An Experimental Investigation On Thermal Performance Of Closed Loop Pulsating Heat Pipe And Conventional Heat Pipe With Hydrocarbon As Working Fluid

Roshan D. Bhagat, Kiran M. Watt

Abstract : An experimentation investigation on thermal performance of closed loop pulsating heat pipe (CLPHP) and conventional heat pipe (CHP) with hydrocarbon as working fluid determine the effect of heat transfer and overall system performance at a given constrained dimensional heat source. The experimental investigation included start-up time, temperature, the average, minimum, and maximum evaporator temperature during its operation, the overall heat transfer capability, and the overall thermal resistance of the system, also the behavior of closed loop pulsating heat pipe (CLPHP) and conventional heat pipe (CHP) under different heat inputs and with the different working fluids. To achieve the goal the experimental setup is fabricated and tested with two different working fluids Acetone and Methanol with the filling ratio of 60 %. This work provides the detailed discussion on the thermal performance and behavior of closed loop pulsating heat pipe (CLPHP) and conventional heat pipe (CHP) with Acetone and Methanol as working fluid at different heat inputs.

Keywords: Thermal resistance, closed loop pulsating heat pipe, conventional heat pipe, working fluid, heat input, thermal performance, thermal resistance.

1 INTRODUCTION

The heat pipe (Faghri, 1995) is a highly effective passive heat transfer device for transmitting heat at high rates over considerable distances with extremely small temperature drops, exceptional flexibility, simple construction, and easy control with no external pumping power. Of the many different types of systems which transport heat, the heat pipe (Faghri, 1995) is one of the most efficient systems known today. The advantage of using a heat pipe over other conventional methods is that large quantities of heat can be transported through a small crossectional area over a considerabledistance with no additional power input to the system. Furthermore, design and manufacturing simplicity, small end-to-end temperature drops, and the ability to control and transport high heat rates at various temperature levels are all unique features of heat pipes.

The predecessor of the heat pipe, the Perkins tube, was introduced by the Perkins family from the mid-nineteenth to the twentieth century through a series of patents in the United Kingdom. Most of the Perkins tubes were wickless gravity-assisted heat pipes (thermosyphon), in which heat transfer was achieved by a change of phase (latent heat of evaporation). The Perkins tube design closest to the present heat pipe was patented by Jacob Perkins (1836). This design was a closed tube containing a small quantity of Water operating as a two-phase cycle.

The introduction of the heat pipe was first conceived by Gaugler (1944) of the General Motors Corporation in the U.S. Patent No. 2350348. Gaugler, who was working on refrigeration problems at that time, envisioned a device which would evaporate a liquid at a point above the place where condensation would occur without requiring any external power source. It consisted of a closed tube in which the liquid would absorb heat at one location causing the liquid to evaporate. The vapor would then travel down the length of the tube, where it would recondense and release its latent heat. It would then travel back up the tube via capillary pressure to start the process over. In order to move the liquid back up to a higher point, Gaugler suggested the use of a capillary structure consisting of a sintered iron wick. A refrigeration unit proposed by Gaugler used a heat pipe to transfer the heat from the interior of a compartment to a pan of crushed ice below.

In 1962, Trefethen (1962) resurrected the idea of a heat pipe in connection with the space program. Serious development started in 1964 when the heat pipe was independently reinvented and a patent application was filed by Grover at Los Alamos National Laboratory in New Mexico. Grover et al. (1964) and Grover (1966) built several prototype heat pipes, the first of which used Water as a working fluid, and was soon followed by a sodium heat pipe which operated at 1100 K. Grover and his co-workers also demonstrated the effectiveness of heat pipes as a high performance heat transmission device and proposed several applications for their use.

The recognition of the heat pipe as a reliable thermal device was initially due to the preliminary theoretical results and design tools that were reported in the first publication on heat pipe analysis by Cotter (1965).

Bhagat and Watt (2015) performed experimentation on closed loop pulsating heat pipe (CLPHP) with hydrocarbon as working fluid and observed that the thermal resistance of CLPHP decreases with increase in heat input. The thermal

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resistance of CLPHP with Acetone as working fluid is less as compared to thermal resistance of Methanol at same heat inputs and filling ratio of 60 % and from the experimentation, it was concluded that out of the two hydrocarbon working fluids, the thermal performance of Acetone is higher.

Working fluid is partially filled in the tube. The closed loop pulsating heat pipe (CLPHP) and conventional heat pipe (CHP) has a condenser, evaporator and adiabatic section. As any other two phase passive thermal control device, heat is acquired from the source through the evaporator section transferring it to the working fluid. The working fluid then flows by the adiabatic section towards the condenser section.

The objective of the present work is to study the CLPHP and CHP with Acetone and Methanol as working fluid. In the present work thermal performance of CLPHP and CHP with Acetone and Methanol as working fluid is investigated at different heat inputs having filling ratio of 60 %.

2 EXPERIMENTATION FOR CLPHP

The purpose of this initiative was to combine fluid dynamics and heat transfer to create a device capable of transferring heat within the small distance. The first phase focused on fabricating the apparatus for CLPHP and performing the initial testing to gain preliminary insight into its functionality. In addition to successfully transferring heat from heat source to the heat sink, this task provided an opportunity for experimental learning and device creation and targeted design through engineering principles.

2.1 Setup Description for CLPHP

2.1.1 Working Fluid

Working fluid is the most important factor that significantly influence on the thermal performance of CLPHP. Hydrocarbon working fluid involves Acetone, Methanol, Ethanol, Methane and Pentane. Experimental setup consists of CLPHPwith Acetone and Methanol as working fluid. The boiling point of Methanol is 64^0C and Acetone 57^0C, 60 % filling ratio has been used for Acetone and Methanol.

2.1.2 Copper Tube

Compatibility of copper with Acetone and Methanol as working fluid made it possible to use copper tube for preparing the experimental setup. The inner diameter of copper tube is 2mm and outer diameter of 3mm. The small diameter is chosen so as to have capillary action. The copper tube is bent into three small turns in evaporator section and two small turns and one large turn in condenser section.

2.1.3 Digital LASER Thermometer

For measuring the evaporator temperature i.e. from T_1 to T_6 and condenser temperature from T_7 to T_{12} as shown in fig. 1 the digital LASER thermometer is used. The digital LASER thermometer provides to flexibility to measure the temperature over the entire length of the copper tube.

2.1.4 Evaporator Tank

The evaporator tank design to the dimension of $8\ inch \times 6\ inch \times 4\ inch$, so as to occupy the heating element and to have sufficient amount of water inside the evaporator tank for heating the copper tube, with the water bath heating is done.

