IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X
PP. 33-37
www.iosrjournals.org

Performance Investigation of Closed Loop Pulsating Heat Pipe with Water and Hydrocarbon as Working Fluid

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Abstract : *An Experimental Investigation Of Closed Loop Pulsating Heat Pipes (Clphps) With Water And 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 And 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 Behaviour Of CLPHP Under Different Heat Inputs And With The Different Working Fluids. To Achieve The Goal The Experimental Setup Is Fabricated And Tested With Three Different Working Fluids Acetone And Methanol And Water With The Filling Ratio Of 60 %. This Work Provides The Detailed Discussion On The Thermal Performance Of CLPHP With Acetone, Methanol And Water As Working Fluid And Behaviour Of CLPHP At Different Heat Inputs*

Keywords -*Heat Input, Pulsating, Thermal Resistance, Working Fluid.*

I. INTRODUCTION

The Pulsating Heat Pipe (PHP) Is A Two-Phase Passive Heat Transfer Device Proposed And Patented By Akachi (1990). The Closed Loop Pulsating Heat Pipe (CLPHP) Is A Heat Exchanger With Very High Thermal Conductivity. It Was Invented To Meet The Requirement For Smaller Heat Transfer Device. It Can Transfer Sufficient Heat For Heat Dissipation Applications In Modern Electronics Devices. The CLPHP Is 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 CLPHP 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 Where The Slug/Plug Pumping Action Will Be Generated. The Working Fluid Then Flows By The Adiabatic Section Towards The Condenser Section. On A Closed Loop Configuration, The Working Fluid Is Allowed To Circulate And After Being Condensed And Returns To The Evaporator 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.

The Pipe Is First Evacuated And Then Filled Partially With A Working Fluid. If The Diameters Of CLPHP Is Not Too Large, The Working Fluid Distributes Itself Into An Arrangement Of Liquid Slugs Separated By Vapour Bubbles. One End Of This Tube Bundle Receives Heat Transferring It To The Other End By A Pulsating Action Of The Liquid-Vapour/Slug-Bubble System. The Liquid And Vapour Slug/Bubble Transport Is Caused By The Thermally Induced Pressure Pulsations Inside The Device And No External Mechanical Power Is Required. The Type Of Working Fluid And The Operating Pressure Inside The Pulsating Heat Pipe Depends On The Operating Temperature Of The Heat Pipe. The Region Between Evaporator And Condenser Is Adiabatic. The Heat Is Transfer From Evaporator To Condenser By The Means Of Pulsating Action Of Vapour And Liquid Slug.

The Objective Of The Present Work Is To Study The CLPHP With Water And Hydrocarbon As Working Fluid With Three Turns In The Evaporator Section And Two Small Turn And One Large Turn In Condenser Section. In The Present Work Thermal Performance Of CLPHP With Acetone And Methanol And Water As Working Fluid Is Investigated At Different Heat Inputs Having Filling Ratio Of 60 %. Also The Effect Of Water Bath Temperature On Evaporator And Condenser Temperature Of CLPHP With Acetone And Methanol And Water As Working Fluid Is Studied.

II. EXPERIMENTATION

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 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

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 CLPHP With Acetone And Methanol And Water As Working Fluid. The Boiling Point Of Water 100^0C Methanol Is 64^0C And Acetone 57^0C, 60 % Filling Ratio Has Been Used For Water And Hydrocarbon.

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 In Evaporator

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 With Acetone, Methanol And Water As Working Fluid.

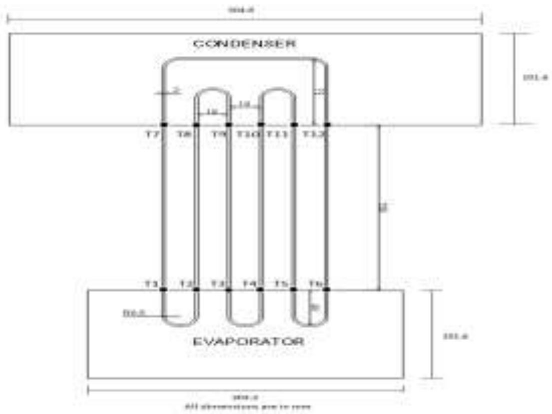

Fig. 1 Specification Of Experimental Setup Of Closed Loop Pulsating Heat Pipe

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.

