

1.3 Working Fluid Filling Ratio

Another critical parameter which affects the performance of a pulsating heat pipe is the fill ratio of the working fluid. The fill ratio is defined as a percentage of the total inner volume of the system. There has been significant research already performed on the operational limits of a Pulsating Heat Pipe and how it is affected by the fill ratio. At a 0% filling ratio, which means no working fluid is present, a heat pipe system behaves as a pure conduction mode heat transfer device [5].

At a 100% filled heat pipe system the operation observed is similar to a single phase thermosyphon. In this situation the desired pulsating effect is nonexistent, however studies have been performed that have shown substantial heat can be transferred due to liquid circulation in the tubes by thermally induced buoyancy. The ideal working range of a Pulsating Heat Pipe is between approximately 20 to 70% filled ratio. Within this range the system performs like an accurate pulsating structure. The ideal range differs for different systems, orientations, working fluids, and operating parameters [7].

1.4 High value of dP/dT

Ensuring that a small change in $T_{\text{evaporator}}$ generates a large corresponding to saturation pressure inside the generated bubble which aids in the bubble pumping action of the device. The same is true in reverse manner in the condenser [8].

1.5 High Specific Heat

It is desirable, given the fact that sensible heat is playing the major role in heat transfer in the pulsating mode of pulsating heat pipe operation; although there are no specific studies which explicitly suggest the effect of specific heat of the liquid on the thermal performance. It is to be noted that if a flow regime change from slug to annular takes place the respective roles of latent and sensible heat transport mechanism may considerably change [9].

1.6 Low Surface Tension

Low surface tension in conjunction with dynamic contact angle hysteresis may create additional pressure drop. The closed loop pulsating heat pipe can be tested by using different working fluids: isopropyl alcohol, propanol, ethanol, methanol, acetone and water. These fluids can be selected according to their Clausius-Clayperon relation and also for the maximum saturation pressure at the evaporation section temperatures. The pulsating heat pipe was under vacuum before charging it with any working fluid, which was able to hold a vacuum level of 10^{-3} mbar.

1.7 Reliability

If the heat pipe material(s) are compatible with the working fluid, they can be expected to provide highly reliable heat transfer performance within their operating limits for years..

The copper/water materials used in heat pipes employed in notebooks technology.

2. Effect of Working Fluid on Thermal Performance

Figure below shows the plot of thermal resistance with heat input for different working fluid at 60 % fill ratio. From the figure it is clear that the thermal resistance decreases with increases in heat input. As the temperature difference between evaporator and con denser is less for acetone, the thermal resistance is also very less. It indicates that acetone is best working fluid compared to other working fluids in heat transfer capability.

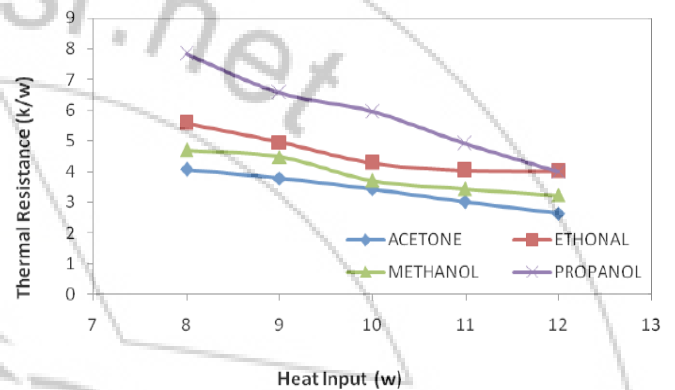


Figure 2: Effect of working fluid on thermal performance

3. Effect of Working Fluid on Heat Transfer Coefficient

Figure below shows the plot of heat transfer coefficient with heat input for different working fluid at 60 % fill ratio. Figure below shows heat transfer coefficient increased with increased in heat input for all working fluids. It is seen that acetone is having higher heat transfer coefficient compared to all other working fluids. As the temperature difference between evaporator and condenser is decreases for acetone the heat transfer coefficient will increases.

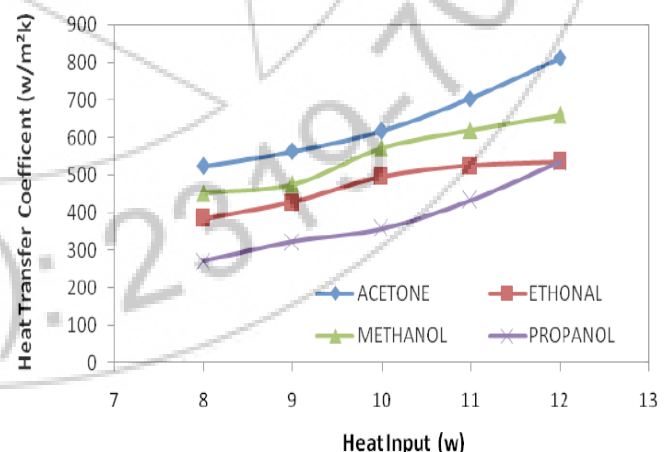


Figure 3: Effect of working fluid on heat transfer coefficient

4. Pure Working Fluids of Closed Loop Pulsating Heat Pipe

Fig. show T_c and T_e of pure working fluids pulsating heat pipe with the filling ratio of 60% and different power inputs. The thermal resistances have the results of $R_{acetone} < R_{methanol} < R_{ethanol} < R_{water}$. For power input less than 60W, T_e , water is higher than T_e of other pure working fluids and T_c , water is lower than T_c of other pure working fluids. For power input larger than 60W, T_e , methanol is lower than T_e of other pure working fluids. From 20W to 100W,

