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Parametric analysis in development of miniature loop heat pipe using ANOVA on heat pipe

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Abstract

Currently in many electronic devices, miniature loop heat pipe is identified as best thermal cooling device. In development of miniature loop heat pipe for application of heat load 45 watts, it necessary to understand the parameters involved which improve performance of miniature loop heat pipe. Major parameters of mlhp should be study thoroughly theoretically and experimentally are fluid charge, working fluid, non-condensable gases, gravity effect, temperature oscillation, startup process and porous wick. Here identified some parameters on basis of experimentation done on heat pipe and finally concluded with importance of wick structure in development of miniature of loop heat pipe. With the help of ANOVA using primary data of experimentation done on heat pipe, it revealed that wick structure provide major impact on reduction evaporator surface temperature and increase in condenser cooling jacket outlet temperature i.e. heat transfer coefficient.

***Key Words*:**Fluid charge, gravity effect, non-condensable gases, porous wick, startup process, temperature oscillation, working fluid.

1 INTROUDCTION

The description of LHPs with selection of working fluid according to the minimum operating temperature, maximum operating temperature, saturation pressure, maximum allowable pressure, safe properties of fluid, compatible materials and characteristics the ability of the fluid to transfer heat i.e. Merit number. According to different applications the design of evaporator and compensation chamber may be change with the amount of parasitic heat flux, vapor channels, thermal-hydraulic link and metal saddle at the evaporator. For condenser design depends on the application, the condenser elements are condensation cross-section, thermal link and mode of external heat transfer [1]. Proper liquid charging ratio should maintain at precise the start-up time, low charging ratio affects for wick-dry out and more charging ratio affects the more active area of the condenser required [2]. The thermal resistance analysis detailed that low boiling temperature working liquid acetone provides the low thermal resistance than methanol with the same inclination at different charging ratio. The heat leak phenomenon is more in

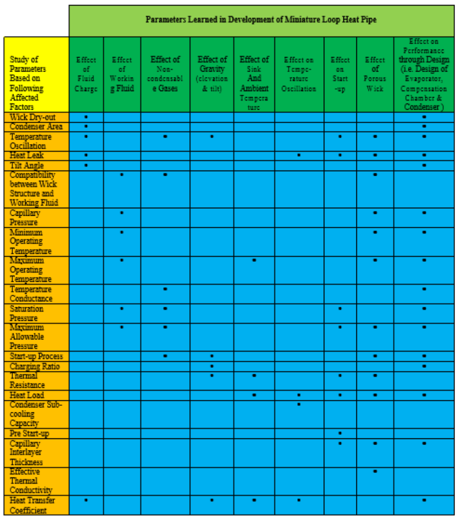
the flat shape than the cylindrical evaporator due to heating wall which also if increases higher that reduces the subcooling and produces bubbles in the compensation chamber or wick dryout which affects the characteristic of startup process i.e. the steady state and temperature oscillating state. The oscillation is depends on the properties of the working fluid, tilt angles, charging ratios, heat loads and the distribution of the liquid/gas in the compensation chamber [3].

The optimal LHP design investigated for the elevated temperature application, the compatibility between the material and working fluid has been identified as one of the main factor for NCG generation. The behavior was observed on the basis different amounts of nitrogen injected in its compensation chamber to simulate NCG generation is analyzed and observed decrease in the LHP thermal conductance. Design of the LHP operating up to high temperature and test set-up made for set of potential combinations of working fluid, envelope material and wick material. Operation of LHP without NCG and with NCG carried for checking LHP performance with heat transfer capability, temperature profile evolution, thermal conductance evolution and other effects of NCG. With results of tests and simulations the conclusion made that the LHP maximum heat transport capability is practically independent of the presence and quantity of NCG in compensation chamber. The additional temperature difference produced by the NCG is less significant at high power levels; make it very difficult to establish any relation between the addition of NCG and the variations in the evaporator conductance. Unstable operation of the LHP found at largest NCG amount due to oscillation in the LHP temperature and pressure. The simulation model has confirmed as oscillatory behavior of the LHP for significant NCG amounts at low powers, linked to the vapor/liquid front oscillation between the vapor line outlet and condenser inlet [4].

