Characteristics Parameters and its Effects on Thermal Performance of Dual Layer Closed Loop Pulsating Heat Pipe: A Review

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ABSTRACT:

The closed loop Pulsating Heat Pipes (CLPHPs) are one of the emerging high heat transfer device for electronics cooling equipment's.It is worldwide accepted due to its simple design and long term durability.It is simple two-phase passive heat transfer device that help to enhances large amount of heat. It is transporting heat from evaporator to condenser by the principle of evaporation and condensation of a working fluid with minimum drop of temperature.it is first evacuated then fill the desire working fluid in appropriate filling ratio.The numerous research had been carried out on the single layer pulsating heat pipe ant its show is excellent performance.This paper aims to define the parameters which is mainly affecting the thermal performance of dual layers heat pipe.That includes Number of turns ,Working fluid ,filling ratio etc.

Keywords: *Pulsating heat pipe, Filling Ratio, Orientation, Working fluids,Thermal resistance*

1. INTRODUCTION : The dual layer closed loop pulsating heat pipe is addition of another same layer on existing pulsating heat pipe circulating same working fluid. The working principal is same as like single layer closed loop pulsating heat pipe.The pulsating heat pipe consist of three sections which are arrange horizontally or vertically.

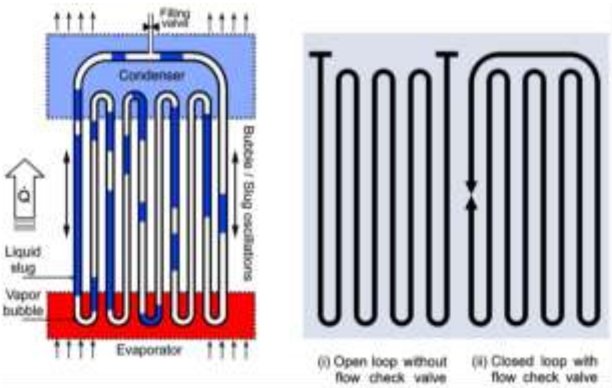

Fig. 1 Schematic of a pulsating heat pipe and its design variations.

The PHP has a better heat transfer performance and most of the research work were associated with this design.The performance mainly depends upon the factors like diameter of the tube,heat input,orientation,working fluid, etc.The unique and key characteristics features feature of CLPHPs as compared with the conventional heat pipe is that it has no internal wick structure for return the condensate to the heating section.Therefore, there is no counter current flow between the liquid and vapor.So that it is become simpler in design and construction as well chief in cost.

WORKING PRINCIPLES OF CLPHP

A. Fluid Dynamic Principle

The CLPHP in a close loop structure, its tubes connected end to end. Initially the tube is evacuated and then filled partially (as per required filling ratio) with working fluid, which distributes itself naturally in the form of liquid vapor plugs and slugs inside the capillary tube. There is no external control over formation of initial sluge or vapour inside the tube. The liquid Plugs are able to completely bridge the tube because of surface tension forces overcome gravitational forces. There is a meniscus region on either end of each slug caused by surface tension at the solid/liquid/vapor interface. The slugs are separated by plugs of the working fluid in the vapor phase. The vapor plug is surrounded by a thin liquid film trailing from the slug.

B. Thermodynamic Principle

The one end of the pulsating capillary tubes filled with desire working fluid is subjected to high temperature, the evaporates receives heat and increases the vapor pressure, which causes the bubbles in the evaporator zone to develop , and extinction of vapor bubbles drive the flow in a PHP.

C. Heat Transfer Principle

This vapor bubbles pushes the liquid column toward the low temperature end (condenser). The temperature and pressure decrease in the condenser due to condensation. Therefore a constant, unsteady internal pressure difference exists in the system which is the driving force. Because of the interconnection of the tubes; motion of liquid slugs and vapor bubbles at one section of the tube toward the condenser also leads to the motion of slugs and bubbles in the next section toward the high temperature end (evaporator), this works as the restoring force.

