at 35° and 60° angles to the horizontal.
3. Result and Discussion

3.1 Using Parabolic Collector

3.1.1 Acetone as Working Fluid. First the experiments were done using parabolic collector with different fill ratios using acetone as the working fluid. In case of parabolic collector, there is gradual increase in the performance of the heat pipe with the increase in the fill ratio as shown in figure 4. From the graph we can see that 100% fill ratio showed proved to be more efficient and it shows a temperature of 60°C at the end of the experiment. Wet run condition is heat pipe filled with water also showed almost same temperature as that of 100%. 25% and 75% fill ratio showed almost similar temperature of 54°C. In case of 50% fill ratio, it showed an increase in the temperature for the first hour and it gradually decreases at the end of the experiment. Dry run condition, that is without any working fluid showed the least temperature 47°C.

3.1.2 Methanol as Working Fluid. The experiments were carried out using parabolic collector with different fill ratios using methanol as the working fluid is shown in figure 5. Both the experiments, using methanol and acetone were carried out in the same conditions. Here also the fill ratio has a significant effect on the performance of the heat pipe. 100% fill ratio proved to be the most efficient and it showed a temperature of 60°C. It showed same temperature as that of acetone as the working fluid. Wet run condition showed almost similar temperatures as that of 100% fill ratio. 25% and 75% fill ratio showed almost similar temperatures but it showed a 30°C less temperature than in the case of the acetone as the working fluid. Same as in case of acetone 50% fill ratio showed an increase in temperature for the first one hour and later it starts decreasing and reaches a temperature of 50°C.

3.2 Using Evacuated Tubes

3.2.1 Acetone as Working Fluid. In case of heat pipe with evacuated tubes 25% fill ratio proved to be the most efficient and it showed a temperature of 85°C is shown in figure 6. In case of 50% fill ratio for the first one hour it showed a temperature of around 80°C and after that the temperature reduced and reaches 70°C. 75% and 100% fill ratio showed almost similar characteristics and almost same temperature. A fast increase in the temperature was shown by 100% fill ratio for the first hour but the rate of increase in temperature decreased afterwards. In case of 75% fill ratio it showed steady increase in the temperature throughout the experiment. Wet run condition also showed similar temperature as that of 100% fill ratio. The least temperature was shown by dry run condition and is about 65°C.
3.2.2 Methanol as Working Fluid. When Methanol is used as working fluid, the system showed almost similar performance as in the case of acetone. Initially a fast response in the performance was shown by acetone but at the end both working fluids reaches almost similar temperature as shown in figure.7. In case of methanol and acetone 25% fill ratio proved to be most efficient. 75% and 100% fill ratio showed almost similar temperatures as that of the acetone. 50% fill ratio showed the same decline in the temperature after one hour as in the case of acetone.

![Figure 6](image1.png) **Figure 6.** Variation of water temperature with time for varying fill ratios (acetone).

![Figure 7](image2.png) **Figure 7.** Variation of water temperature with time for varying fill ratios (methanol).

3.3 Comparison of Acetone And Methanol With 25% Fill Ratio Using EVC

From the experimental results we can see that the heat pipe coupled twin evacuated tubes with 25% fill ratio proved to be the most efficient. 25% fill ratio shows a consistent and a steady increase in the temperature as shown in figure.8. By comparing the working fluid acetone and methanol we can see that the heat pipe using acetone as the working fluid showed a sudden increase in the temperature of water than the methanol. There is always a 2 to 4°C temperature difference between the acetone and methanol heat pipe. At the end we can see that both acetone and methanol heat pipe showed almost a same temperature of 84°C.

3.4 Comparison of Parabolic Collector And Evacuated Tubes With 25% Fill Ratio.

Heat pipe with evacuated tube showed 30°C more temperature than the heat pipe using parabolic collector as shown in figure.9. From the beginning of the experiment itself heat pipe with evacuated tubes was leading the temperature. For the first 30min itself heat pipe with evacuated tubes got 10°C more temperature than the parabolic collector. After one hour it showed a temperature difference of more than 25°C and at the end the experiment it showed a temperature difference of 30°C.

3.5 Comparison of 60° And 35° Inclinations With 25% Fill Ratio.

The heat pipe with evacuated tubes is tested for two inclinations 60° and 35° to determine the effect of inclinations on the heat pipes. Here 25% fill ratio is used for testing and is shown in the figure.10. For the first 30min a large increase in the temperature was shown by 35° inclinations and it leads by a temperature of 15°C than the 60° inclination. But after one hour the 60° inclination shows slight increase in the temperature than the 35° inclination. After one hour the rate of increase in the temperature starts to decrease in case of 35° inclinations but almost a steady rate of increase in temperature was shown by 60° inclinations. At the end of the experiment 60° inclinations leads the 35° inclination by a temperature of 6°C.
4. Conclusion

From the present experimental study, we can conclude that the working fluid, filling amount, mode of collector and inclination angles have a significant effect on the performance of the heat pipe. Heat pipe with evacuated tubes showed a greater performance compared to the parabolic collector. About 30°C increase in temperature was obtained by using evacuated tubes as the collector. When the level of the working fluid is about 25% of the evaporator volume, the heat pipe showed maximum efficiency and consistency. Though a rapid increase in the performance was shown by acetone initially, by the end acetone and methanol showed almost similar temperature. As working fluids, both acetone and methanol showed better performance than water. In addition, it was also clear that the solar heat pipe is sensitive to angle of orientation. A 60° inclination proved to be more efficient and consistent than 35° inclination.

5. References

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Figure 8. Variation of water Temperature with time for 25% fill ratio.

Figure 9. Variation of water Temperature with time for parabolic and EVC tubes.

Figure 10. Variation of water Temperature with time for 60° and 35° inclinations.
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