An Experimental Investigation of Methanol Closed Loop Pulsating Heat Pipe at Variable Water Bath Temperature

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Abstract: ***The objective of this paper is to investigate the closed loop pulsating heat pipe with Methanol as working fluid. Working fluid is very important factor that significantly influence the thermal performance of closed loop pulsating heat pipe. The working fluids which are usually available are methane, ethane, pentane, acetone, methanol, and ethanol. This paper investigates closed loop pulsating heat pipe with methanol as working fluid. Compatibility of working fluid with heat pipe material is also the important factor hence copper is selected as compatible material for methanol heat pipe. Filling ratio of working fluid is also the important factor that significantly influence on the thermal performance of closed loop pulsating heat pipe. The filling ratio of 30 to 75 % provides the best result. Here in this paper the filling ratio of 60% has been selected for methanol.***

Keywords: closed loop pulsating heat pipe, working fluid, filling ratio.

1. Introduction

The closed-loop pulsating heat pipe is a type of small heat transfer device with a very high thermal conductivity. It was invented to meet the requirement for smaller heat transfer devices. It can transfer sufficient heat for heat dissipation applications in modern electronic devices. The Closed loop pulsating heat pipe was made of a long copper capillary tube, bent into an undulating tube and connected at the ends to form a closed-loop with no internal wick structure. Working fluid is partially filled in the tube. The closed loop pulsating heat pipe has a condenser, evaporator section and may also present an adiabatic section. As any other two-phase passive thermal control device, heat is acquired from the source through the evaporation section transferring it to the working fluid where the slug/plug pumping action will be generated. The fluid then flows by the adiabatic section towards the condensation section. On a closed loop configuration, the fluid is allowed to circulate and after being condensed, the fluid returns to the evaporation section to complete the loop. The tube is evacuated and consequently partially filled with working fluid. Since an inner diameter of the tube is very small and then meets a capillary scale, the inside working fluid forms into liquid slugs alternating with vapour plugs along the entire length of the tube [1].

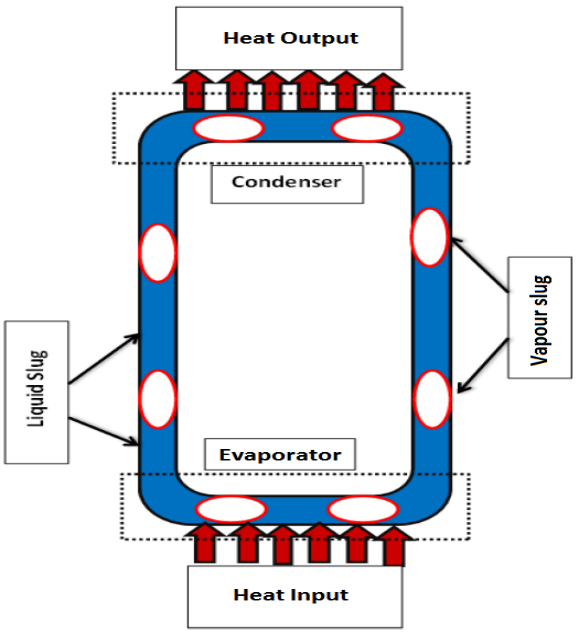

Figure 1: Closed loop pulsating heat pipe

When one end of the closed-loop pulsating heat pipe, called 'evaporator section', is subjected to heat or high temperature, the working fluid, which is in liquid slug form, will evaporate, expand, and move through the no heat transferring zone, or 'adiabatic section', toward a cooler Section, 'condenser section' namely. Then, the vapour plugs will condense, collapse, and release the heat into the environment. Therefore, the vapour plug evaporating in the evaporator section will consequently flow to replace the vapour plug collapsing in the condenser section. Due to this mechanism, the working fluid can circulate and continuously transfer heat in a cycle. The structure of the closed loop pulsating heat pipe is as shown in Figure 1.

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Table 1: Compatibility of closed loop pulsating heat pipe material with the working fluid

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

Table 2: Boiling point and operating ranges of working fluid

Working fluid	Boiling point At 1 atm in K	Temperature ranges in K
Methane	111.4	91-150
Ethane	184.6	150-240
Pentane	309.2	252-393
Acetone	329.4	273-393
Methanol	337.8	283-403
Ethanol	351.5	273-403
Heptanes	371.5	273-423
Water	373.1	303-350