2.1.5 Condenser Tank

The surface area of copper tube inside the condenser tank should be higher than the surface area of copper tube inside the evaporator tank hence the dimension of condenser tank is taken as$12\ inch \times 3\ inch \times 4\ inch$. The condenser tank should hold sufficient water so as to have heat rejection by the working fluid through the copper tube and to have condensation of working fluid.

2.1.6 Coil Heater

The coil heater with capacity of 500 Watt is used to heat the water inside the evaporator tank.

2.1.7 Temperature Indicator for Water Bath

For measuring the water bath temperature inside the evaporator tank, temperature indicator is used to monitor the temperature of water bath so as to prevent the excessive heating of water which may cause the dry out of working fluid in the copper tube.

2.1.8 Variable AC Power Supply

For changing the heat inputs to the coil heater variable AC power supply is used. 0-240 VAC can be adjusted with the help of dimmerstat. Digital voltmeter and ammeter are connected to show the voltage and current reading.

2.1.9 Control Panel

Digital voltmeter, ammeter and water bath temperature indicator are mounted on the control panel.

2.1.10 Tank Material

Evaporator and condenser tank are prepared with acrylic. Acrylic is non conducting material and heat loss to the surrounding is kept minimum. Magnabond instant adhesive is used for preparing leak proof tank.

2.2 Experimentation and Testing of CLPHP

The experimentation performed on CLPHP by heating the water bath with the help of coil heater. The heat inputs to the coil heater can be adjusted by using 0 to 240 VAC power supply. Heat transfer by convection takes place from water to the copper tube and heat is conducted through the copper tube, this heat is now transferred to the working fluid present inside the copper tube. This working fluid reject heat to the water available in the condenser tank by sensible heat of liquid and latent heat of vapour.

The evaporator temperature T_1 to T_6 and condenser temperature T_7 to T_{12} measured with the help of digital LASER thermometer. The twelve temperature points are as shown in the fig. 1. The thermal resistance of CLPHP was calculated for the given heat inputs by taking the temperature difference between the evaporator and condenser and dividing it by the heat input.

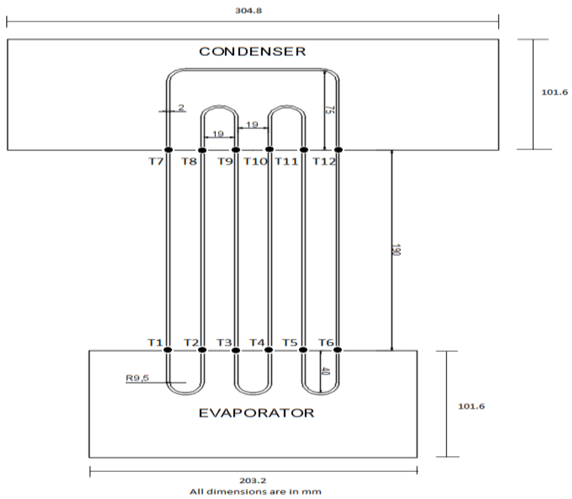

Fig. 1 Specification of experimental setup of closed loop pulsating heat pipe

2.3 Calculation

The thermal resistance of CLPHP can be calculated by using the following equations,

$$R_{thermal} = \frac{T_e - T_c}{Q} \quad (1)$$

$R_{thermal}$ − *Thermal resistance*

T_e − *Average evaporator temperature*

T_c − *Average condenser temperature*

$$Q = Voltage \times Current \quad (2)$$

Average evaporator temperature

is calculated by using the equation

$$T_e = \frac{T_1 + T_2 + T_3 + T_4 + T_5 + T_6}{6} \quad (3)$$

Average condenser temperature

is calculated by using the equation

$$T_c = \frac{T_7 + T_8 + T_9 + T_{10} + T_{11} + T_{12}}{6} \quad (4)$$

3 EXPERIMENTATION FOR CONVENTIONAL HEAT PIPE

The purpose of this initiative was to combine fluid dynamics and heat transfer to create a device capable of transferring heat within the small distance. The first phase focused on fabricating the experimental setup for CHP and performing the initial testing to gain preliminary insight into its functionality. In addition to successfully transferring heat from heat source to the heat sink, this task provides an opportunity for experimental learning, device creation and targeted design through engineering principles.

3.1 Setup Description for CHP

3.1.1 Working Fluid

Working fluid is the most important factor that significantly influence on the thermal performance of CHP. Experimental setup consists of CHP with Acetone and Methanol as working fluid. The boiling point of Methanol 64^0C and Acetone 57^0C, at 1 atmospheric pressure. 60 % filling ratio has been used for Acetone and Methanol.

3.1.2 Copper Tube

Compatibility of copper with Water, Acetone and Methanol as working fluid made it possible to use copper tube for preparing the experimental setup. The diameter of copper tube is $0.315\ inch$ and length of $9.64\ inch$. The copper tube is $1.57\ inch$ dipped inside the evaporator section and $2.16\ inch$ inside the condenser section. Along the $6.49\ inch$ length of tube which is exposed to surrounding, a glass wool insulation is provided to prevent heat loss.

3.1.3 Digital LASER Thermometer

For measuring the evaporator temperature i.e. from T_1 to T_4 and condenser temperature from T_5 to T_8 as shown in fig. 2 the digital LASER thermometer is used. The digital LASER thermometer provides to flexibility to measure the temperature over the entire length of the copper tube.

3.1.4 Evaporator Tank

The evaporator tank design to the dimension of $8\ inch \times 6\ inch \times 4\ inch$, so as to occupy the heating element and to have sufficient amount of Water inside the evaporator tank for heating the copper tube, with the Water bath heating is done.

3.1.5 Condenser Tank

The surface area of copper tube inside the condenser tank should be higher than the surface area of copper tube inside the evaporator tank hence the dimension of condenser tank is taken as $8\ inch \times 3\ inch \times 3\ inch$. The condenser tank should hold sufficient Water so as to have heat rejection by the working fluid through the copper tube and to have condensation of working fluid.

3.1.6 Coil Heater

The coil heater with capacity of 500 Watt is used to heat the Water inside the evaporator tank.

3.1.7 Temperature Indicator for Water

For measuring the Water bath temperature inside the evaporator tank, temperature indicator is used to monitor the temperature of Water bath so as to prevent the excessive heating of Water which may cause the dry out of working fluid in the copper tube.

3.1.8 Variable AC Power Supply

For changing the heat inputs to the coil heater variable AC power supply is used. 0-240 VAC can be adjusted with the help of dimmerstat. Digital voltmeter and ammeter are connected to show the voltage and current reading.