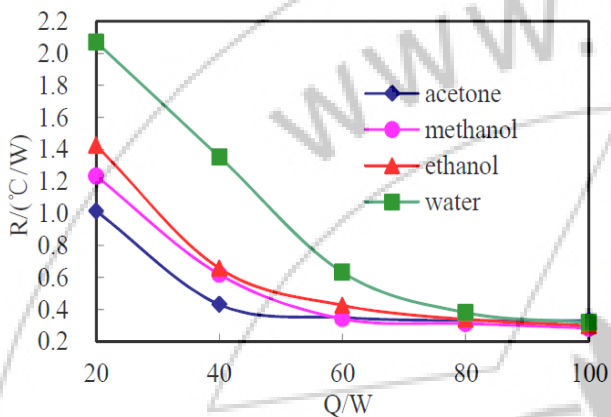


Figure 4: Thermal resistance of pure working fluids of closed loop pulsating heat pipe at different heat Input

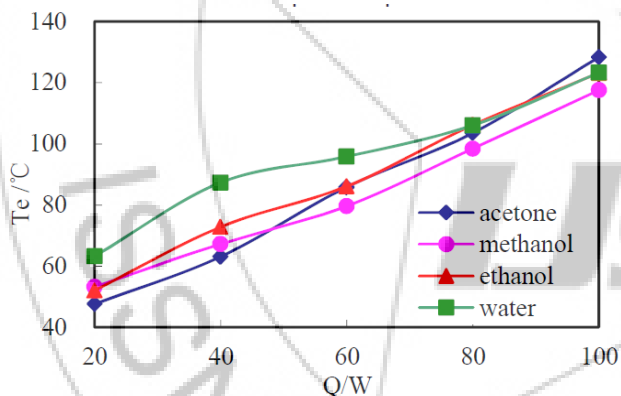


Figure 5: Evaporator temperature of pure working fluids of pulsating heat pipe at different power input

Figure 6: Condenser temperature of pure working fluids of closed loop pulsating heat pipe at different power input

5. Working Fluids and Temperature Ranges

Each heat pipe application has a particular temperature range in which the heat pipe needs to operate. Therefore, the design of the heat pipe must account for the intended temperature range by specifying the proper working fluid [13]. Life of a heat pipe can be assured by selecting a container, materials that are compatible with one another and with the working fluid of interest. Performance can be degraded and failures can occur in the container wall if any of the parts (including the working fluid) are not compatible. For instance, the parts can react chemically or set up a galvanic cell within the heat pipe. Additionally, the container material may be soluble in the working fluid or may catalyze the decomposition of the working fluid at the expected operating temperature. This situation is more advantageous than underfilling the heat pipe, which may significantly reduce the maximum heat transfer. With extreme overfill, however, any excess fluid might collect as liquid in the condenser section and increase the thermal resistance, thereby decreasing the heat transport capability of the heat pipe.

Table 1: Thermo-physical properties of various working fluid

Working fluid	Saturation temperature t_{sat} °C	Specific heat C_p kJ/kgK	Thermal conductivity k kw/mK	Latent heat h_{fg} kJ/kgK	$\frac{dp}{dT}$ $\frac{Pa}{°C} \times 10^3$	$\nu \times 10^6$ $Pa.s$	$\sigma \times 10^3$ N/m
Methanol	64.7	2.48	0.212	1101	3.55	0.60	22.6
Ethanol	78.3	2.39	0.172	846	3.51	0.15	22.8
Acetone	56.2	2.35	0.170	523	3.1	0.32	23.7
Water	100	4.18	0.599	2257	1.3	1.01	72.8

5.1 Temperature Range

The temperature range is from 200 to 550 K. Most heat pipe applications fall within this range. Commonly used fluids are ammonia, acetone, the Freon compounds, and water. Water, which is perhaps the most widely used working fluid, has good thermo physical properties such as large heat of vaporization and surface tension, and has the added benefit of being safe to use during handling.

