A Literature Review To Predict Performance Analysis Of Miniature Loop Heat Pipe

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ABSTRACT: In Industries for cooling the different components of electronic equipment and desktop computers, devices like fans, blowers, capillary pumped loop and loop heat pipe (LHP) are used. A literature study provide information that loop heat pipes are highly efficient heat-transfer devices capable of possessing mechanical flexibility and high adaptability to various operating conditions. A new generation of these devices, miniature heat pipes can solve the problem of cooling of promising electronics and computer equipment with heat dissipation levels which are forecast to rise from current levels to high. The possibility of carrying research of miniature LHP parameters provides effects on the performance like choice of the working fluid, the fill charge ratio, the porous wick geometry and thermal properties, etc for capacity improvement. Present research work aims to design and carry performance analysis by using several methodological techniques leading to improve the performance of miniature LHP. The recent research work also suggests that computational fluid dynamics (CFD) software which will predict different parameters and design components to be validated. By observations and results can be served as efficient parameters to solve complex heat and mass transfer problems. The present work will be supported with the aid of several statistical techniques to provide the empirical analysis and generate the conclusion.

Keywords: LHP, CFD, Heat Pipe, Electronic Equipment Cooling, miniature LHP, wick structure, evaporator, condenser.

INTRODUCTION

Loop heat pipe is an improved version of a heat pipe that addresses these limitations of the conventional heat pipe by completely separating the liquid and vapor phases from each other and localizing the capillary structure in the evaporator section only. LHPs possess all the main advantages of conventional heat pipes and are additionally capable of transferring large heat loads for distances up to several meters in any orientation in the gravity field. These devices are one of the most promising thermal control technologies for ground based as well as space applications. In the electronics cooling, LHPs can be considered as potential alternatives to the convectional heat pipes due to the high heat transport capacity of their evaporator and wickless transportation lines that can be easily bent for installation inside device cabinet. The evaporator is the most critical and main structural element of the loop heat pipe. It consists of the evaporation section and the integrated liquid reservoir also known as compensation chamber, which are hydraulically and thermally connected via wick structure. The wick is an integral part of the loop heat pipe evaporator and provides the necessary capillary forces to the working fluid for its continuous circulation in the loop. As a connecting link between the evaporator and compensation chamber, the wick is also expected to perform as a thermal and hydraulic barrier to minimize back flow of heat and vapor from the evaporation zone to the compensation chamber. Use of fine pore wicks in LHPs helps to provide the necessary high capillary pressure to inhibit the migration of vapor from the evaporation zone to the compensation chamber. The problem of back conduction of heat through liquid saturated wick is very critical in the proper functioning of the loop evaporator and to a large extent dictates the thermal behavior of the LHP. Unlike conventional heat pipes, the wick structure used in the LHPs should not have excessively high effective thermal conductivity to avoid heat leaks to the liquid present in the compensation chamber. It should be noted that there is a need for compromise between back conduction problem and the desire for good thermal conductivity of wick to promote efficient heat exchange in the evaporating zone.

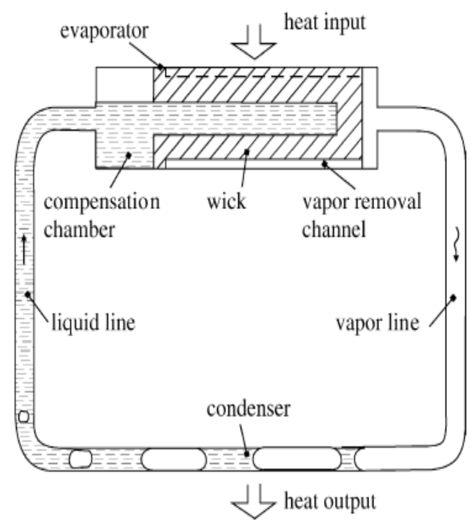

Fig: A schematic of the structure and principle of operation of a loop heat pipe

Miniature designs of the loop heat pipes have been investigated by different researchers for the cooling of compact electronic equipment like laptops. The main restriction in the development of the small scale loop heat pipes is imposed on the down scaling of evaporator thickness, which is the diameter for the cylindrical evaporators and overall thickness for the flat evaporators. This is directly related to the heat leakage issue that is more dominating in the miniature loop heat pipes mLHPs due to the smaller wick thickness. As a result, the thermal performance of the miniature LHPs is lower than the larger size loop systems, which have wick structures of considerable thickness. Within the framework of the evaporator, there is considerable scope to address the thermal performance issues for miniature LHP by optimizing the structure topology, geometric parameters and thermal characteristics of the wick. Miniature LHP parametric study has