Originate the relationship between the startup time with increase in the heat load (particular range) affects the condenser length and outlet temperature or sub-cooling. Start-up phenomenon occurs due to filling of the liquid into the LHP components with finally filled into the compensation chamber and pressure difference across the wick to circulate liquid in the loop (condition achieved when the development of steady temperature difference across the wick and this thermal gradient across the wick due to hydraulic losses). Also introduce the concept of the pre start-up inside the evaporator and compensation chamber for the dropping the start-up time or the time requisite for stable temperature gradient across the wick. Temperature oscillation occurred at the small range of heat load continuously for heat leaks from evaporator to the compensation chamber and for condenser sub-cooling capacity which may convey hot charge to the compensation chamber. Damping amplitude of the temperature oscillations at particular range of heat load done by the liquid flow from condenser to compensation chamber and liquid present inside the compensation chamber [2].

2 PARAMETRIC STUDY AND EXPERIMENTAL PROCEDURE

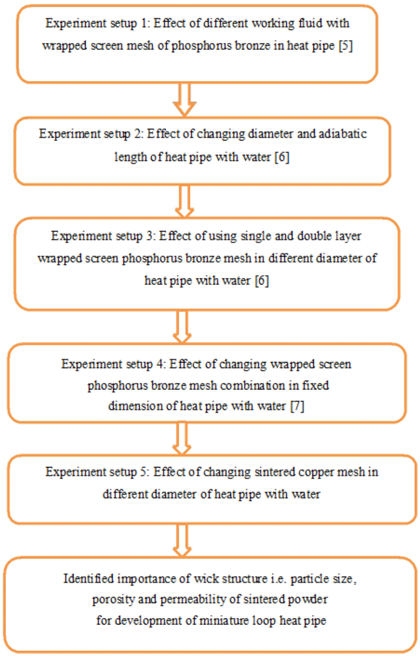
Table 1. Parameters investigated from literature of miniature loop heat pipe [1-74]



	Parameters Learned in Development of Miniature Loop Heat Pipe								
Study of Parameters Based on Following Affected Factors	Effect of Fluid Charge	Effect of Working Fluid	Effect of Non-condensable Gases	Effect of Gravity (elevation & tilt)	Effect of Sink And Ambient Temperature	Effect on Temperature Oscillation	Effect on Start-up	Effect of Porous Wick	Effect on Performance through Design (i.e. Design of Evaporator, Compensation Chamber & Condenser)
Wick Dry-out	●								●
Condenser Area	●								●
Temperature Oscillation	●		●	●			●	●	●
Heat Leak	●					●	●	●	●
Tilt Angle	●								●
Compatibility between Wick Structure and Working Fluid		●	●					●	
Capillary Pressure		●						●	●
Minimum Operating Temperature		●						●	●
Maximum Operating Temperature		●			●			●	●
Temperature Conductance			●						●
Saturation Pressure		●	●				●		●
Maximum Allowable Pressure		●	●				●	●	●
Start-up Process			●	●				●	●
Charging Ratio				●					●
Thermal Resistance				●	●		●	●	
Heat Load					●	●	●	●	●
Condenser Sub-cooling Capacity						●			
Pre Start-up							●		
Capillary Interlayer Thickness							●	●	●
Effective Thermal Conductivity								●	
Heat Transfer Coefficient	●			●	●	●			●

Main parameters of miniature loop heat pipe are identified for development and performance improvement with applied heat load. From table 1, it identified the main parameters are selection of working fluid, wick structure dimension and wick structure property that more impact on performance and in development of miniature loop heat pipe. Possible parameters find during experimentation and testing on heat pipe to identify main effective parameter at starting in development of miniature loop heat pipe.