3.1.9 Control Panel

Digital voltmeter, ammeter and Water bath temperature indicator are mounted on the control panel.

3.1.10 Tank Material

Evaporator and condenser tank are prepared with acrylic. Acrylic is non conducting material and heat loss to the surrounding is kept minimum. Magnabond instant adhesive is used for preparing leak proof tank.

3.2 Experimentation and Testing of CHP with Acetone and Methanol as Working Fluid.

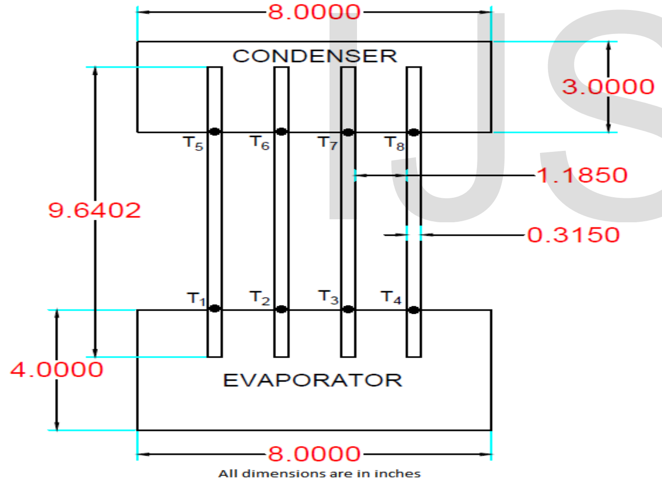

Fig. 2 Specification of experimental setup of CHP

The experimentation performed on CHP by heating the Water bath with the help of coil heater. The heat inputs to the coil heater can be adjusted by using 0 to 240 VAC power supply. Heat transfer by convection takes place from Water to the copper tube and heat is conducted through the copper tube, this heat is now transferred to the working fluid present inside the copper tube. This working fluid reject heat to the Water available in the condenser tank by sensible heat of liquid and latent heat of vapour.

The evaporator temperature T_1 to T_4 and condenser temperature T_5 to T_8 measure with the help of digital LASER thermometer. The eight temperature points are as shown in the fig. 2. The thermal resistance of CHP was calculated for the given heat inputs by taking the ratio of temperature difference between the evaporator and condenser to the heat input.

3.3 Calculation

The thermal resistance of CHP can be calculated by using the following equations,

$$R_{thermal} = \frac{T_e - T_c}{Q} \quad (5)$$

$R_{thermal}$ − *Thermal resistance*

T_e − *Average evaporator temperature*

T_c − *Average condenser temperature*

Q − *Heat input*

$$Q = Voltage \times Current \quad (6)$$

Average evaporator temperature

is calculated by using the equation

$$T_e = \frac{T_1 + T_2 + T_3 + T_4}{4} \quad (7)$$

Average condenser temperature

is calculated by using the equation

$$T_c = \frac{T_5 + T_6 + T_7 + T_8}{4} \quad (8)$$

TABLE 1

Thermal resistance of CLPHP with Acetone and Methanol as working fluid

S.N.	Heat Input Watt	Average Evaporator Temperature Acetone in^0C	Average Condenser Temperature Acetone in^0C	Average Evaporator Temperature Methanol in^0C	Average Condenser Temperature Methanol in^0C	Thermal Resistance Acetone $in\ K/W$	Thermal Resistance Methanol $in\ K/W$
1	1	25.98333333	25.93333333	24.83333333	23.91666667	0.05	0.916666667
2	4	25.83333333	25.81666667	24.48333333	23.76666667	0.004166667	0.179166667
3	9.3	25.8	25.46666667	24.9	19.81666667	0.035842294	0.546594982
4	16.4	26.2	25.43333333	25.31666667	24	0.046747967	0.080284553
5	16.4	26.85	25.51666667	25.75	24.11666667	0.081300813	0.099593496
6	26.5	26.96666667	25.51666667	26.71666667	24.1	0.054716981	0.098742138
7	26.5	27.63333333	25.45	27.53333333	24.3	0.082389937	0.122012579
8	26.5	28.25	25.56666667	27.83333333	24.26666667	0.101257862	0.134591195
9	26.5	28.16666667	25.3	28.81666667	24.2	0.108176101	0.174213836
10	26.5	28.61666667	25.45	29.48333333	24.71666667	0.119496855	0.179874214
11	26.5	29.06666667	25.46666667	29.7	24.43333333	0.135849057	0.198742138
12	37.8	29.36666667	25.35	29.61666667	24.25	0.106261023	0.141975309
13	37.8	29.76666667	25.06666667	30.4	24.38333333	0.124338624	0.159171076
14	37.8	30.11666667	25.01666667	30.55	24.43333333	0.134920635	0.161816578
15	37.8	30.28333333	25.06666667	30.93333333	24.78333333	0.138007055	0.162698413
16	37.8	30.51666667	25.05	31.2	24.55	0.144620811	0.175925926
17	51.1	30.91666667	25.05	31.4	24.76666667	0.114807567	0.129810828
18	51.1	31.4	25.05	31.7	24.7	0.124266145	0.136986301
19	51.1	31.7	25.06666667	32.5	24.86666667	0.129810828	0.1493803
20	51.1	32.23333333	25.06666667	32.38333333	24.91666667	0.14024788	0.146118721
21	51.1	32.26666667	25.06666667	33	25	0.140900196	0.156555773
22	51.1	32.91666667	25.11666667	33.32166667	24.96666667	0.152641879	0.163502935
23	67.2	33.11666667	25.3	33.83333333	25.1	0.116319444	0.129960317
24	67.2	33.9	25.41666667	34.25	25.16666667	0.126240079	0.135168651
25	67.2	34.21666667	25.46666667	34.75	25.15	0.130208333	0.142857143
26	67.2	34.53333333	25.55	35.05	25.38333333	0.133680556	0.143849206
27	67.2	34.75	25.48333333	35.51666667	25.38333333	0.137896825	0.150793651
28	84.6	33.53333333	25.83333333	35.53333333	25.5	0.091016548	0.118597321
29	84.6	35.5	25.81666667	36.7	25.45	0.114460205	0.132978723
30	84.6	36.33333333	26.06666667	37.63333333	25.58333333	0.121355398	0.142434988
31	84.6	36.76666667	26.15	37.93333333	25.61666667	0.125492514	0.145587076
32	84.6	37.15	26.26666667	38.56666667	25.86666667	0.128644602	0.150118203
33	84.6	37.35	26.5	39.13333333	26.01666667	0.128250591	0.155043341
34	84.6	37.71666667	26.5	39.5	26.11666667	0.132584712	0.158195429
35	104	38.58333333	26.51666667	40.46666667	26.05	0.116025641	0.138621795
36	104	38.8	26.6	41.96666667	26.16666667	0.117307692	0.151923077
37	104	39.6	26.78333333	43.75	26.4	0.123237179	0.166826923
38	104	40.15	27.11666667	44.9	26.56666667	0.125320513	0.176282051
39	104	42.51666667	27.13333333	46.03333333	26.88333333	0.147916667	0.184134615
40	104	42.58333333	27.1	46.2	26.93333333	0.148878205	0.18525641
41	104	43.9	27.28333333	46.96666667	27.03333333	0.159775641	0.191666667
42	126.5	44.85	27.26666667	49.18333333	27.18333333	0.138998682	0.173913043
43	126.5	46.9	27.28333333	50.78333333	27.28333333	0.155072464	0.185770751
44	126.5	48.78333333	27.46666667	52.26666667	27.33333333	0.168511199	0.197101449
45	126.5	50.16666667	27.55	52.6	27.53333333	0.178787879	0.198155468
46	126.5	50.95	27.75	53.4	27.56666667	0.183399209	0.204216074
47	163.75	51.53333333	28.15	54.35	27.33333333	0.142798982	0.164987277
48	163.75	52.43333333	28.66666667	50.76666667	27.35	0.145139949	0.143002545
49	163.75	54.31666667	28.83333333	60.83333333	27.96666667	0.15562341	0.200712468
50	163.75	55.05	29.4	60.46666667	28.1	0.156641221	0.197659033
51	163.75	56.36666667	29.63333333	60.16666667	28.05	0.163256997	0.196132316
52	163.75	56.93333333	29.75	60.91666667	28.1	0.166005089	0.200407125
53	163.75	58.35	29.96666667	61.46666667	28.23333333	0.173333333	0.202951654
54	163.75	58.71666667	30.48333333	62.85	28.95	0.172417303	0.207022901
55	190.35	59.03333333	30.38333333	63.6	29.41666667	0.150512214	0.179581473
56	190.35	59.76666667	30.35	64.33333333	30.35	0.154539883	0.178530777
57	190.35	62.1	30.95	65	30.43333333	0.163645915	0.181595307
58	190.35	62.36666667	30.73333333	66.23333333	29.06666667	0.166185098	0.195254356
59	221.85	62.95	31.16666667	67.63333333	30.08333333	0.143264969	0.169258508
60	221.85	63.76666667	31.61666667	67.91666667	30.93333333	0.144917737	0.16670423
61	238.5	63.6	31.31666667	69.56666667	31.33333333	0.135359888	0.160307477
62	285.45	65.1	32.03333333	70.6	31.73333333	0.115840486	0.136159281
63	309.75	66.85	32.06666667	70.95	31.93333333	0.112294861	0.125961797
64	360.75	68.65	32.61666667	71.76666667	32.18333333	0.0998845	0.10972511