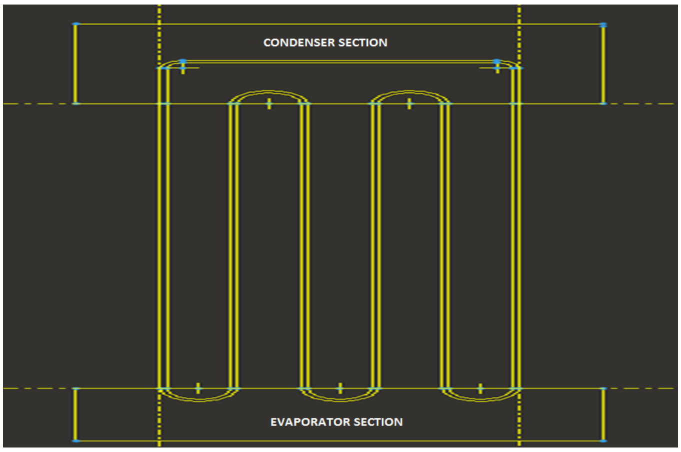

Figure 2: Experimental diagram of closed loop methanol heat pipe with inner diameter of 2mm.

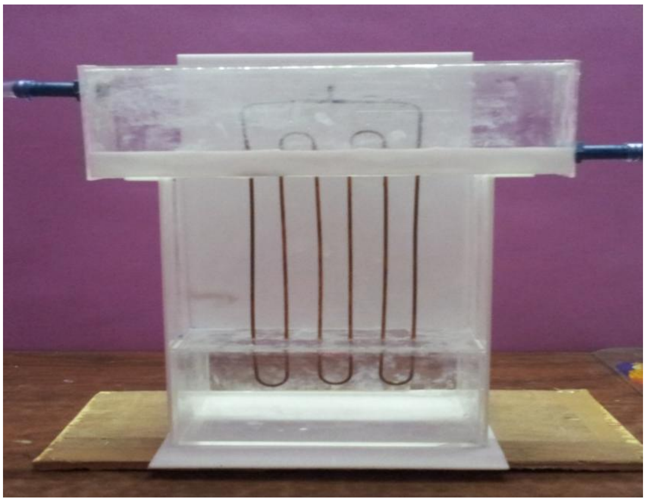

Figure 3: Experimental setup of Methanol Closed Loop Pulsating Heat Pipe

2. Experimentation and testing methanol closed loop pulsating heat pipe

Table 3: Evaporator and condenser temperature of methanol closed loop pulsating heat pipe at water bath temperature of 72^0C

Evaporator Temperature	*Condenser Temperature*
65.5	29.0
66	29.2
67.1	29.8
67.3	30.9
67.3	30.8
67.2	29.3

$$average\ evaporator\ temperature = 66.73^0C$$
$$average\ condenser\ temperature = 29.83^0C$$

Table 4: Evaporator and condenser temperature of methanol closed loop pulsating heat pipe at water bath temperature of 70^0C

Evaporator Temperature	*Condenser Temperature*
63.3	28.4
63.8	28.5
64.4	29.0
65.0	29.5
65.0	29.5
64.8	27.4

$$average\ evaporator\ temperature = 64.38^0C$$
$$average\ condenser\ temperature = 29.31^0C$$

Table 5: Evaporator and condenser temperature of methanol closed loop pulsating heat pipe at water bath temperature of 68^0C

Evaporator Temperature	*Condenser Temperature*
61.9	27.7
61.9	28.0
63.6	29.9
64.1	30.2
64.1	28.2
64.1	28.0

$$average\ evaporator\ temperature = 63.28^0C$$
$$average\ condenser\ temperature = 28.66.^0C$$

Table 6: Evaporator and condenser temperature of methanol closed loop pulsating heat pipe at water bath temperature of 66^0C

Evaporator Temperature	*Condenser Temperature*
61.4	28.1
62.4	28.6
62.8	29.1
62.9	29.1
62.7	29.1
62.4	27.2

$$average\ evaporator\ temperature = 62.43^0C$$
$$average\ condenser\ temperature = 28.53^0C$$

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Table 7: Evaporator and condenser temperature of methanol closed loop pulsating heat pipe at water bath temperature of 64^0C

Evaporator Temperature	Condenser Temperature
60.0	27.3
60.3	27.4
60.2	28.4
60.0	29.3
60.2	27.1
60.2	28.1

$average\ evaporator\ temperature = 60.15^0C$

$average\ condenser\ temperature = 27.93^0C$

Table 8: Evaporator and condenser temperature of methanol closed loop pulsating heat pipe at water bath temperature of 62^0C

Evaporator Temperature	Condenser Temperature
58.5	26.5
58.7	27.0
58.9	27.1
58.9	27.3
59.0	27.0
58.2	27.5