Flow chart of experimentation to find effectiveness of wick structure in miniature loop heat pipe.



Finally from study of literature on miniature loop heat pipe and experimentation done on heat pipe, we identified the development of wick structure is more important than any other parameters in proper working of miniature loop heat pipe at applied heat load. In development of wick structure will identify the parameters like particle size, porosity, permeability, capillary pressure and effective thermal conductivity, which are more effectively elaborate the working of miniature loop heat pipe at applied heat load.

3 RESULT AND DISCUSSION

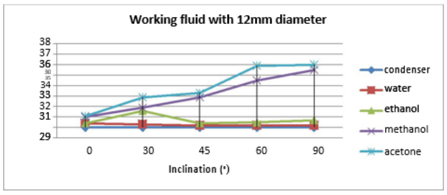


Figure 1. Heat pipe with different working fluid with 12 mm diameter of wrapped screen mesh

The design of the heat pipe jackets are such that the inside area of jacket on evaporator section and inside area of jacket on condenser section is same. For experiment purpose, same flow rate of cold water over condenser section and hot water over evaporator section is maintained. The adiabatic section is used as 10% of the total length and remaining length is equally distributed in evaporator section and condenser section. The heat pipe shape is annular with copper material used for manufacturing pipe. The wick material used is phosphorus bronze and wick structure used for heat pipe is wrapped screen with single layer of wick with 180 wire mesh. The diameter of heat pipe is 12mm and evaporator section is directly below the condenser section at 90° inclination. The design of each pipe same as above, only the working fluid is different such as water, acetone, ethanol and methanol [5]. Selection of water as working fluid for further research as its property of compatibility with wick material, low pressure working fluid, high surface tension, high figure of merit number.

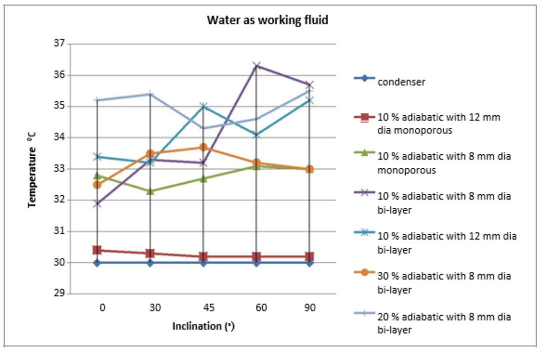


Figure 2. Heat pipe with different adiabatic section, single and double layer mesh with water

Here we study the unlike heat pipes using dissimilar diameter, wire mesh layer and adiabatic section for diverse application of heat pipe. The configuration of cooling jacket and heating jacket on condenser section and evaporator section such as size of jacket is same and flow rate of hot and cold water through jacket is same. The manufacturing of pipe using copper material with annular shape, also wrapped screen mesh used as wick structure with phosphorus bronze as wick material for all heat pipes. The wick material used is phosphorus bronze and wick structure used for heat pipe is wrapped screen with single layer of wick with 180 wire mesh and double layer of 180 wire meshes. The result of different heat pipes elaborate in figures with mostly used water as working fluid in all heat pipes. Also the results show the temperature of condenser inlet water and condenser outlet water with different inclinations [6]. Selection of 12 mm diameter with 25 % of adiabatic section of double layer wrapped screen mesh for further study and revealed of parameters in improvement of heat pipe performance.