The heat is transferred from the evaporator to the condenser by sensible and latent heat transfer, which is a result of the working fluid oscillations and phase changes.

D. Flow Pattern

During the startup period the working fluid oscillate with large amplitude, after this period continuous circulation can in the working fluid occurs. The direction of circulation for working fluid is consistent once circulation is obtained but the direction of circulation can be different for same experiment.

2. CHARACTERISTICS PARAMETERS OF PULSATING HEAT PIPE

The various parameter are directly or indirectly affects the thermal performance of the PHP,which are as follows

1. Internal tube diameter
2. material,
2. Orientation
3. Number of turns
4. Filling ratio,
5.Heat Flux/Temperature.
6.Operating temperature range,
7.Sensible heat and latent heat.
8.Viscosity of oil
9. Surface Tension
10. Ratio of Pressure difference to temperature

3. THE OPERATING RANGE OF WORKING FLUID

3.1. Filling ratio:

It is defined as the ratio of working fluid volume actually present in the device to that of the total volume of the device.In optimal filling ratio where maximum heat transfer rate is achieved at a given temperature. There are two optimum filling ratios limits 0% and 100%. In between these two extremities here exist three distinct sub-regions.

3.2.100% filling ratio:

It is completely with operating liquid.There is very few bubble formation is taking place.These bubbles are not sufficient to generate the required pumping action. Resulting in a small heat transfer takes place. Thus, the performance of the device is seriously hampered in 100% filled PHP.

3.3. 0% filling ratio:

In this mode, there is no liquid or very small liquid contained within the tubes to formation of required or enough slugs and there is a tendency towards evaporator to become dry-out.The operational characteristics are unstable.It works purely on the conduction basic.To become pulsating heat pipe two phase thermosyphons should passes by device.So it is ineffective without the working fluid.

3.4. PHP TRUE WORKING RANGE:

In between about 20% to 80% filling ratio the PHP operates as a true pulsating device. The exact range will differ for different working fluids, operating parameters and construction. The more bubbles (lower fill charges), the higher is the degree of freedom but simultaneously there is less liquid mass for sensible heat transfer. Less bubble (higher fill charges) cause less perturbations and the bubble pumping action is reduced thereby lowering the performance. Thus, an optimum fill charge exists[11,12] Khandekar S. et al.[13] conducted experiments on a CLPHP

4. PROPERTIES WORKING FLUID:

Selection of working fluid is directly linked to the properties of the fluid.The properties are going to affect both the ability to transfer heat and the compatibility with the tube material.The following characteristics should be examined while selecting working fluid :

1. Compatibility with the OHP material,
2. Thermal stability,
3. Wet ability
4. Reasonable vapor pressure,
5. High latent heat and thermal conductivity,
6. Low liquid and vapor viscosities,
7. Acceptable freezing point.

5.LITERATURE REVIEW ON CLPHP

The PHP was first invented by Akachi (1990). In his patent (US Patent, 4921041), he described 24 different types of loop type heat pipes.

Kyle Moris on 2012 conducted series of an experiments to investigation of The heat transfer cap ability and performance of dual layer Pulsating heat pipes.The thesis show the comparison between Single layer and dual layer of Pulsating heat pipe.PHP may copper of 3.17mm of internal diameter.The working fluid is water and its performance investigate at filling ratio from 0%, 25,% 50% ,75% ,90%. The heat input supplied to evaporator ranges from 0 W to 120W.By comparing thermal performance between single and dual layer pulsating heat pipe from experimental investigation it is indicate that for dual layer has lowest thermal resistant ie 0.12 attained^{0}c/W when 75 % FR and heat input is 120W.It was concluded that the dual-layer system exposed to the same input Power and area achieved an overall increase in performance with respect to start-up time and temperature.