$average\ evaporator\ temperature = 58.7^0C$

$average\ condenser\ temperature = 27.06^0C$

Table 9: Evaporator and condenser temperature of methanol closed loop pulsating heat pipe at water bath temperature of 60^0C

Evaporator Temperature	Condenser Temperature
56.9	26.9
56.8	27.2
57.0	27.6
57.1	28.0
56.6	27.9
56.2	26.7

$average\ evaporator\ temperature = 56.76^0C$

$average\ condenser\ temperature = 27.38^0C$

Table 10: Evaporator and condenser temperature of methanol closed loop pulsating heat pipe at water bath temperature of 58^0C

Evaporator Temperature	Condenser Temperature
52.1	26.1
54.6	26.4
54.5	27.0
54.1	27.6
53.8	27.3
53.7	27.0

$average\ evaporator\ temperature = 53.8^0C$

$average\ condenser\ temperature = 26.9^0C$

Table 11: Evaporator and condenser temperature of methanol closed loop pulsating heat pipe at water bath temperature of 56^0C

Evaporator Temperature	Condenser Temperature
51.2	26.3
52.7	26.3
52.2	26.5
51.8	26.7
51.8	26.2
51.5	26.1

$average\ evaporator\ temperature = 51.86^0C$

$average\ condenser\ temperature = 26.35^0C$

Table 12: Evaporator and condenser temperature of methanol closed loop pulsating heat pipe at water bath temperature of 54^0C

Evaporator Temperature	Condenser Temperature
49.6	25.5
49.2	26.0
49.2	26.5
49.2	26.7
49.4	26.2
50.1	26.1

$average\ evaporator\ temperature = 49.45^0C$

$average\ condenser\ temperature = 26.16^0C$

Table 13: Evaporator and condenser temperature of methanol closed loop pulsating heat pipe at water bath temperature of 50^0C

Evaporator Temperature	Condenser Temperature
44.9	26.0
45.6	26.2
46.2	26.3
46.7	26.2
48.2	25.7
45.7	25.7

$average\ evaporator\ temperature = 46.21^0C$

$average\ condenser\ temperature = 26.016^0C$

Table 14: Evaporator and condenser temperature of methanol closed loop pulsating heat pipe at water bath temperature of 46^0C

Evaporator Temperature	Condenser Temperature
42.7	25.9
43.2	26.0
43.7	26.2
43.8	26.1
43.8	26.1
44.4	25.8

$average\ evaporator\ temperature = 43.6^0C$

$average\ condenser\ temperature = 26.01^0C$

Table 15: Evaporator and condenser temperature of methanol closed loop pulsating heat pipe at water bath temperature of 42^0C

Evaporator Temperature	Condenser Temperature
38.3	25.9
38.5	25.7
38.6	25.7
39	26.2
39.2	26.3
39.3	25.8

$average\ evaporator\ temperature = 38.81^0C$

$average\ condenser\ temperature = 25.93^0C$

Table 16: Evaporator and condenser temperature of methanol closed loop pulsating heat pipe at water bath temperature of 38^0C

Evaporator Temperature	Condenser Temperature
35.2	26
36	25.8
36	25.7

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36.3	25.8
36.5	25.9
36.6	25.8

$$average\ evaporator\ temperature = 36.1^0 C$$
$$average\ condenser\ temperature = 25.83^0 C$$