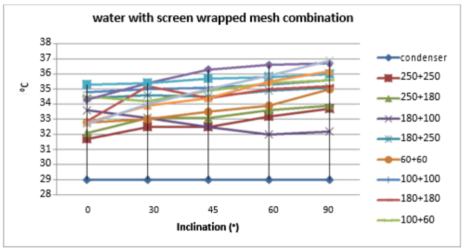


Figure 3. Heat pipe with different combination of wrapped screen mesh with water

Table 2: Parameters same for all 11 heat pipes of double layer mesh [3]

Parameter	Specification	Parameter	Specification
overall length of heat pipe	250 mm	Mass flow rate of water	4 ml/sec
Length of evaporator section	93.75 mm	Heat input	45 watt
Length of condenser section	93.75 mm	Heat pipe material	Copper
Length of adiabatic section	62.5 mm	Wick material	Phosphorus Bonze
Pipe Diameter	12 mm	Wick structure	Wrapped screen mesh
Pipe shape	Annular	At 90° inclination	Evaporator section is exactly below the condenser section.
Thickness of wick: 250 mesh	0.11mm	Thickness of wick:180 mesh	0.12mm
Thickness of wick: 100 mesh	0.205mm	Thickness of wick: 60 mesh	0.35mm

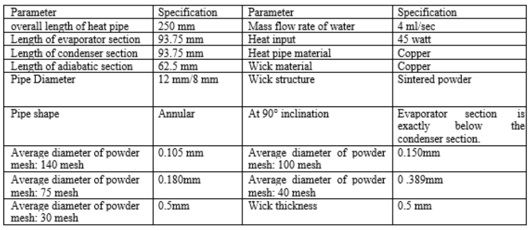
Table 3: Capillary limit at different inclination angle of combination mesh [3]

Sr. No.	Wrapped Screen Mesh type (outer + inner)	Capillary Limit in Watt at Different Inclination				
		90°	60°	45°	30°	0°
1	250+250	19.083	18.081	16.747	14.967	10.576
2	250+180	64.676	61.276	56.757	50.725	35.843
3	180+250	64.676	61.276	56.757	50.725	35.843
4	180+180	54.991	51.601	47.079	41.047	26.165
5	180+100	248.701	233.281	212.814	185.276	118.205
6	100+180	248.701	233.281	212.814	185.516	118.205
7	100+100	248.572	229.22	203.588	169.413	85.177
8	100+60	888.948	819	727.291	604.748	302.876
9	60+100	888.948	819	727.291	604.748	302.876
10	60+60	965.902	880.438	765.64	611.657	236.077

Results of dissimilar combination of double wrapped screen mesh of heat pipe shown with temperature versus inclination angle of heat pipe. Among above results the combination of 60 (outer mesh) + 100 (inner mesh) revealed highest temperature difference between condenser inlet and condenser outlet water temperature of cooling jacket. Subsequently 100 (outer mesh) + 180 (inner mesh) and 100 (outer mesh) + 100 (inner mesh) are present higher temperature difference between condenser inlet and condenser outlet. Most of the combination of double layer wrapped screen mesh shows better result at inclination angle of 90 i.e. evaporator section is exactly below the condenser section of heat pipe. Charts also show better results if use of coarse mesh at outer side (wall side) and fine mesh at inner side (liquid side) i.e. 180 (outer mesh) + 250 (inner mesh) afford better result than 250 (outer mesh) + 250 (inner mesh) and 250 (outer mesh) + 180 (inner mesh) combination in double layer wrapped screen mesh [7]. In finding performance of combination mesh heat pipe, it mainly observed different mesh have different values of porosity and permeability. 60 mesh has higher value of porosity and permeability which provides it to act with high heat transfer capacity. Based on keeping values of porosity and permeability higher for efficient working of heat pipe, further research continue with sintered copper powder with different mesh.

The Experimental setup with different components used for testing different size copper sintered powder mesh heat Pipe using water as working fluid. Here 10 heat pipes are used for testing at different inclination with dissimilar size copper sintered powder mesh heat pipe. Unlike 5 heat pipes with diameter 8 mm and 5 heat pipes with diameter 12 mm of 140 mesh, 100 mesh, 75 mesh, 40 mesh and 30 mesh of copper sintered powder mesh. Dimmerstat control heat input to evaporator section with heating coils and rotameter control water flow through cooling jacket for cooling condenser section. RTD indicator shows 7 temperatures of Evaporator end, Condenser end, condenser jacket inlet, condenser jacket outlet, adiabatic, evaporator and water bath.