2. Wang Jiansheng et.al. On December 2013, successfully conducted an experiment to ascertain the thermal performance of PHP with different heating patterns.The water used as working fluid at filling ratios of 30% ,50% and 70%.The PHP has 5 meandering turns vertical heat mode with heat input from ranges 10 W to 60W.The The heated turn is labeled B1, B2, B3,B4, and B5. Three heating patterns, uniform heating on all the five turns, uniform heating on B1, B3, B5, and uniform heating on B2, B4 are used.The results reveal that the PHPs at a lower filling ratio can start easily in the considered range. Moreover, the heating structure have a significant effect on the start-up process and thermal resistance of PHPs. The PHP has Compared with the uniform heating pattern and non-uniform heating pattern can reduce the start-up period and increase the thermal resistance of PHPs

Pramod R.Pachghare ,AshishM. Mahalle on 2013 conducted an experiment to find thermal performance of closed loop pulsating heat pipe(PHP) by using copper tube having internal and external diameter with 2.0 mm and 3.6 mm.The filling ratio(FR) was maintained at 50% for all experimentation.Ten turns used with different heat inputs of 10W to 100W was supplied to PHP. The position of the PHP was vertical bottom heat mode.The equal length of evaporator,adiabatic and condenser section was maintained 50 mm. Working fluids are selected as Methanol,ethanol,acetone,water and different binary mixtures.The Experimental study show the working fluid is an important factor for the performance of PHPs. The result also shows that, the thermal resistance decreases more rapidly with the increase of the heating power from 20 to 60 W, whereas slowly decreases above 60 W. Pure acetone gives best thermal performance in comparisons with the other working fluid. No measurable difference has been recorded between the PHP running with pure and binary mixture working fluids

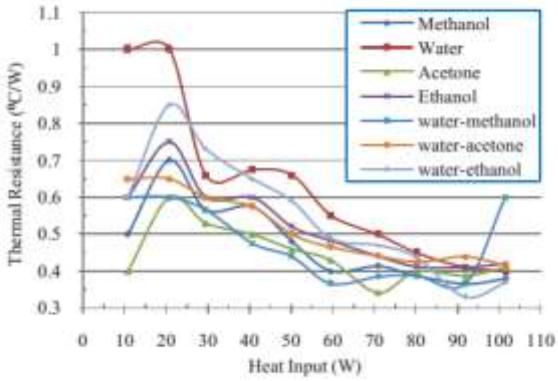

Fig. 10: Thermal resistance of all working fluid PHP

Himel Barua, Mohammad Ali et.al.on 2013 investigate the Effect of filling ratio on heat transfer characteristics and performance of a closed loop pulsating heat pipe. The copper tube of 2mm ID and 2.3mm OD made up of copper of 2 meandering turns filling with working fluid Ethanol and water at an ratios of 28% ,41.3% ,63% ,82.5% ,to 100%. The vertical heading pattern with air cooled condenser give heat input ranges from the 5.3W to 70W. The experimental result shows that For lower heat input Water is better working fluid up to 70W but after ethanol and water show the same thermal resistance.For ethanol at 50% FR at low heat input show best performance because lower thermal resistance.And For high heat input ethanol shows effective working fluid at all filling ratio.

Suchana Akter Jahan, Mohammad Ali et.al. On 2013 perform an experiment to investigate the Effect of inclination angles on heat transfer characteristics and thermal performance of a closed loop pulsating heat pipe.The two different working fluids water and ethanol are used with inclination angle of 0˚(vertical),30˚,45˚,60˚,75˚and 90˚(horizontal). The experiment conducted on a CLPHP made of 148 cm long copper capillary tube of 3.0 mm outer diameter and 2.0 mm inner diameter creating a total of 13 turns. The total length of evaporator section is 39.5 cm and condenser section is 31.5 cm; while the rest is assumed to be adiabatic.The result indicates that The best thermal performance is found at 75^{o} orientation.In all circumstances ,water is providing the better performance than the ethanol.

