Thermal Performance of Closed Loop Pulsating Heat Pipe Using Different Nanofluids

Atul N. Pote[1] Pramod R. Pachghare[2]
[1]P.G Scholar [2]Assistant Professor
[1,2]Department of Mechanical Engineering
[1,2]Government College of Engineering, Amravati – 444604 [M.S.] India

Abstract— Due to huge development in electronic industries, there should be challenge to direct heat transfer investigations for thermal management of high performance chips and again in industries, electronics field always demands robust and promising cooling devices. For this reason, pulsating heat pipe is best option due to simple structure, reliability, and low manufacturing and operating cost. Moreover, working fluid play an important role in PHP's performance. Nanofluids, having high thermal conductivity, are outstanding substitutes for PHP's over conventional working fluids. Focusing on recent advances on nanofluidic PHPs, this paper reviews operating principles and conducted experiments in this field. Furthermore, unsolved concerns regarding this field are mentioned.

Key words: Closed loop Pulsating Heat Pipes (CLPHPs); working fluids; Nanofluids

I. Introduction

Due to huge development in electronic field, thermal management of high performance chips has become a challenging issue to direct heat transfer investigations. And again in industries, there had been always a great demand for having robust and promising cooling devices. For this reason pulsating heat pipe is best option due to simplicity of structure, reliability, and low manufacturing cost.

A heat pipe is simply a type of heat exchanger that is very simple in construction, easy and straight forward for use. Improvements have been done over time in Heat pipes used for heat transfer. Over the years, researchers have continuously search new methods of heat transfer augmentation. The results of employing different working fluid proved to be one effective way of improving the system's overall performance. Nanofluid is a new working fluid used in heat exchangers which is ecofriendly because it uses water as a base fluid. Nanofluids are prepared by suspending metallic or nonmetallic nanometer dimension particles in base fluids (water, oil, and ethylene glycol). So the nanofluid is used as working fluid in the pulsating heat pipe and analyzed the improvement of performance.

Phase changing phenomenon is used in heat pipe and the PHP to take away the heat. Because of the phase change, it will cause to absorb a large amount of latent heat. So the heat from the heat source can be rapidly extracted from the condenser. The principal of pulsating heat pipe proposed and presented by Akachi H. in 1990[1], due to its excellent features the device used in many electronic cooling application.

II. Construction

The basic structure of typical pulsating heat pipe (PHP) is small, light in weight, simple in structure, high effective thermal conductivity and highly efficient. A PHP consists of capillary tubes with many U turns and they are categorized in following manner:-

- Open loop system
- Closed loop system and
- Closed loop pulsating heat pipe (CLPHP) with additional flow control check valves

The pulsating heat pipe has two main region i.e. evaporator and condenser. The evaporator is the heating section and condenser is the cooling section, which is separated by adiabatic region. Adiabatic section is optional and its presence is depends on the location of evaporator and condenser.

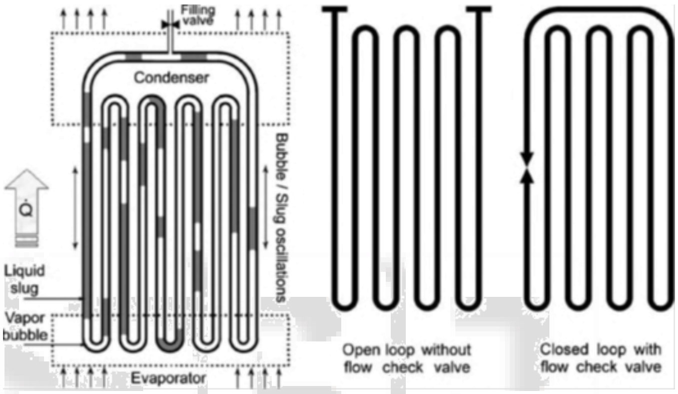

Fig. 1: Schematic diagram of Pulsating Heat Pipe and its variations physical configuration from "An introduction to pulsating heat pipe", by Manfred Groll et.al. 2003 [13]

A. *Tube Diameter:*

The internal tube diameter is very important parameters to define a PHP. Only a certain range of diameters can adheres physical behavior to the "pulsating" mode. The critical Bond number (or Eötvös) criterion gives the tentative design rule for the diameter [16]. Akachi H. in 1990 presented formula for theoretical maximum inner diameter of capillary tube, which is as follows-

$$D_{crit} \approx \sqrt{\frac{\sigma}{(\rho_{liq} - \rho_{vap})g}}$$

If $D < D_{cri}$, surface tension force dominate and stable liquid plugs and vapour slugs are formed. However, if $D > D_{cri}$, the surface tension is reduced and the working fluid will fall down by gravity and oscillations will not happen. The OHP may operate as an interconnected array of two-phase thermosyphons.

III. Operation

Firstly, device is evacuated and then filled with the suitable working fluid. Due to capillary dimension of PHP and surface tension of fluid, fluid fills takes a shape of vapor plugs and liquid slugs. When heat is input to the evaporator section the thin film liquid layer near the vapor plug starts evaporate, this evaporation of causes the expansion of vapor plug and pressure difference. So the expanded vapor plugs pushes the liquid slugs towards the cooler section (i.e. condenser section), where the heat is removed by cold water and vapor plugs regain its size. If tube is closed by end to end forming a loop then fluid is oscillates in this tube.