International Journal of Scientific & Engineering Research, Volume 8, Issue 4, April-2017
ISSN 2229-5518

TABLE 2

Thermal resistance of CHP with Acetone and Methanol as working fluid

S.N	Heat Input Watt	Average Evaporator Temperature Acetone in^0C	Average Condenser Temperature Acetone in^0C	Average Evaporator Temperature Methanol in^0C	Average Condenser Temperature Methanol in^0C	Thermal Resistance Acetone $in\ K/W$	Thermal Resistance Methanol $in\ K/W$
1	60.9	30.75	30.15	31.525	30.8	0.00985	0.0119
2	69.75	31.9	30.5	31.775	30.95	0.02007	0.01183
3	80	32.35	30.475	31.85	30.65	0.02344	0.015
4	90.1	33.525	30.575	32.075	30.775	0.03274	0.01443
5	99.9	33.8	30.725	32.7	30.825	0.03078	0.01877
6	112.1	34.95	30.9	34.25	30.825	0.03613	0.03055
7	123	35.175	30.825	35.3	30.9	0.03537	0.03577
8	136.5	36.05	30.95	35.9	30.8	0.03736	0.03736
9	149.6	36.85	31	35.75	30.725	0.0391	0.03359
10	163.3	37.175	31.075	36.225	30.95	0.03735	0.0323
11	177.6	38.1	31.1	38.625	30.95	0.03941	0.04322
12	192.5	39.925	31.225	41.125	31.6	0.04519	0.04948
13	209.3	40.275	31.65	40.625	31.45	0.04121	0.04384
14	225.45	44.125	31.425	42.075	32.1	0.05633	0.04424
15	242.2	43.175	31.425	44.55	32.375	0.04851	0.05027
16	261	44.8	31.45	49.925	32.75	0.05115	0.0658
17	277.5	44.45	31.725	48.4	33.05	0.04586	0.05532
18	296.05	44.4	31.8	48.825	33.25	0.04256	0.05261
19	316.8	45.85	32	51.2	33.625	0.04372	0.05548
20	338.25	49.75	32.2	52.55	33.775	0.05188	0.05551
21	357	50.05	32.7	53.1	33.725	0.0486	0.05427
22	378	51.3	32.775	53.05	33.425	0.04901	0.05192
23	396	50.95	33.05	55.225	33.575	0.0452	0.05467
24	421.8	55.525	33.625	55.9	33.9	0.05192	0.05216
25	444.6	56.025	33.425	56.725	34.05	0.05083	0.051
26	469.95	56.625	33.625	58.475	34.65	0.04894	0.0507
27	490	56	34.075	59.5	34.975	0.04474	0.05005
28	512.5	57.325	33.825	60.9	35.45	0.04585	0.04966
29	535.5	61.475	34.925	62.55	35.25	0.04958	0.05098