Table 4: Parameters same for all 10 heat pipes of sintered powder copper mesh



Parameter	Specification	Parameter	Specification
overall length of heat pipe	250 mm	Mass flow rate of water	4 ml/sec
Length of evaporator section	93.75 mm	Heat input	45 watt
Length of condenser section	93.75 mm	Heat pipe material	Copper
Length of adiabatic section	62.5 mm	Wick material	Copper
Pipe Diameter	12 mm/8 mm	Wick structure	Sintered powder
Pipe shape	Annular	At 90° inclination	Evaporator section is exactly below the condenser section.
Average diameter of powder mesh: 140 mesh	0.105 mm	Average diameter of powder mesh: 100 mesh	0.150mm
Average diameter of powder mesh: 75 mesh	0.180mm	Average diameter of powder mesh: 40 mesh	0 .389mm
Average diameter of powder mesh: 30 mesh	0.5mm	Wick thickness	0.5 mm

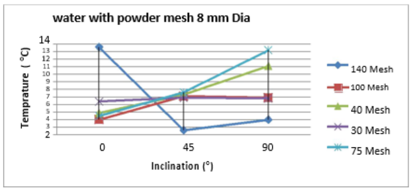


Figure 4. Heat pipe with different mesh of sintered copper using water with 8 mm diameter

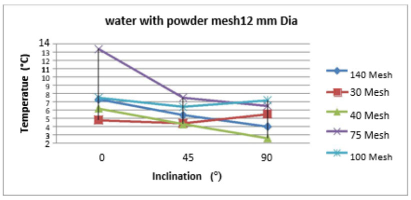


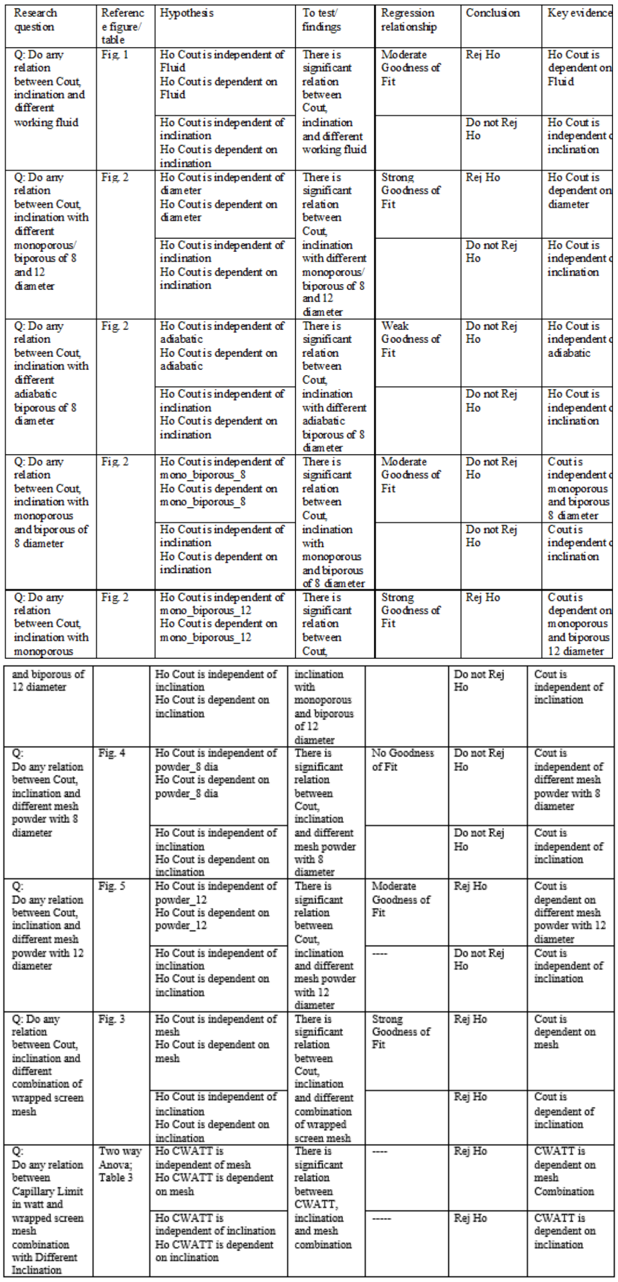
Figure 5. Heat pipe with different mesh of sintered copper using water with 12 mm diameter