Calculation

The Thermal Resistance Of CLPHP Can Be Calculated By Using The Following Equations,

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

$$Q = V \times I \quad (2)$$

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

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

III. Result And Discussion

3.1 RESULT

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 And Water 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 And Water 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 And Water. CLPHP With Acetone As Working Fluid Gives Higher Thermal Performance.

3.2 DISCUSSION

The Latent Heat For Methanol Is 1101 Kj/Kg While The Latent Heat For Acetone 523 Kj/Kg, And Water 2255 Kj/Kg So The CLPHP With Acetone As Working Fluid Can Be Used For Lower Heat Application In The Temperature Range, Because Excessive Heat Can Cause The Dry Out Of Working Fluid. Whereas, Methanol And Water Can Be Used For Comparatively Higher Heat Applications 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 Of Working Fluid Used In CLPHP

Table 1 Thermal Resistance Of CLPHP With Acetone And Methanol As And Water As Working Fluid

S.N.	Heat Input	Thermal Resistance Of Acetone	Thermal Resistance Of Methanol	Thermal Resistance Of Water
1	1	0.05	0.916666667	0.9765
2	4	0.004166667	0.179166667	0.189146
3	26.5	0.135849057	0.174213836	0.194255
4	37.8	0.134920635	0.162698413	0.174266
5	51.1	0.129810828	0.156555773	0.160387
6	67.2	0.126240079	0.150793651	0.1594985
7	84.6	0.125492514	0.150118203	0.155554
8	104	0.125320513	0.138621795	0.148644
9	285.45	0.115840486	0.136159281	0.140765
10	309.75	0.112294861	0.125961797	0.135876
11	360.75	0.0998845	0.10972511	0.125987

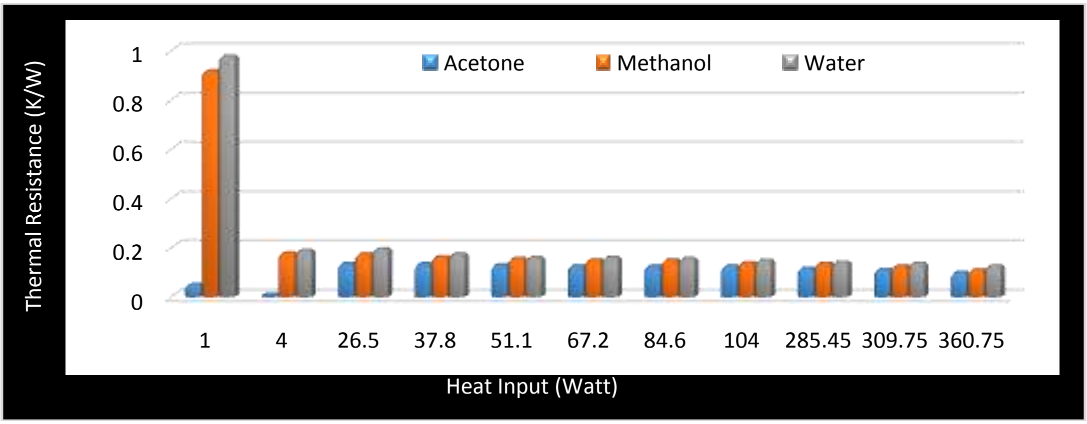

Fig. 2 Thermal Resistance Of CLPHP With Acetone, Methanol And Water As Working Fluid

3.3 SOURCES OF ERRORS

- The Temperature Of Tube From T_1 To T_{12} Is 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 With Acetone And Methanol As Working Fluid, The Temperature Should Be Noted At Ambient Condition, There Could Be Errors While The Observations Obtained With Different Working Fluids, If Water Bath Temperature Is Not Same In All Experimentation.
- Heat Loss From Water To The Surrounding Should Be Minimize To Maximum Possible Extent To Avoid Deceptive Evaporator And Condenser Readings.
- Care Should Be Taken To Avoid Excessive Heat Inputs Which May Cause Drying Out Of Working Fluid In The Tubes.

IV. CONCLUSION

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 And Water At Same Heat Inputs And Filling Ratio Of 60 %. Hence From The Experimentation, It Can Be Concluded That Out Of The Two Hydrocarbon And Water As 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.

References

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

[2]. 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.

[3]. 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.

[4]. 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, Vol. 5/2, Pp. 33-42.