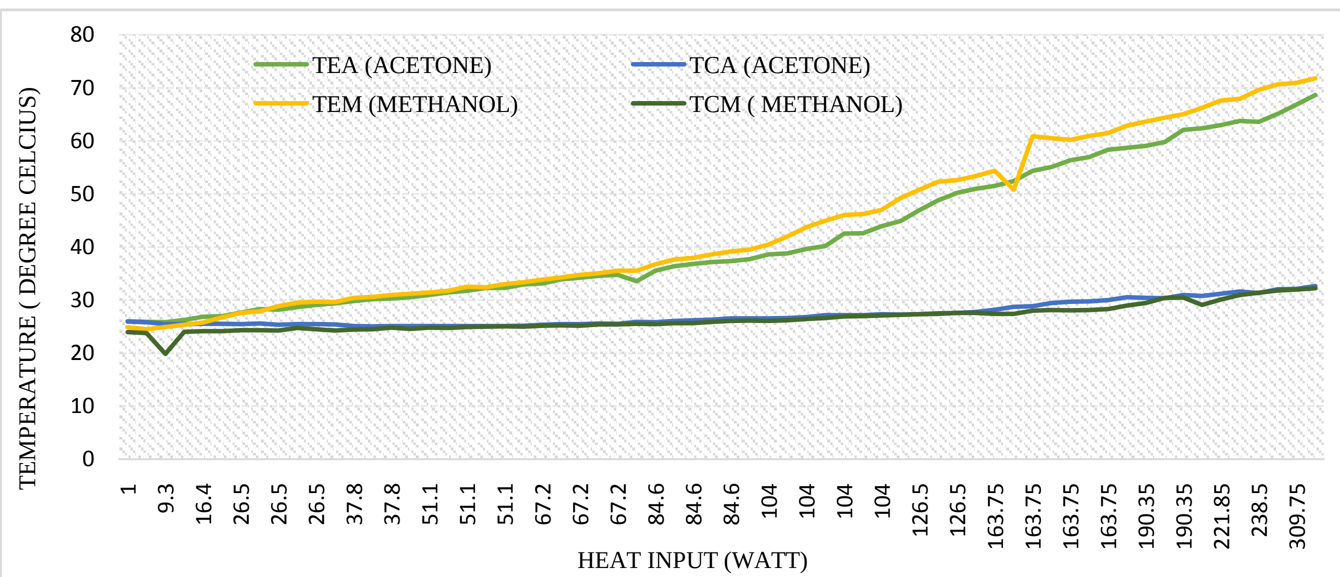

Fig. 3 Evaporator and condenser temperature of CLPHP with Acetone and Methanol as working fluid

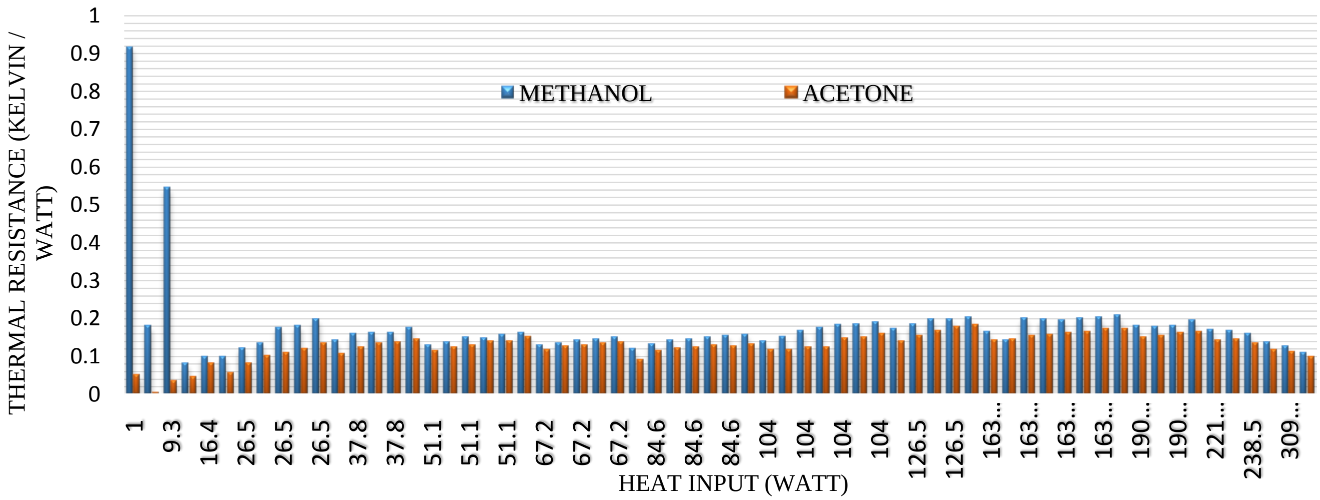

Fig. 4 Thermal resistance of CLPHP with Acetone and Methanol as working fluid

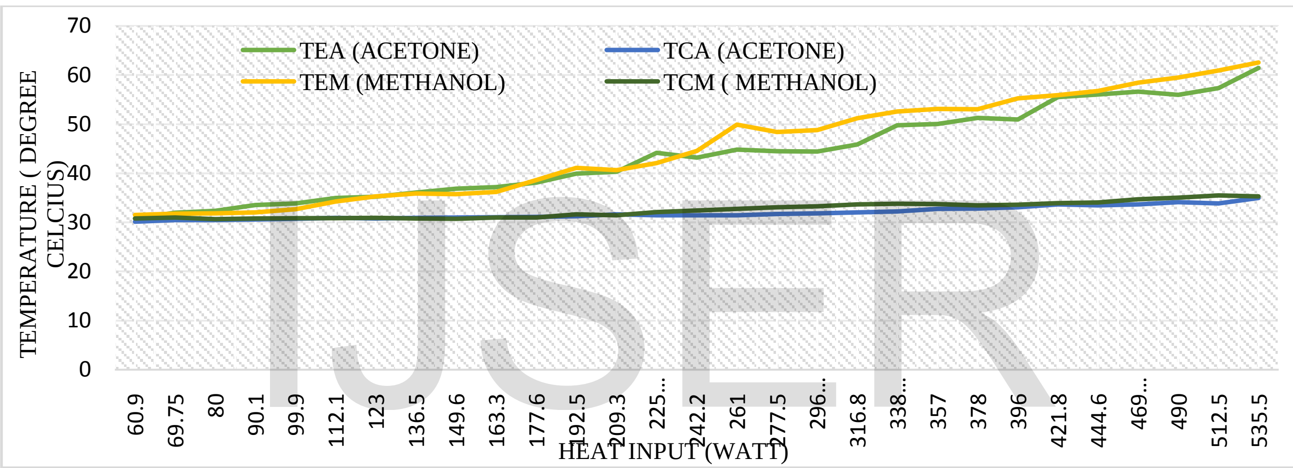

Fig. 5 Average evaporator and condenser temperature of CHP with Acetone and Methanol as working fluid