- Effect of fluid charge
- Effect of the porous wick characteristic
- Effect of the working fluid
- Effect of non condensable gases
- Effect of the gravity (elevation and tilt)

- Effect of the evaporator/reservoir design on the heat leak
- Effect of pressure drops
- Effect of sink and ambient temperatures.

Miniature LHP is of a special type as much reduced area for heat dissipation is available and the transport lines also present reduced diameters. Especially important, different shapes of evaporators applied to mini-LHPs are a must as this geometry simply eliminates the requirement of a saddle as an interface between the surface to be controlled and the LHP. Miniature LHPs having evaporators with outer diameter of less than 8 mm and the transport lines should not exceed 3 mm in diameter. The capillary evaporator active zone should be in the range between 10-50 mm and the total length of heat transport should not exceed 500 mm. Several types of miniature LHPs were designed and built, using different working fluids for an operation heat load of 60 W to 120 W.
Desired outcomes or the general intentions of the research are

- The tendency to a constant increase of heat load on the functional components of industrial equipment with a simultaneous decrease of its mass and dimensions which create a situation when heat pipes can no longer cope with heat removal. So new and more efficient and sufficiently miniature heat-transfer devices are required.
- The advantages of miniature LHPs are most pronounced at large dimensions and capacities of other devices.
- New challenges make to evaluate different possibilities for developing the miniature LHP principle directed at the creation of miniature and more efficient heat-transfer devices for electronic equipments cooling.

Objectives or the steps of research work going to take to answer research questions or a specific list of tasks needed to accomplish the goals of the research work - they:

- By previous research with evaluation of the miniature loop heat pipe factors with involving the understanding heat conduction in different parts with the effect of different variables with different governing equations.
- Numerical modeling, analysis and experimental simulation of miniature loop heat pipe with a much greater understanding of various physical phenomena in heat pipes as well as advances in computational and experimental methodologies.
- Analyze the research going for new approaches of the loop-heat-pipe modeling, those are facilitates the identification of the physical mechanisms which are influence its operating behavior.
- Creation of miniature and more efficient heat-transfer device that satisfaction the all parametric study, proper and efficient design with analysis for different applications as heat transfer device.
- During research work, the main focus on the operation reliability, durability, validity and suitability through meta-analysis research as look for differences in results among the research studies.
- Validity: Miniature loop heat pipe satisfy the all requirements of the heat transfer device by analyze all various parameters theoretically and then test experimentally.
- Reliability: Heat transfer device measures the current and upcoming challenges using research methodology techniques for acceptance of the other devices.
- Suitability: Research work can find out the thermal and environmental constraints, thermal performance with economic factor of weight, cost of manufacturing.

The scope of research work can be summarize as

- Research work includes heat pipe fundamentals, operations, heat transport limitations and simulation.
- Study review provides a self contained document to design and simulate miniature loop heat pipes under different operating conditions.
- Numerical and analytical analyses of heat pipes have progressed significantly over the last several decades.
- State-of-the-art modeling is capable of predicting thermal performance under various operating conditions.
- In particular, advances related to the simulation of miniature loop heat pipes under steady state, continuum transient and frozen startup operation have been very successful, with complex multiphase and multidomain transport phenomena in heat pipes.
- In general, it has been shown that heat pipe simulations must include conjugate heat transfer with the wall, wick and vapor, since these affect both the transient and steady state operating conditions.
- More fundamental works are needed to better understand the physical phenomena and mechanism of miniature loop heat pipes.
- An accurate simulation of liquid/vapor interface, including multiphase phenomena in various wicks, is important to accurately predict the heat transport limitation of miniature loop heat pipes.