11. V.K.Karthikeyanet .al. On 2013 conduct an experiment for Understanding Thermo fluidic characteristics of a glass tube closed loop pulsating heat pipe .The results show the Flow pattern and Oscillations.The PHP made by Pyrex glass tube of 2.5mm ID and 6mm OD with 5 turns.Deionized Water Copper oxide nanofluid are working fluid utilized with constant filling ratio of different Working fluid maintained by 50 % FR.Total length of glass tube is 200mm and vertical bottom heating to evaporator ranges from 10W to 110W. The results shows that the Visual study helps to identifying the flow patterns and fluid oscillations and understand thermofluidic behavior of the device.And The Gravity affects on performance also at horizontal conditions device is not performing. Nano fluid charged with PHP leads to improve the thermal performance

Xiangdong Liu et.al.on 2013 had conducted an experiment to find out the Dynamic performance to start-up of closed-loop pulsating heat pipes.The PHP made up of the copper meandering turns are 10 with 2.6mm ID and 4mm OD.The working fluids are Methanol ,Ethanol and Water used with different filling ratios from 17% FR to 86% **FR.** PHP heated at bottom and kept at vertical and tilt to from vertical to horizontal at different angles.The hating to evaporator ranges from 100W to 300W .The results are strongly demonstrate that The start up performance is increases as inclination angle is increases ie from 0 to 90 with increasing heat load.The Working fluids with small dynamic viscosity, small specific heat and large pressure to temperature gradient is better for the start up performance.The optimal filling ratio for start up performance of CLPHP is about 41% Water,52% Ethanol and 35to 41% Methanol.

Mauro Mameli, Sameer Khandekar on July 2013 had conducted an experiment to measure Local Heat transfer and thermofluid characterization of pulsating heat pipe.The PHP utilized of 2mm ID and 3mm OD made up of copper with 2 meandering turns.The Azeotropic mixture with Ethanol and water used as the working fluid maintained at 65% filling ratio.The electric heating provide at evaporator sections from 10W to 100W. The result indicate that filling of azeotropic mixtures of ethanol and water as working fluid does not alter thermal performance as compare to pure ethanol.

Pramod R. Pachghare and Ashish M. Mahalle on 2014 presents a paper on Hydrodynamics of the closed loop pulsating heat pipe an experimental study to investigate heat transfer performance.The working fluids employed are water, ethanol, methanol and acetone and binary mixture (1:1 by volume) of water-ethanol, water-methanol and water-acetone. For all experimentation, filling ratio(FR) 50%, two-turns and vertical bottom heat mode position was maintained. The lengths of evaporator, condenser and adiabatic section are selected as 42 mm, 50 mm and 170 mm, respectively. The transparent adiabatic section is partially made of glass tube having length 80 mm, for flow visualization. The CFD analysis by VOF model in Star CCM+ simulation is carried out to validate the experimental results. The result shows that the thermal resistance decreases smoothly up to 40W heat input, thereafter reasonably steady. In comparison with all working fluids, water-acetone binary working fluid has shown the best thermal performance over other working fluids used in CLPHPs.Thermal performance of binary fluid is better than pure working fluid.

Nandan Saha et .al .July 2014 conducted an experiment to investigate Influence of process variables on the hydrodynamics and performance of a single loop pulsating heat pipe with flow pattern and fluid oscillation.The PHP mad up of Quard glass tube which has 4mm ID and 6mm OD and single loop.The performance of the PHP checked by changing filling ratios of the working fluid deionized water and copper nano fluid by 52%The effect of orientations also observe.The orientation used from vertical to horizontal.The heat is supplied to the evaporator ranges from 10W to 100W.The results of this experiment that selected ID of the loop fails to give a stable distribution ofinitial vapor plug–liquid slug. Yet it acts as a true pulsating heat pipe in all respects.It also indicate that There exists a minimum start-up power or threshold power below which no movement of fluid is observed inside CLPHP.This start-up power increases with the decrease in inclination angle due to the reduced effect of gravity and also with the increase in FR due to restriction in bubble movement and flow regime transition