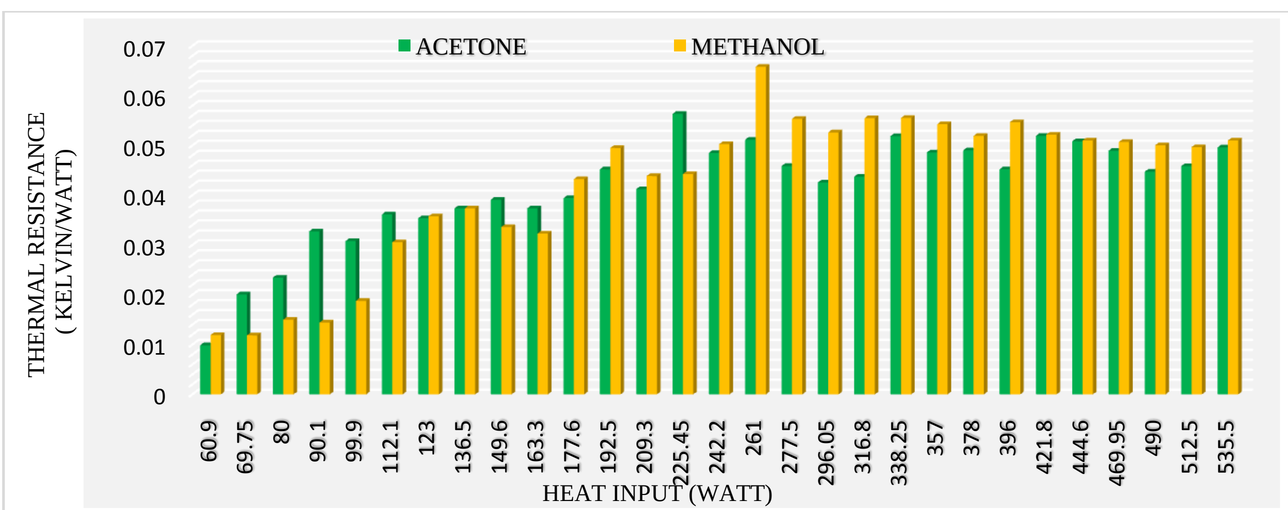

Fig. 6 Thermal resistance of CHP with Acetone and Methanol as working fluid

4 RESULT AND DISCUSSION

4.1 Result for CLPHP

It was observed during the experimentation that as the water bath temperature increases there is increase in evaporator and condenser temperature of CLPHP. With increase in the heat input the thermal resistance of CLPHP decreases. For Methanol it was observed that the thermal resistance decreases with increase in heat input. For Acetone it was observed that the thermal resistance of CLPHP first increases then decreases. After comparing the thermal resistance of CLPHP with Acetone and Methanol as working fluid, it was observed that at the same heat input and the filling ratio of 60 % Acetone has lesser thermal resistance than Methanol. CLPHP with Acetone as working fluid gives higher thermal performance.

Also it was observed from the table 1 that if the heat input is kept constant for some duration the thermal resistance is increase as shown in table 1 for the heat input of 26.5 watt initially the thermal resistance was 0.0547 for Acetone and 0.09874 for Methanol but this thermal resistance is increase if we observed the last reading of 26.5 watt the thermal resistance was found to be 0.13548 for Acetone and 0.1987 for Methanol. This shows that if the heat input is kept constant for longer period of time the thermal resistance of both working fluid increases. But when the heat input is change as if we observed the reading from 26.5 watt to 37.8 watt, there is sudden drop in the thermal resistance for Acetone from the value of 0.135 to 0.1062 and for Methanol drop in the thermal resistance from 0.1987 to 0.1419. When the heat input was not kept constant as per the reading at 221.85 watt to 360.75 watt, sudden drop in the thermal resistance was observed for Acetone and Methanol. The thermal resistance of Acetone was change from 0.1449 to 0.09 and for Methanol the thermal resistance was change from 0.1667 to 0.1097. At negligible heat input of 1 watt, the thermal resistance of Methanol found to be very high as depicted in fig. 4.

4.2 Result for CHP

It was observed during the experimentation that, as the Water bath temperature increases there is increase in evaporator and condenser temperature of CHP. With increase in the heat input the thermal resistance of CHP increases for each of the working fluid. After comparing the thermal resistance of CHP with Acetone and Methanol as working fluid, it was observed that at the same heat input and the filling ratio of 60 % Acetone has higher thermal resistance than Methanol at lower heat input i.e. from 60.9 watt to 163.3 watt, but when the heat input is increase the thermal resistance of Acetone is lower than Methanol i.e. from 177.6 watt to 535.5 watt. Methanol has higher thermal resistance than Acetone at the heat input of 177.6 watt to 535.5 watt.

The evaporator temperature for Methanol was found to be higher than Acetone at the heat input from 225.45 watt to 535.5 watt, whereas, the evaporator temperature for Acetone is lower than Methanol from 225.45 watt to 535.5 watt.

4.3 Discussion

4.3.1 Discussion for CLPHP

The latent heat for Methanol is 1101 kJ/kg while the latent heat for Acetone 523 kJ/kg, so the CLPHP with Acetone as working fluid can be used for lower heat application in the temperature range of 0 to 68.65 as shown in table 1, because excessive heat can cause the dry out of working fluid. Whereas, Methanol can be used for higher heat applications in the temperature range of 0 to 71.76 as shown in the table 1 the advantage associated with Acetone due to lower latent heat is that it required less heat for converting liquid into vapour. The working fluid with higher value of Bond number gives higher thermal performance than the working fluid with lower value of Bond number. Acetone has lesser thermal resistance and has higher Bond number, whereas Methanol has higher thermal resistance and lower Bond number.

The evaporator temperature increases more rapidly when both the working fluid reaches to their boiling point this can be observed from the fig. 3 the evaporator temperature of Acetone and Methanol increases rapidly after heat input of 67.2 watt. And there is more difference in the evaporator temperatures for Acetone and Methanol after the heat input of 104 watt this is clearly observed from the fig. 3. Whereas the condenser temperature remains nearly same for both working fluid till the heat input reaches to 163.75 watt but after that some difference can be observed up to the heat input of 238.5 watt as shown in fig.3.

4.3.2 Discussion for CHP

The latent heat for Methanol is 1101 kJ/kg while the latent heat for Acetone 523 kJ/kg, so the CHP with Acetone as working fluid can be used for lower heat application, because excessive heat can cause the dry out of working fluid. Methanol can be used for intermediate heat applications. The advantage associated with Acetone due to lower latent heat is that it required less heat for converting liquid into vapour. Considerable loss of heat takes place from the length of heat pipe exposed to surrounding, hence glass wool insulation is provided making it an adiabatic section of 6.49 *inch* length.