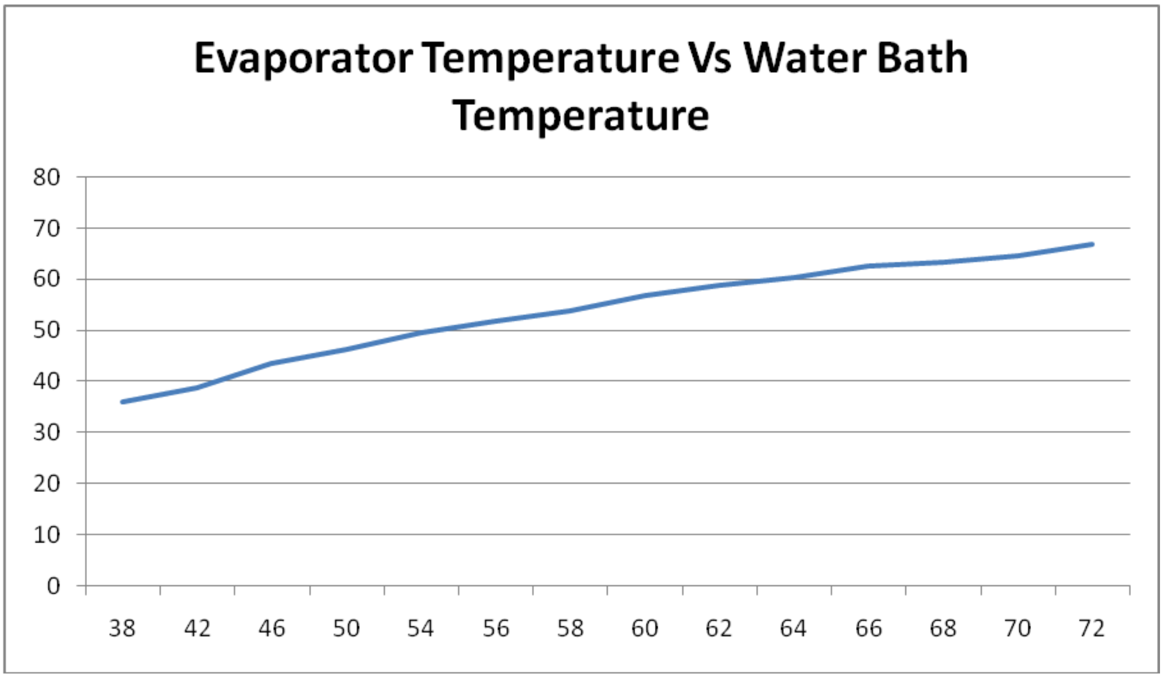

Figure 3: Evaporator temperature of methanol closed loop pulsating heat pipe at different water bath temperature

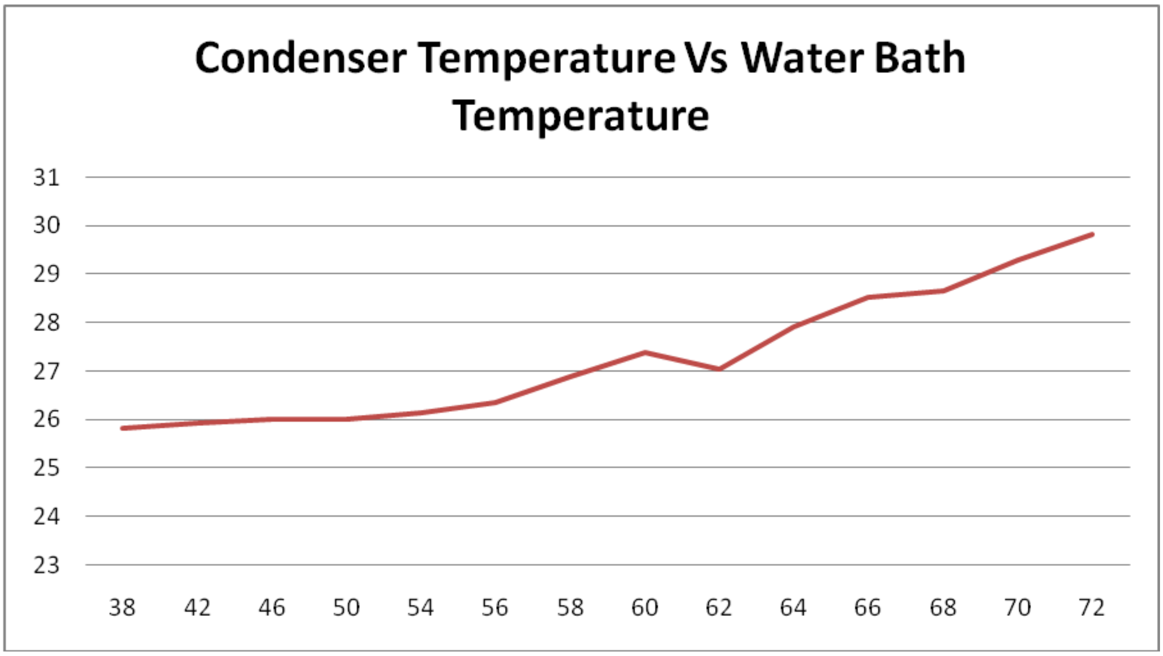

Figure 4: Condenser temperature of methanol closed loop pulsating heat pipe at different water bath temperature.

3. Conclusion

When the temperature of the water bath increases there is increase in the evaporator and condenser temperature the temperature of condenser increases more rapidly when the temperature of water bath increases above $58^0 C$. as the temperature of water bath increases the thermal resistance of closed loop pulsating heat piped decreases. Saturation temperature of working fluids affect on the temperature difference between evaporator and condenser section and therefore lower saturation temperature working fluids gives better performance.

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