For testing of sintered copper powder of different mesh, we measure evaporator side end temperature (Ein) and condenser side end temperature (Cend). Where minimum difference between Ein and Cend observed, that heat pipe shows better performance at applied heat load of 45 watt at inclination 0 , 45 and 90 . In case of heat pipe using 8 mm diameter for different mesh of sintered copper powder wick identified less difference in case of 30 mesh and 100 mesh. That indicate heat pipe of 30 mesh and 100 mesh of 8 mm diameter at corresponding length dimension sustain 45 watts heat load. In case of heat pipe using 12 mm diameter for different mesh of sintered copper powder wick identified less difference in case of 40 mesh and 30 mesh. That indicate heat pipe of 40 mesh and 30 mesh of 12 mm diameter at corresponding length dimension sustain 45 watts heat load. From experimentation of different mesh powder in heat pipe, it identified the effect of sintering process with change particle size of powder and its effect on performance of heat pipe. Research in development of miniature loop heat pipe concluded with selection of proper particle size, sintering process, percentage mixture of pore former, selection of working fluid, gravity effect and condenser cooling heat transfer coefficient.

Experimentally we find out the effects of parameters on the performance and the relation between working fluid, evaporator section diameter, wick structure dimension, wick structure property i.e. particle size, porosity and

permeability. If we focused on the wick structure incorporates with working fluid which directly impact on the performance directly and heat transfer coefficient. Also with using ANOVA we find out the relations between parameters and effectiveness of parameters. Table 5 indicates the parameters effect on condenser jacket outlet temperature, evaporator surface temperature, inclination and working at applied heat load of 45 watt. The parameters such as working fluid, monoporous, bi-layer, diameter and porosity with changing inclination affect the results.

Table 5. ANOVA result to identify parameters effected on evaporator temperature and heat transport capability.