Mauro Mameli et.al on 2014 perform experimentation to find thermal instability of a Closed Loop Pulsating Heat Pipe with Combined effect of orientation and filling ratio..The PHP had made by copper and 1mm ID and 2mm OD.The copper has 31 meandering turns and working fluid used FC -72..maintained it 50% filling ratio. Results show that this CLPHP is very much sensitive to the gravity head and that the vertical operation is affected by unstable operation at high heat input levels. On theother hand the CLPHP in the horizontal position is less efficient, but it does not undergo any performance drop with respect to the heat input level until the maximum heat input level is reached
(Effect of orientation and filling ration on PHP)

Ramod R. Pachghare Ashish M.Mahalle on 2014 perform an experiment to find thermo- hydrodynamics of closed loop pulsating heat pipe.The PHP has 2mm ID and 3.6mm OD made up up copper and has 2 turns. Binary Mixture ,Water and Ethanol ,Water -Methanol mixtures were used as the working fluid.Heat input to evaporator zone ranges from 10W to 80W.The filling ratio maintained 50 % throughout the experiments.The results indicate that the thermal resistance decreases smoothly up to 40W heat input, thereafter reasonably steady .In comparison with all working fluids, water-acetone binary working fluid has shown the best thermal performance over other working fluids used in CLPHPs.This result is validated by CFD analysis.

Jiansheng Wang,et.al. 2015 perform experimentation on two-dimensional single loop closed-loop pulsating heat pipe (CLPHP) which is made up copper of 2mm I.D.and 3mm OD.It is look into by CFD analysis.The working fluid used as water.The volume of fluid (VOF) method is used to investigate the start-up characteristic and thermal performance of CLPHP with different ratios of the evaporator length to that of the condenser. The investigation performed by changing input power from 10 W to 40 W and filling ratio from 30% to 60% and The numerical results are compared with available experimental results at the same condition. It's found that the start-up time and the thermal resistance of CLPHP reduces with the increase of input power. At the same filling ratio and input power condition, reducing the length of condenser within a suitable range would accelerate the start-up process and decrease the thermal resistance while the dry-out occurred easily at low filling ratio.

Yu WANG on 2015 perform an experiment to evaluate operating characteristics of a closed loop pulsating heat pipe. a closed loop PHP with 5 turns made of copper capillary tube of 2 mm in inner
diameter. Two different working fluids viz. ethanol and acetone were employed. The operating characteristics were studied for the variation of heat input,filling ratio (FR) and inclination angle of the tested device.The experimental results shows that A lower FR results in higher thermal performance.The properties of the working fluid with low latent heat like acetone shows lower thermal resistance in stable operating conditions.

D. Mangini , M. Mameli et.al.on 2015 Investigated a pulsating heat pipe for space applications at Ground and Micro gravity.The PHP made up of aluminum with 3mmID and 5MM OD and 10 meandering turns.The working fluid is FC72 Nano fluid always maintained at 50 % FR.The total lenght of pipe is 2.55m.The heat input ranges from 10W to 160W. The device tested at ground level as well as at high altitude where gravity effect negligible.The results shows that the fluid circulations is activated at high heat input in vertical mode and no fluid motion is occur at horizontal orientations. Ground tests show that effectively the device works as a thermosyphon when gravity assisted.but at micro gravity in vertical position the start up at lowest heat input at 10W to 20W.In Horizontal orientations also slug/plug are observed.

19.V. K. Karthikeyan · K. Ramachandran et.al. On 2015 conducted an experiments to Understanding thermo- fluidic characteristics of a glass tube closed loop pulsating heat pipe as well flow patterns fluid oscillations.The PHP made by Pyrex glass tube with 2.5mm ID and 6mm OD.The meandering turns were 5.The working fluids Copper Nano fluid and Deionized water by maintaining 50% filling ratios by PHP volume.The results show that The performance of CLPHP having simple geometry and less number of turns is affected due to gravity effect. The device does not perform on the horizontal position under the present experimental condition. With the preliminary results of a nano-fluid charged CLPHP leads to improve thermal performance of the device at a given condition.