The effect of heat input and thermal resistance on thermal performance of CHP is not so clear from the fig. 6, as the results obtained are not straight forward either in terms of heat input increases and thermal performance increases or heat input increases and thermal performance decreases. Large variation in thermal resistance is observed at heat input from 60.9 watt to 535.5 watt, for the two working fluids used i.e. Acetone and Methanol. Also, it was observed from fig. 6 that the thermal performance of CHP with Acetone and Methanol as a working fluid depends entirely on operating temperature range that the working fluid is subjected, i.e. working fluid may give higher thermal performance at lower heat input and may give lower thermal performance at higher heat input and vice versa.

4.4 Sources of Errors

- The temperature of tube from T_1 to $T_{12}$for CLPHP and temperature of tube fromT_1 to T_8 for CHPis measured with the help of digital LASER thermometer, the accuracy of digital LASER thermometer depends on the distance to spot ratio. Hence, improper distance to spot ratio has possibility of creating errors while measurement of evaporator and condenser temperature.
- For investigating the thermal performance of CLPHP and CHPwith Acetone and Methanol as working fluid, the temperature should be noted at ambient condition, there could be errors while the observations are recorded with three different working fluid i.e. acetone and methanol. If Water bath temperature is not same during experimentation.
- Heat loss from Water to the surrounding should be minimize to maximum possible extent to avoid deceptive evaporator and condenser readings.
- Heat loss from the heat pipe to the surrounding cannot be completely eliminated even though insulation is provided on heat pipe as digital laser thermometer is used because, it requires bare spot on heat pipe for measuring temperature.
- Care should be taken to avoid excessive heat inputs which may cause drying out of working fluid in the tubes.

5 CONCLUSIONS

5.1 Conclusion for CLPHP

When water bath temperature increases, there is increase in the evaporator and condenser temperature of CLPHP. The condenser temperature increases more rapidly when the water bath temperature reaches to the boiling point of working fluid used in CLPHP. The thermal resistance of CLPHP decreases with increase in heat input. The thermal resistance of CLPHP with Acetone as working fluid is less as compared to thermal resistance of Methanol at same heat inputs and filling ratio of 60 %. Hence from the experimentation, it can be concluded that out of the two hydrocarbon working fluids, the thermal performance of Acetone is higher. CLPHP is a highly attractive heat transfer technology due to its excellent thermal performance, it is expected to meet the requirement for smaller heat transfer device which can transfer heat with minimum temperature difference.

5.2 Conclusion for CHP

When Water bath temperature increases, there is increase in the evaporator and condenser temperature of CHP. The condenser temperature increases more rapidly when the Water bath temperature reaches to the boiling point of working fluid used in CHP. For lower heat input Acetone has higher thermal resistance than Methanol and for higher heat input Acetone has lower thermal resistance than Methanol at same heat input and filling ratio of 60 %. Hence from the experimentation, it can be concluded that out of the two hydrocarbon working fluid, for lower heat input thermal performance of Methanol is higher and for higher heat input thermal performance of Acetone is higher.

5.3 Final Conclusion on Thermal Performance for CLPHP and CHP

After comparing the thermal resistance of CLPHP and CHP, it was observed that for CLPHP thermal resistance of Acetone is lower than the thermal resistance of Methanol at all the given heat input i.e. thermal performance of Acetone is higher from 1 watt to 309.75 watt, at same heat input and filling ratio of 60%. For CHP Acetone has higher thermal resistance than Methanol at lower heat input and lower thermal resistance than Methanol at higher heat input. Hence at lower heat input i.e. from 60.9 watt to 163.3 watt, thermal performance of Methanol is higher and at higher heat input i.e. from 177.6 watt to 535.5 watt thermal performance of Acetone is higher.

NONMENCLATURE

CHP	Conventional heat pipe
PHP	Pulsating heat pipe
CLPHP	Closed loop pulsating heat pipe
LASER	Light amplification by stimulated emission of radiation
V	Voltage
I	Current
Q	Heat input
W	Watt
T	Temperature $in^0 C$
TEM	Average evaporator temperature of Methanol
TCM	Average condenser temperature of Methanol
TEA	Average evaporator temperature of Acetone
TCA	Average condenser temperature of Acetone
VAC	Variable AC power supply
Rtherm	Thermal resistance

REFERENCES

[1] Harley, C., and Faghri, A., 1995, "Two-Dimensional Rotating Heat Pipe Analysis," Journal of Heat Transfer, 117(1), 202-208. http://dx.doi.org/10.1115/1.2822304
[2] Perkins, J., 1836, UK Patent No. 7059.
[3] Gaugler, R., 1944, "Heat Transfer Device," U.S. Patent No. 2350348.

[4] Trefethen, L., 1962, "On the Surface Tension Pumping of Liquids or a Possible Role of the Candlewick in Space Exploration," G.E. Tech.Info., Serial No. 615 D114.

[5] Cotter, T. P., 1965, "Theory of Heat Pipes," Los Alamos Scientific Laboratory Report No. LA-3246-MS.

[6] Grover, G., 1966, "Evaporation-Condensation Heat Transfer Device,"U.S. Patent No. 3229759.

[7] Akachi H., Polasek F., Stulc P., 1990, "Pulsating Heat Pipes", Proceedings of 5^{th} International Heat Pipe Symposium, Melbourne, Australia, 208-217.

[8] Khandekar S., Groll M., 2003, "On the Definition of Pulsating Heat Pipe", Proceedings of 5^{th} Minsk International Seminar (Heat Pipes, Heat Pumps and Refrigerators), Minsk, Belarus.

[9] Dadong Wang, Xiaoyu. Cui, 2010, "Experimental Research on Pulsating Heat Pipe with Different Mixtures Working Fluids", the 21^{st} International Symposium on Transport Phenomena 2-5 November, Kaohsiung City, Taiwan.

[10] Narasimha K. R., Sridhara S.N., Rajagopal M.S., Seetharamu K.N., 2012, "Influence of Heat Input, Working Fluid and Evacuation Level on the Performance of Pulsating Heat Pipe", Journal of Applied Fluid Mechanics, 5(2), 33-42.

[11] Shafii M. B., Faghri A., Zhang Y., 2001, "Thermal Modeling of Unlooped and Looped Pulsating Heat Pipes", ASME Journal of Heat Transfer 123 (2001) 1159-1172. http://dx.doi.org/10.1115/1.1409266

[12] Charoensawan P., Khandekar S. Groll M., 2004, "Closed Loop and Open Loop Pulsating Heat Pipes", Proceedings of 13^{th} International Heat Pipe Conference, Shanghai, China, pp.21-25.