Research question	Reference figure/ table	Hypothesis	To test/ findings	Regression relationship	Conclusion	Key evidence
Q: Do any relation between Cout, inclination and different working fluid	Fig. 1	Ho Cout is independent of Fluid Ho Cout is dependent on Fluid	There is significant relation between Cout, inclination and different working fluid	Moderate Goodness of Fit	Rej Ho	Ho Cout is dependent on Fluid
		Ho Cout is independent of inclination Ho Cout is dependent on inclination			Do not Rej Ho	Ho Cout is independent inclination
Q: Do any relation between Cout, inclination with different monoporous/ biporous of 8 and 12 diameter	Fig. 2	Ho Cout is independent of diameter Ho Cout is dependent on diameter	There is significant relation between Cout, inclination with different monoporous/ biporous of 8 and 12 diameter	Strong Goodness of Fit	Rej Ho	Ho Cout is dependent on diameter
		Ho Cout is independent of inclination Ho Cout is dependent on inclination			Do not Rej Ho	Ho Cout is independent inclination
Q: Do any relation between Cout, inclination with different adiabatic biporous of 8 diameter	Fig. 2	Ho Cout is independent of adiabatic Ho Cout is dependent on adiabatic	There is significant relation between Cout, inclination with different adiabatic biporous of 8 diameter	Weak Goodness of Fit	Do not Rej Ho	Ho Cout is independent adiabatic
		Ho Cout is independent of inclination Ho Cout is dependent on inclination			Do not Rej Ho	Ho Cout is independent inclination
Q: Do any relation between Cout, inclination with monoporous and biporous of 8 diameter	Fig. 2	Ho Cout is independent of mono_biporous_8 Ho Cout is dependent on mono_biporous_8	There is significant relation between Cout, inclination with monoporous and biporous of 8 diameter	Moderate Goodness of Fit	Do not Rej Ho	Cout is independent monoporous and biporous 8 diameter
		Ho Cout is independent of inclination Ho Cout is dependent on inclination			Do not Rej Ho	Cout is independent inclination
Q: Do any relation between Cout, inclination with monoporous and biporous of 12 diameter	Fig. 2	Ho Cout is independent of mono_biporous_12 Ho Cout is dependent on mono_biporous_12	There is significant relation between Cout, inclination with monoporous and biporous of 12 diameter	Strong Goodness of Fit	Rej Ho	Cout is dependent on monoporous and biporous 12 diameter
		Ho Cout is independent of inclination Ho Cout is dependent on inclination			Do not Rej Ho	Cout is independent of inclination
Q: Do any relation between Cout, inclination and different mesh powder with 8 diameter	Fig. 4	Ho Cout is independent of powder_8 dia Ho Cout is dependent on powder_8 dia	There is significant relation between Cout, inclination and different mesh powder with 8 diameter	No Goodness of Fit	Do not Rej Ho	Cout is independent of different mesh powder with 8 diameter
		Ho Cout is independent of inclination Ho Cout is dependent on inclination			Do not Rej Ho	Cout is independent of inclination
Q: Do any relation between Cout, inclination and different mesh powder with 12 diameter	Fig. 5	Ho Cout is independent of powder_12 Ho Cout is dependent on powder_12	There is significant relation between Cout, inclination and different mesh powder with 12 diameter	Moderate Goodness of Fit	Rej Ho	Cout is dependent on different mesh powder with 12 diameter
		Ho Cout is independent of inclination Ho Cout is dependent on inclination		----	Do not Rej Ho	Cout is independent of inclination
Q: Do any relation between Cout, inclination and different combination of wrapped screen mesh	Fig. 3	Ho Cout is independent of mesh Ho Cout is dependent on mesh	There is significant relation between Cout, inclination and different combination of wrapped screen mesh	Strong Goodness of Fit	Rej Ho	Cout is dependent on mesh
		Ho Cout is independent of inclination Ho Cout is dependent on inclination			Rej Ho	Cout is dependent of inclination
Q: Do any relation between Capillary Limit in watt and wrapped screen mesh combination with Different Inclination	Two way Anova; Table 3	Ho CWATT is independent of mesh Ho CWATT is dependent on mesh	There is significant relation between CWATT, inclination and mesh combination	----	Rej Ho	CWATT is dependent on mesh Combination
		Ho CWATT is independent of inclination Ho CWATT is dependent on inclination		-----	Rej Ho	CWATT is dependent on inclination

4 CONCLUSION

With the study of parameters involved in development of miniature loop heat pipe, identify many factor which effects working at applied heat load. To handle such factor, experimentation and parametric analysis must be done for development of miniature loop heat pipe. For this research done and concluded with following fact:

1) Parametric analysis of miniature loop heat pipe shows many factors which effects on performance and should handle properly in development for particular application. Specifically selection of working fluid and wick structure manufacturing play important role in development of miniature loop heat pipe. As wick structure directly impact on heat capacity of miniature loop heat pipe and maintaining low temperature at evaporator surface.

2) ANOVA provide strong goodness of fit for vary in wick mesh i.e. vary the value of porosity and permeability. While fabricating wick structure as in development of mLHP, adopt such material and sintering process which provide more value of porosity and permeability.

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