M Lutfor Rahman, Rasel A Sultan et.al. On 2015 had done an An experimental investigation on the effect of fin on the performance of closed loop pulsating heat pipe. A closed loop pulsating heat pipe made of copper with 2 mm ID and 2.5 mm OD **with fin** in the condenser section is used in the present work to evaluate the heat transfer performances where the evaporation section is 50 mm, adiabatic section is 120 mm and condensation section is 80 mm.The attempt is to analyze and compare the effects on the heat transfer performances of CLPHP with finned and un-finned condenser section with inclination angle of 0^0 (vertical), $30^0$and 45^0 .Methanol is used as working fluid with 50% filling ratio in CLPHP with 8 loops during the experimentation.The result indicate that The finned CLPHP at 45^o inclination exhibits the considerable enhancement of heat transfer compared with that of CLPHP without fin.it also indicate a strong influence of gravity and thermo physical
properties of the working fluid on the performance of the CLPHP studied with different orientation and heat load.

Saiyan Shi , Xiaoyu Cui,et.al.on 2016 conduct an experiment to investigate heat transfer performance of Pulsating heat pipe with ethanol based mixtures.The PHP has 2mm ID and 4mm OD made by copper single meandering turn with vertical heating mode.It is tested with ethanol–water, ethanol–methanol and ethanol–acetone binary mixtures in proportion of 2:1 and 4:1 with filling ratios of from 45% to 90% and the heat input from 10 W to 100 W.The results shows that When the mixing ratio is 2:1,the thermal performance with ethanol-water is better than other working fluid when filling ratio is 45%. and at 55% filling ratio ethanol -acetone show the better performance in mixed working fluid. But at 62%,70 % and 90% the heat transfer performance of PHP with the pure working fluid is better than the ethanol based mixtures **Xiaoyu Cui , Ziqian Qiu et,al. on 2016** perform an experiment to find heat transfer performance of PHP with methanol base binary mixtures. The PHP made up by copper of 2mm ID and 4mm ODand 5 meandering turns. The working fluids were methanol mixed with deionized water, acetone and ethanol and volume mixing ratios utilized 2:1, 4:1 and 7:1. The heating power limit from 10 W to 100 W with the filling ratios of 45%, 62%, 70% and 90%.The result strongly demonstrate that the Additions of other working fluid with methanol change the thermal resistance of PHP.It is found at 45 % FR ,Water with Methanol prevent dry out condition at high heating mode.Ethanol to methanol thermal resistance is between Pure Ethanol and Methanol and Methanol with Acetone Thermal resistance is slightly lower than pure ethanol and Methanol.For high Filling Ratio, Methanol Based mixture where not much different from those with Pure Mixtures except Methanol Water Mixture

Hua Han, Xiaoyu Cui et.al. On 2016 execute an experiment to study of closed loop pulsating heat pipe with water based zeotropes and its corresponding pure fluids.The PHP has 5 turns. It is made of copper with 2mm ID and 4mm OD.By filling of water-methanol, water-ethanol and water-acetone zeotropic mixtures at 35 % ,45 % ,55% and 62% mixing ratios. A perpendicular closed-loop PHP experimentally investigated with heat input ranged from 10 W to 100 W. It shows that For small or medium Filling ratio (35,%45% ,55%) most of binary mixture have better anti dry performance than pure fluid. Also find that at large filling ratio (32% and 70%)Dry out seldom happens and thermal performance is not show superior than pure fluid but at filling ratio of 62% PHP charge with water methanol of various mixing ratio (13:1 to 1:13) almost have excellent thermal performance throughout heat input investigated.For mixing ratio 1:1 half water and half counterpart at relatively high heat input 65W exhibite similar thermal performance.