The maximum capacity of the mLHP is limited by three main conditions that include

- The maximum permissible operating temperature of the source,
- Mode of cooling of the condenser (or maximum heat dissipation capacity of the condenser),
- Capillary limit of the wick structure.

REVIEW OF THE RESEARCH

Victar V. Maziuk [1] proceeds with the design and principles of LHP with capillary structure, size of capillary structure, vapour and liquid lines, evaporation zones and LHP constructive elements. Also operating characteristics of evaporator studies with theoretical analyze of evaporator operation may be carried out using physical model. The experimental investigation reveals the concept of miniature heat pipes with noninverted meniscus with relations of main operation characteristic of evaporator. With the experimental test of MLHP with noninverted meniscus , Victar V. Maziuk [1] concluded that own thermal resistance of evaporator with noninverted meniscus is reduce as compare with thermal resistance of evaporators with inverted meniscus and additionally remove heat fluxes with much greater density. Le-lun JIANG [2] elaborate Miniature cylindrical metal powder sintered wick heat pipe is an ideal component with super-high thermal efficiency for high heat flux electronics cooling. The sintering process was optimally designed based on the equation of the heat transfer limit of sintered heat pipe The sintering parameters including with theory analysis through characterization of sintered wick, heat transfer limit of sintered heat pipe, optimization design of sintered wick and experimental steps like preparation, sintering process, sample testing. Result on the sintering temperature, sintering time, sintering atmosphere and sintering position were discussed. Viachaslau V. Doktarau, Victar V. Maziuk [3] focused on the concept of miniature loop heat pipe with noninverted meniscus with new principle and volume correlation for mLHP startup through experimental investigation. It experimental investigation of design and manufacture of mLHP with noninverted meniscus allow using capillary structure with high thermal conductivity, reduced in thermal resistance of evaporators. Also proved to remove heat fluxes with much greater density than mLHP with inverted meniscus. It studied more the concept of volume, porosity, compensation chamber, capillary structure in evaporation zone and vapour line for better comparison and improve performance and observed effects. C.I. Chu [4] obtains a comparison between theory and experiment, according to the LHP limitations, wick structure parameters including vapor groove size, pore radius, permeability, and wick thickness were analyzed theoretically. An experiment was conducted to fabricate a miniature LHP and to verify the theoretical analysis. The major results are listed below through the theoretical analysis, the optimal parameter combination of wick structure was found, and the basis for designing an LHP was established. The fabricated miniature LHP achieved a high heat transfer capacity at the high working temperature and reduces the thermal resistance compare with normal range of mLHP. The theoretical and experimental results both showed that decreasing the wick thickness would lower the evaporator temperature and enhance the LHP performance. J. H. Choi [5] investigated one of the mLHP system, here is demonstrated to have an increased thermal performance at a reduced system weight. Studied the primary wick secondary wick for design to improve the evaporation and ensure adequate pumping. Also the no requirements of the compensation chamber with primary and secondary wicks are required different thickness and porosity. Experiential results observed the increasing the active evaporation zone is expected to enhance the vaporization rate and improve the effectiveness of heat removal from the hot junction. Randeep Singh [6] studied the mLHP parameters and design for enhance the performance of loop in different conditions. Design which will develop using novel concept with very small thickness for the mLHP evaporator, in which the compensation chamber was positioned on the sides of the wick structure and incorporated in the same plane as a evaporator. Selection of proper material with working fluid for loop and considering capillary pumping pressure, wick material, pore radius, porosity, transfer line with inner diameter over range of applied power with achieving steady state condition without any temperature overshoots or symptoms of capillary structure dry outs. It is concluded with minimum total thermal resistance with proposed design for range of high transfer heat flux, maximum heat load with high temperature. Xiao-wu Wang [7] observed through the experimental study of heat transfer performance of mLHP employing nanofluid with different mass concentration of nanoparticle through the particle of the mLHP, preparation of nanofluids, and experimental study for measurement thermodynamic model