[5]. M. B. Shafii, A. Faghri, Y. Zhang, 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

[6]. 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.

[7]. Khandekar S., Dollinger N., Groll M., 2003, “Understanding Operational Regimes Of Closed Loop Pulsating Heat Pipes: An Experimental Study”,Applied Thermal Engineering, Vol. 23, Pp.707-719.Http://Dx.Doi.Org/10.1016/S1359-4311(02)00237-5

[8]. Arab M., Soltanieh M., Shafii M., 2012, “Experimental Investigation Of Extra-Long Pulsating Heat Pipe Application In Solar Water Heaters”,Experimental Thermal And Fluid Science,Http://Dx.Doi.Org/10.1016/J.Expthermflusci.2012.03.006

[9]. 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, Vol. 4, Pp. 459-464, Grenoble, France.

[10]. P. Charoensawan, S. Khandekar, M. Groll, P. Terdtoon, 2003 “Closed Loop Pulsating Heat Pipes- Part A: Parametric Experimental Investigations”, Applied Thermal Engineering”, Vol. 23, No. 16, Pp. 2009-2020.Http://Dx.Doi.Org/10.1016/S1359-4311(03)00159-5

[11]. S. Khandekar, P. Charoensawan, M. Groll, P. Terdtoon, 2003, “Closed Loop Pulsating Heat Pipes- Part B: Visualization And Semi-Empirical Modeling”,Applied Thermal Engineering, Vol. 23, No. 16, Pp. 2021-2033,Http://Dx.Doi.Org/10.1016/S1359-4311(03)00168-6

[12]. N. Soponpongpipat, P. Sakulchangsatjatai, N. Kammuanglue, P. Terdtoon, 2009, “Investigation Of The Start-Up Condition Of A Closed Loop Oscillating Heat Pipe”,Heat Transfer Engineering, Vol. 30, No. 8, Pp. 626-642.Http://Dx.Doi.Org/10.1080/01457630802656876

[13]. Y. Zhang, Amir Faghri, 2002, “Heat Transfer In A Pulsating Heat Pipe With Open End”, Heat Mass Transfer, Vol. 45, Pp. 755-764.Http://Dx.Doi.Org/10.1016/S0017-9310(01)00203-4

[14]. M. B. Shafii, A. Faghri, Y. Zhang, 2002, “Analysis Of Heat Transfer In Unlooped And Looped Pulsating Heat Pipes”,International Journal Of Numerical Methods For Heat And Fluid Flow, Vol. 12, No. 5, Pp. 585-609, Http://Dx.Doi.Org/10.1108/09615530210434304

[15]. Tong B.Y., Wong T.N., Ooi K.T., 2001, “Closed Loop Pulsating Heat Pipe”,Applied Thermal Engineering, ISSN 1359-4311, Vol. 21/18, Pp. 1845-1862. Http://Dx.Doi.Org/10.1016/S1359-4311(01)00063-1

[16]. Kothandaraman C.P., Subramanyam S., 2014, Heat And Mass Transfer Data Book, Eight Edition, New Age International Publishers Pp 189-190.

[17]. Amir Faghri, 2014, “Heat Pipes: Review, Opportunities And Challenges”,Frontiers In Heat Pipes (FHP),Global Digital Central,ISSN: 2155-658X,Http://Dx.Doi.Org10.5098/Fhp.5.1

[18]. 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.

[19]. 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.

[20]. 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.

[21]. 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

[22]. 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

[23]. 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

[24]. 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.

[25]. 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.

[26]. 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.

[27]. Bhagat R.D., Watt K.M., 2015, “An Experimental Investigation Of Heat Transfer Capability And Thermal Performance Of Closed Loop Pulsating Heat Pipe With A Hydrocarbon As Working Fluid”Frontiers In Heat Pipes, **6**, 7http://Dx.Doi.Org10.5098/Fhp.6.7

[28]. 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

[29]. 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

[30]. Bhagat R.D., 2016, “An 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.Org/10.5098/Fhp.7.4

[31]. Bhagat R.D., Watt K.M., 2017, “An Experimental Investigation On Thermal Performance Of Closed Loop Pulsating Heat Pipe And Conventional Heat Pipe With Hydrocarbon As Working Fluid”, 5th National Conference On “Innovations In Mechanical Engineering”, At SIT, Lonavala On 07-09th April 2017