Table 2: Working fluid and temperature ranges of various working fluids

Working fluid	Melting point At 1 atm in K	Boiling point At 1 atm in K	Temperature ranges in K

Methane	90.6	111.4	91-150
Ethane	89.9	184.6	150-240
Pentane	143.1	309.2	252-393
Acetone	180.0	329.4	273-393
Methanol	175.1	337.8	283-403
Ethanol	158.7	351.5	273-403
Heptanes	182.5	371.5	273-423
Water	273.1	373.1	303-350

Table 3: Compatibility of metals with working fluids for heat pipes

Working fluid	Compatible Material	Incompatible Material
Water	Stainless Steel, Copper, Silica, Nickel, Titanium	Aluminum
Ammonia	Aluminum, Stainless Steel, Cold Rolled Steel, Iron, Nickel	
Methanol	Stainless Steel, Iron, Copper, Brass, Silica, Nickel	Aluminum
Acetone	Aluminum, Stainless Steel, Copper, Brass, Silica	
Heptane	Aluminum	

6. Conclusion

From the literature studies it was found that methanol, ethanol and acetone presented higher thermal conductance when compared to the other fluids. The analysis made on these results point the better performance achieved with acetone, methanol and ethanol during all tests, which show the great potential in using these working fluids. From the literature studies it was observed that results, for filling ratio of 60 % and vertical orientation, acetone presented the best results. On the other way, water has presented the worse performance.

The device can be tested with different working fluids, which can be used to compare the performance. The results gathered in this investigation have the objective to compare the thermal performance of the pulsating heat pipe with different working fluids. The temperature difference between evaporator and condenser is lower for acetone compared to other working fluids. When heat input increases the thermal resistance will decrease and heat transfer coefficient will be increases. When heat input increases the fluid circulation velocity is also increases. Acetone is the most suitable working fluid for pulsating heat pipe operation when compared to other working fluid.

7. Future Scope

Analysis need to be done on closed loop pulsating heat pipe hydrocarbon fluids like methane ethane, pentane, acetone, methanol, ethanol, heptanes by comparing their results so as to know which working fluid which will have higher performance under the given set of operating condition and various filling ratio. It is expected that the performance of hydrocarbon fluid may be different at different filling ratio. There is need to do thermal analysis of closed loop pulsating heat pipe with software packages like ANSYS and need to study the position of vapour slug at particular intervals of time and temperature variation inside the channel of closed loop pulsating heat pipe with hydrocarbon as working fluid.

Additional research is required to fully understand the operating principles behind closed loop pulsating heat pipes as well as to better understand the heat transfer characteristics. Some key areas of focus would include decreasing the time required for pulsating action of working fluid.

References

- [1] H. Akachi, F. Polasek, and P. Stulc, "Pulsating heat pipes," in Proc. 5th Intl. Heat Pipe Symp., Melbourne, Australia, 1996, pp. 208–217.
- [2] P.K.Nag, Engineering Thermodynamics (Mc Graw Hill Education India Private Limited)
- [3] T. N. Wong, "High speed flow visualization of a closed loop pulsating heat pipe," Heat Mass Transfer, vol. 48, pp. 3338–3351, 2005.
- [4] N. Saponpongpipat, P. Sakulchangsattajai, N. Kammuang-lue, and P. Terdtoon, "Investigation of the startup condition of a closed loop oscillating heat pipe," Heat Transfer Eng., vol. 30, no. 8, pp. 626–642, 2009.
- [5] Khandekar, S., Dollinger, N., Groll, M., "Understanding Operational Regimes of Closed Loop Pulsating Heat Pipes: An Experimental Study", 2003, Applied Thermal Engineering, Vol. 23, pp.707-719.
- [6] T. Mallikharjuna Rao, Dr. S. S. Rao, Heat Pipes for Steam Condensation, IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN: 2278-1684, ISSN: 2320-334X, Volume 11, Issue 2 Ver. I (Mar- Apr. 2014), PP 16-19.
- [7] M. Groll, S. Khandekar, Pulsating heat pipes: a challenge and still unsolved problem in heat pipe science, Proceedings of the 3rd International Conference on Transport Phenomena in Multiphase Systems, Kielce, Poland, 2002, 35–44 (ISBN 83-88906-03-8).
- [8] M.B. Shafii, A. Faghri, Y. Zhang, Thermal modeling of unlooped and looped pulsating heat pipes, ASME J. Heat Transfer 123 (2001) 1159–1172.
- [9] S. Khandekar, M. Schneider, R. Kulenovic, M. Groll, Thermofluid dynamic study of flat plate closed loop pulsating heat pipes, Microsc. Thermophys. Eng. 6 (4) (2002) 303–318 (ISSN 1089-3954)
- [10] Niti Kammuang-lue, Kritsada, Phrut Sakulchangsattajai, Pradit Terdtoon, Correlation to Predict Thermal Performance According to Working Fluids of Vertical Closed-Loop Pulsating Heat Pipe, International Journal of Mechanical, Aerospace, Industrial and Mechatronics Engineering Vol:8 No:5, 2014
- [11] N. Saponpongpipat, P. Sakulchangsattajai, N. Kammuang-lue, and P. Terdtoon, "Investigation of the startup condition of a closed loop oscillating heat pipe," Heat Transfer Eng., vol. 30, no. 8, pp. 626–642, 2009.
- [12] N. Saponpongpipat, P. Sakulchangsattajai, N. Kammuang-lue, and P. Terdtoon, "Investigation of the startup condition of a closed loop oscillating heat pipe," Heat Transfer Eng., vol. 30, no. 8, pp. 626–642, 2009.
- [13] Zhang, Y., Faghri, A., "Heat Transfer in a Pulsating Heat pipe with an Open End", International Journal of Heat and Mass Transfer, Vol. 45, 2002, pp. 755- 764.