of nanofluid, differential equation of heat diffusion using average speed, boiling temperature and analysis. According to thermodynamic law, the slope of two phased equilibrium curve is found to can be expressed as Clapeyron equation, based on these deduced theory for heat diffusion and boiling temperature to calculate the heat flux. M Ghajar [8] studied the present model in concept with the operating conditions of LHP, evaporator surface temperatures varying with respect to the applied heat load, modeling of 2D CFD conduction with the considering different quantities (like mass, evaporator heat input, evaporator temperature, evaporator surface temperature with different boundary condition for stable condition), also checked for heat leak through energy balance through the subcooled temperature, liquid line temperature, evaporator temperature. It found the optimize dimensions for groove wall thickness, groove width, wicking structure length, vapour line with respect to heat flux and maximum operating surface temperature. It concluded with factors affecting the evaporator surface temperature like heat input, ambient temperature and geometry as it plays important role to the varying heat source which will help in predicting behavior of temperature sensitive electronic components. Randeep Singh [9] presented an experimental investigation of the mLHP with flat disk shaped evaporator for different diameter and thickness for thermal control of computer microprocessors. Tests were conducted with water as the heat transfer fluid for different heat load with considering reliable startup and achieving steady state condition without any wick dry out with observing minimum thermal resistance. The results observed efficient with superior heat transfer coefficients over entire range of input power and has proven promising device for thermal control of electronic devices. Ahmed M. Habtour [10] described the effort performed on design and verify the performance of next generation miniature LHPs through the system overview with overall design, test program overview with startup, thermal conductance, maximum power, sink transients, power switching and condenser cycling, test setup and instrumentation. The results and discussion on startup, heat load sharing, steady state performance or conductance measurements, condenser switching, power switching, condenser cycling. It is concluded with multiple evaporator and multi condenser proved the capabilities for many thermal management devices. Randeep Singh [11] developed theoretical model comparing with the experimental results for evaporator temperature and loop thermal resistance with different evaporator shape and different wick material. Also mathematical model developed through considering steady state of LHP, single phase correlations, natural convection, temperatures in the different zones like in compensation chamber, condenser, evaporator with solving resulting equation along considering different parameter including fluid properties, system pressure drop, mass flow rate, heat transfer coefficients. Jentung Ku [12] presented the detail study and experimental data for thermal loop concept, advances and validation for the technical approach for technology of mLHP. Technical advances and benefits of thermal loop technology with the state of the art (through LHP single evaporator, multiple evaporators, multiple condensers, startup time, control heater on compensation chamber for temperature control), transient model for mLHP, developing an analytical model which can predict the loop critical temperatures during steady state and transient operation for different environment. Also focused on the influence of gravity, as it effects on the performance of capillary two phase devices. It found that the model predictions agreed very well with experimental results in the laboratory and thermal vacuum testing. Jentung Ku [13] observed the controllable thermal system through multi evaporators and multi condensers design for mLHP for requirement of future system with low mass, different power and compactness. Considering the different parameter and characteristics for improve the functionality, performance and reliability of mLHP system through experimental tests. In addition, an analytical model was developed to simulate the steady state and transient behaviors of the MHLP during various validation tests. It is concluded with the presenting the validation results, both experimental and analytical, of such a technology development effort through the test on the startup, heat transport, operation, heat load sharing, LHP model correlation. Jentung Ku [14] observed that the MLHP Thermal Management System consists of a miniature LHP with multiple evaporators and multiple deployable radiators, coupling block, analytical models and scaling criteria, technical advances, performance characteristics, operating scenarios through the laboratory test, thermal vacuum test and analytical model correlation. The