[13] Khandekar S., Dollinger N., Groll M., 2003, "Understanding Operational Regimes of Closed Loop Pulsating Heat Pipes: An Experimental Study,"

[14] Groll M., Khandekar S., 2004, "An Insight into Thermo-Hydrodynamic Coupling in Closed Loop Pulsating Heat Pipes," International Journal ofThermal Sciences, 43, 13-20. http://dx.doi.org/10.1016/S1290-0729(03)00100-5

[15] Arab M., Soltanieh M., Shafii M., 2012, "ExperimentalInvestigation ofExtra-Long Pulsating Heat Pipe Application in Solar Water Heaters,"Experimental Thermal and Fluid Science, 42, 6-15.http://dx.doi.org/10.1016/j.expthermflusci.2012.03.006

[16] Khandekar S., Groll M., Charoensawan P., Terdtoon P., 2002, "Pulsating Heat Pipes: Thermo-Fluidic Characteristics and Comparative Study with Single Phase Thermosyphon", Proceedings of 12^{th} International Heat Transfer Conference, ISBN-2-84299-307-1, 4, 459-464.

[17] Charoensawan, P., Khandekar, S., Groll, M., Terdtoon, P., 2003 "Closed Loop Pulsating Heat Pipes- Part A: Parametric Experimental Investigations," Applied Thermal Engineering," 23(16), 2009-2020. http://dx.doi.org/10.1016/s1359-4311(03)00159-5

[18] Khandekar, S., Charoensawan, P., Groll, M., Terdtoon, P., 2003, "Closed Loop Pulsating Heat Pipes- Part B: Visualization and Semi-Empirical Modeling," Applied Thermal Engineering, 23(16), 2021-2033, http://dx.doi.org/10.1016/s1359-4311(03)00168-6

[19] Zhang, Y., Faghri, A., 2002, "Heat Transfer in a Pulsating Heat Pipe with Open End," International Journal of Heat Mass Transfer, 45, 755-764. http://dx.doi.org/10.1016/s0017-9310(01)00203-4

[20] Shafii, M. B., Faghri, A., Zhang, Y., 2002, "Analysis of Heat Transfer in Unlooped and Looped Pulsating Heat Pipes," International Journal of Numerical Methods for Heat and Fluid Flow, 12(5), 585-609. http://dx.doi.org/10.1108/09615530210434304

[21] Tong B.Y., Wong T.N., Ooi K.T., 2001, "Closed Loop Pulsating Heat Pipe," Applied Thermal Engineering, 21(18), 1845-1862. http://dx.doi.org/10.1016/S1359-4311(01)00063-1

[22] Amir Faghri, 2014, "Heat Pipes: Review, Opportunities and Challenges," Frontiers in Heat Pipes, 5, 1 http://dx.doi.org10.5098/fhp.5.1

[23] Bhagat R.D., Watt K.M., 2014, "Closed Loop Pulsating Heat Pipe with Hydrocarbon as Working Fluid: A Review," International Journal of Science and Research, 3(10), 1576-1579.

[24] Bhagat R.D., Watt K.M., 2015, "Effect of Dimensionless Number on Thermal Performance of Closed Loop Pulsating Heat Pipe: A Review, "International Journal of Science and Research, 4(2), 486-491.

[25] Bhagat R.D., Watt K.M., 2015, "An Experimental Investigation of Methanol Closed Loop Pulsating Heat Pipe at Variable Water Bath Temperature," International Journal of Science and Research (IJSR), 4(2), 1157-1161.

[26] Bhagat R.D., Watt K.M., 2015. "Effect of Water Bath Temperature on Evaporator and Condenser Temperature of Closed Loop Pulsating Heat Pipe with Acetone as Working Fluid," International Journal for Research in Engineering and Technology, 4(2), 383-387. http://dx.doi.org/10.15623/ijret.2015.0402050

[27] Bhagat R.D., Watt K.M., 2015, "Experimentation to Predict the Thermal Performance of Closed Loop Pulsating Heat Pipe with Acetone and Methanol as Working Fluid," International Journal for Research in Engineering and Technology, 4(4), 23-27. http://dx.doi.org/10.15623/ijret.2015.0404005

[28] Bhagat R.D., Watt K.M., 2015, "Performance Investigation of Closed Loop Pulsating Heat Pipe with Acetone as Working Fluid," International Journal for Research in Engineering and Technology, 4(4), 1-4. http://dx.doi.org/10.15623/ijret.2015.0404001

[29] Bhagat R.D., Watt K.M., 2015, "Performance Investigation of Closed Loop Pulsating Heat Pipe with Methanol as Working Fluid", Proceedings of Mechanical Engineering Post Graduate Conference at PRMIT & R Badnera-Amravati, MEPCON-2015. International Journal of Innovative and Emerging Research in Engineering, 2(1), 57-61.

[30] Bhagat R.D., Watt K.M., 2015, "Effect of Bond Number on Thermophysical Properties of Working Fluid used in Closed Loop Pulsating Heat Pipe: A Review," International Journal of Science and Research (IJSR), 4(9), 544-551.

[31] Bhagat R.D., Watt K.M., 2016, "Effect of Bond Number, Working Fluid and Operating Temperature on Thermal Performance of Closed Loop Pulsating Heat Pipe", International Conference of Science Technology and Sustainable Development Kuala Lumpur, Malaysia, Satellite Venue at PRMIT & R Badnera-Amravati, ICSTSD 2016.

[32] Bhagat R.D., Watt K.M., 2015, "An Experimental Investigation of Heat Transfer Capability and Thermal Performance of Closed LoopPulsating Heat Pipe with A Hydrocarbon as Working Fluid" Frontiers in Heat Pipes, 6, 7 http://dx.doi.org10.5098/fhp.6.7

[33] Bhagat R.D., Thakare S.R., Makwana S.C., 2016, "Experimentation To Predict the Thermal Performance of Conventional Heat Pipe with Water and Hydrocarbon as Working Fluid", International Journal for Research in Engineering and Technology, 5(3), 404-411. https://doi.org/10.15623/ijret.2016.0503073

[34] Bhagat R.D., Dhomane S.P., 2016, "Performance Investigation of Conventional Heat Pipe with Hydrocarbon as Working Fluid", International Journal for Research in Engineering and Technology, 5(3), 252-258. https://doi.org/10.15623/ijret.2016.0503050

[35] Bhagat R.D., 2016, "Experimental Investigation of Thermal Performance of Conventional Heat Pipe with Water, Acetone and Methanol as Working Fluid", Frontiers in Heat Pipes, 7, 4http://dx.doi.org10.5098/fhp.7.4