Hamid Reza Goshayeshi, et.al. On October 2016 conducted an experimental to investigate effect of Particle size and type effects on heat transfer enhancement of Ferro-nanofluids in a pulsating heat pipe. The nanoparticles had a size ranged from 10 nm to 30 nm. The heat transfer rate and the temperature distribution of the heat pipe were examined with and without the magnetic field.The results showed that both heat transfer coefficient and thermal performance of the pulsating heat pipe are enhanced by the addition of Fe_2O_3 nanoparticles, especially when the magnetic field is present.The increment of input heat flux rises the heat transfer coefficient of the condenser and the evaporator.The optimum type and size of Iron oxide nanoparticles under similar conditions for attaining the best heat transfer performance was 20 nmγ-Fe2O3 nanoparticles.

The literature survey shows that the numerous experiment has been already done before to determine heat transfer characteristic on single turn or multy turn PHP.The experimentation's are restricted to single layer PHP. Only Kyle Morris had performed the experimentation to find heat transfer capacity and performance of dual layer pulsating heat pipe .

Kyle Morris has conducted experiments by using water as a working fluid and he concluded that dual layer PHP has lower thermal resistance ,hence of thermal performance of dual layer is more than single layer.This Dual layer experimentation is limited to water as working fluid.The working fluid,Internal diameter,and filling ratios are important parameters of the CLPHP,If this parameters are change ,then results are also change.What parameters are creating more effect on heat transfer capacity is need to find out in the dual layer pulsating pipe.Also need a attempt to enhance heat transfer capacity of the CLPHP. This literature survey shows that the worked on Dual layer is limited.The more detail experimental study is required.

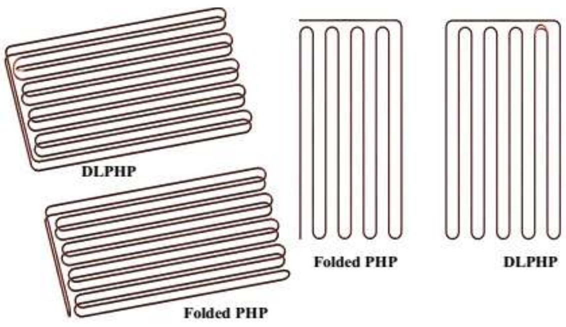

Fig.2 Dual Layer Closed loop Pulsating heat pipe Figures. **Fig.3. Schematic diagram of PHP**

6. PROBLEM IDENTIFICATION :

1.The experimentation has been restricted only on single layer pulsating heat pipe. Only one experiment has conducted on dual layer PHP.This singular study is not sufficient to show its validations and perfections.
2.The dual layer PHP is important to investigate the exact evaluation of transportation of heat transfer.Whether addition of another same layer can transfer double heat transfer? It is a part of research area.
3.By Kyle Morris experimentation on dual layer is restricted to single working fluid i.e. water only.So, there is a scope to find performance can be check by using different working fluid like methanol,ethanol, acetone, nano particles etc.
4.The Internal diameter is also an important parameter.Internal diameter used between the range of 2mm to 4mm. But at which diameter give more heat transfer is still the part of research area.
5.Changes of filling ratios changes the heat transport capacities of the PHP.It is necessary to know the optimum quantity of filling ratios which gives the maximum rate of heat transfer.
6.The effect of gravity on in dual layer pulsation of fluid investigations become necessary for understanding orientation on which rate of heat transfer get maximum.Still it is a part of area.
7.Start up performance for the dual layer is also need to investigate.
8.The dry out mechanism of this device certainly remain unexposed and one of the most vital information which is needed at this stage for future acceptance of the technology.

7. CONCLUSION :

From the literature survey it is found that the numerous experimental study had perform but only one ie.Kyle Morris had perform the experiment on the dual layer with using water as a working fluid.There is a need to work on the dual layer to find thermal performance on dual layer by using the different working fluid like ethanol, methanol ,acetone and nano fluid. There are lots of unsolved issues are still present in closed loop pulsating heat pipe like dual layer whether give the double performance than single layer or not etc. Also need to work on the working fluids to define the proper and commercial fluid used as a working fluid and appropriate filling ratios.

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