technology advances of mLHP thermal management system through the terms like internal thermal subsystem, LHP configuration, LHP evaporation diameter, analytical modeling of LHPs, LHPs startup method, LHP temperature control prevention of fluid freezing. Experimental results show excellent performance of the thermal system and correlate very well with theoretical predictions. Dongxing Gai [15] concluded the main outcomes of the study can be summarized that the effect of applied heat load on the thermal resistance and start up time of mLHP in manner as low heat input load that require the maximum startup time for mLHP, also reduction in thermal resistance with increasing in applied heat load. Also observed that the increase in temperature and thermal resistance with increasing of charging ratio. Major effects observed with the tilt angle increases the thermal resistance decreases and if the tilt angle decreases, the start up time and temperature of evaporator increases. Also deals with the thermal oscillations, the variation in the thermal oscillations with changing the applied heat load, charging ratio and tilt angle. Randeep Singh [16] experimentally investigates the effect of non-condensable gases (NCGs) on the thermal performance of the miniature loop heat pipe (mLHP). The results of the experiments to characterize the thermal performance of the miniature loop heat pipe with non-condensable gases are now presented through NCG generation and storage, effect of the NCG on steady-state performance, effect of the NCG on the start-up process, purging of NCG from mLHP, methods to decrease NCG generation. Finally it was established through prolonged testing that majority of NCG is produced from the contamination of the working fluid and wick/envelope material. Notable improvements were achieved by improving the purity of the working fluid through degassing process. H. Arthur Kariya [17] focused on air-cooled heat sinks offer ease and flexibility in installation and are currently the most widely used solution for cooling electronics. Study provides the detailed thermal fluidic considerations needed to generate capillary pressure in the condenser for controlling the condensation behavior and serves as the basis of developing multiple condenser LHPs with low thermal resistance. Result and discussion on the requirements for phase separation in the condenser, evaporator and condenser design, startup, phase separation, heat removal performance, effect of filling volume on heat pipe performance, also this study demonstrates vapor–liquid pressure separation in a LHP by the integration of a wick in the condenser as a possible mechanism of utilizing multiple condensers for high surface area heat sinks. V.G. Pastukhov [18] observed the results for different evaporator diameter and effective length for varying heat input power with considering the minimum thermal resistance for the better performance. It also elaborates the different types of miniature loop heat pipe with the different parameters considered in design of the miniature loop heat pipe through the effect of thermal resistance. A.A.M. Delil and V. Baturkin [19] observed through the tests with experimental model that effect of the porous parameters and vapour removal grooves on the loop heat pipe characteristics and heat transfer intensity. Also experimentally proposed that a decrease of maximum pore diameter in the evaporator results in achieving the maximum of heat transfer intensity for the larger thermal loads with identified effects considering from the gravity and inclination. Randeep Singh [20] had done detailed study which was conducted on the start-up reliability of the mLHP at high as well as low heat loads. It starting from low input power as low of 5 W, it is observed that it gives result like it took much more time for short heat input power. While operating under different power loading cycles, the mLHP presented very fast response to the changes in the input power and was able to achieve steady state within short transient period of 2 to 3 minutes. It also followed with required minimum thermal resistance for input power with the range of temperature. The effect of varying heat input power on the thermal and hydraulic oscillations were observed for the loop. Also provide support for determining the thermal characteristics and chemical compatibility of the different metals and working fluids. Randeep Singh [21] experimentally observed that the thermal performance largely effect due to the changing the material of wicks for low to moderate heat loads. These changes observed due to their different heat conductive resistance. The work was able to classified the improvement in the thermal performance and characteristics for miniature loop heat pipe through wick structure, capillary structures of different materials, flow properties, porous structure. These studies help in the improve the efficiency of the heat exchange process inside the evaporation zone.

ILLUSTRATION OF PROPOSED EXPERIMENTAL SETUP

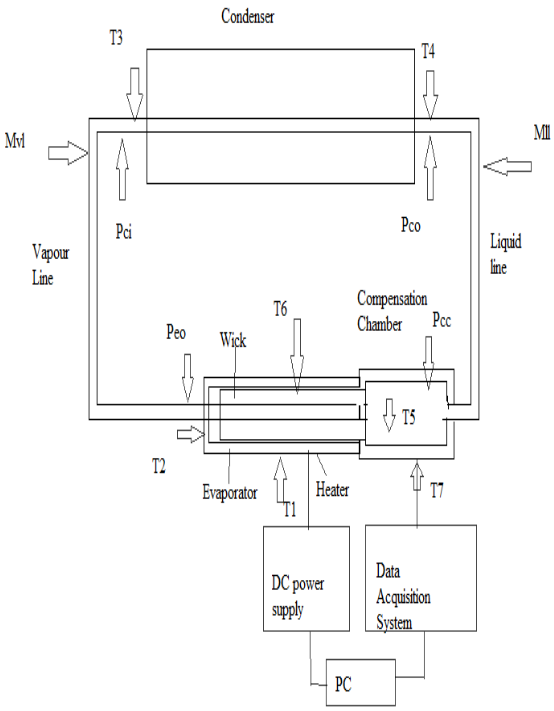

Fig. Schematic of the Test Setup

T1 Wall temperature of evaporator, T2 Temperature of evaporator outlet / vapour temp, T3 Temperature of condenser inlet, T4Temperatureof condenser outlet, T5 Temperature of compensation chamber, T6 Temperature of internal surface of wick / evaporator core temp, T7 Temperature of compensation chamber wall.
Main design parameters of mLHP prototype

PARAMETER	VALUE
Evaporator shape	Circular*
Evaporator material	Aluminum
Evaporator ID/OD/length (mm)	20/24/150
Evaporator heating face area cm^2	7.1
Total thermal conductance of the wall	50-250 W
Evaporator thermal resistance	0.0 - .07 ^{0} C/W
Heat transfer coefficient in evaporator	78,000 W/m^{2}K
Heat flow density in evaporator	21.1 W/cm^2
Vapour removal channels (Groove top width / Groove bottom width / Groove depth) (mm)	1.5/2/2
No. of vapour groove/ vapour groove radius/ tolerance between wick and evaporator with slope wick include vapour groove	10/1 mm/0.06 mm/1^0
Wick material	sintered powder nickel
Wick ID/OD (mm), Wick length (mm)	12/21/120 mm interference fit
Wick mean pore radius (μm),wick thickness	40, 3-5 mm
Wick porosity, permeability	50 % Cu, 1.43 $10^{-12}m^2$
Area of contact of wick with wall mm^2	11.0
Shape of wick	Conic
Fill ratio	40 – 60 %
Effective thermal conductivity of wick	10- 40 W/mK, Ni 5-10 W/mK
LHP material (except evaporator)	Stainless steel
Reservoir volume (litre)	0.75
Reservoir wall heat capacity	100 J/K
Flow lines ID/OD (mm)	1.2/6.5 (3-8)
Vapour/liquid line length (mm)	1000
Condenser line length (mm)	1000
Condenser type	Circular, tube in tube
Condenser material	Aluminum
Working fluid/ heat flow density/density/viscosity/ thermal conductivity	Ammonia,44.5 W/cm^2,682kg/ m^3,9.8 10^{-4}Ns/m^2, 22.19 W/mK
Temperature range	-20 to 150˚C
Heat load or heat capacity	70 W - 95 W
Heat Pipe - Outer, Inner, Pitch Diameter And Cross Sectional Area Of Heat Pipe	16/14
Heat Pipe With Thermal Conductivity, Density And Specific Heat	387.6 W/mK, 8978 kg/m^3, 381 j/kgK for Cu
heat transfer coefficient in the evaporator and condenser zones	10^3–10^5 W/m^2 K,
heat pipe thermal resistance	0.01–0.03 ˚C/W,0.65 in horizontal position

Heat load simulator area cm^2 (heater size)	3.75
Max. heat flux	$30W/m^2$
Start up time (min)	2-4
adhesive material/ceramic/ Cu particle	reduce heat leak
compensation chamber	stainless steel will bolt to evaporator

CONCLUSION

By the observation of data analysis and simulation parameters we may expect results better than existing systems which enhance the capacity and performance of mLHP. Also by these theoretical data analysis the proposed scheme is may provide highly effective component design, parametric simulations, results are higher than that of their counter parts, the components design using proposed scheme can be used in various mechanical composite products. Simulation results will help at all levels of design and parametric analysis. From above discussion the possibility of result and data analysis can observed with effective manner but some points also considered like,

- Capacity of heat input to be handled and temperature range control is in desirable range.
- Working fluid to be use for proper implementations.
- May be the optimum values of different factors and parameters find out.
- Design and performance may be as per specifications.
- Flow of fluid and heat transfer as per desired simulated things or results.
- Cost estimations should be under probable control.

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