IV. DESIRABLE PROPERTIES OF WORKING FLUID

From the previous study, it can be said that, the working fluid used in PHP's should possesses some properties [17]:

- High value of $\left(\frac{dP}{dT}\right)_{sat}$: ensuring that rate of change of pressure with temperature in evaporate and condenser should be high enough to generated bubble in evaporator and collpas bubble in condenser
- Low dynamic viscosity: This means lower shear stress.
- Low latent heat: should be desirable, because of quick bubble generation and collapse.
- High specific heat: is desirable complimenting the low latent heat requirement; although there are no specific studies which can confidently suggest the effect of specific heat of the liquid on the thermal performance of PHP. It is to be noted that if a flow pattern change from slug to annular takes place, the respective roles of latent and sensible heat transport mechanism may considerably change, as explained earlier. This aspect requires further investigation.
- Low surface tension: Large number of vapor plugs and liquid slugs are produce, which helps in heat transfer

V. EFFECT OF WORKING FLUID ON PHP

Although Pulsating Heat Pipes (PHPs) were first developed and tested by using working fluids as water or acetone for power electronic cooling, then after with advancement of material and necessity of more powerful cooling system PHP's are used with ammonia for spacecraft thermal control. And again for various application PHP's are used with fluids like water, acetone, methanol or ethanol for computer cooling. The first experimental results showed a significant effect of the working fluid on the PHP performance.

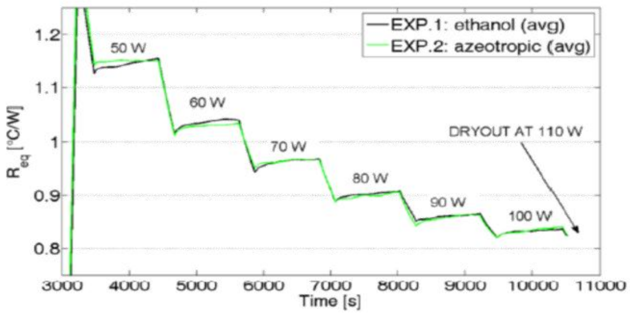

Fig. 4: Temporal evolution of overall thermal resistance for different heat inputs [3]

Mauro Mameli et al. [3] experimentally investigated the Pulsating Heat Pipe (PHP) with working fluid as pure ethanol and with its azeotropic binary mixture. Experiment has been performed first with pure ethanol and then with an azeotropic binary mixture of water (95.5% weight) and ethanol (4.5% weight) as the working fluid. Form the experimental analysis, it is concluded the azeotropic binary mixture perform same as that of pure ethanol.

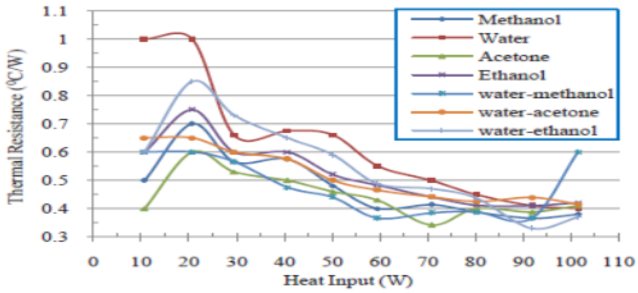

Fig. 5: Thermal resistance of various working fluid PHP (Pramod R. Pachghare, NUiCONE 2012)[3]

Pramod R. Pachghare[6] experimentally investigates the PHP using Methanol, ethanol, acetone, water and different binary mixtures as working fluid in closed loop pulsating heat pipe (CLPHP). copper tube with internal diameter 2.0 mm and external diameter 3.6 mm, filling ratio (FR) was 50 %, ten turns and different heat inputs of 10 to 100W was supplied, the result shows that, from 20 to 60 W heat input, thermal resistance decreases more rapidly. And above 60 W thermal resistance slowly decreases as shown in figure 5. No significant change has been seen between the PHP running with pure and binary mixture working fluids. Best thermal performance is given by Pure acetone in comparisons with the other working fluid.

S. Wannapakhe et al. [5] investigated the a closed-loop oscillating heat pipe with check valves (CLOHP/CV) with silver nanofluid as working fluid to evaluate the heat transfer rate. The CLOHP/CV was made from copper with an internal diameter of 2 mm with 40 turns. Two check valves were inserted into the tube. 0.25, 0.5, 0.75, and 1 %w/v concentration of silver nanofluid with water a base fluid was used.

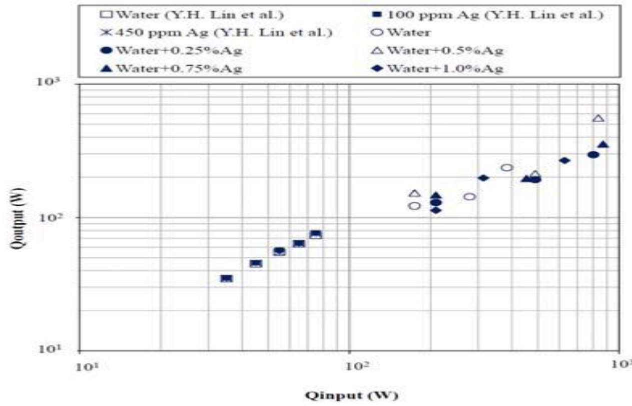

Fig. 6: A comparison of the heat transfer rates of silver nanoflid with water[5]

It was found that, with silver nanofluids the heat transfer rate of the CLOHP/CV was better than that the heat transfer rate when pure water is used because the silver nanofluid increases the heat flux by more than 10%.

Qu et al. [15] in 2011, conducted an experiment on PHP charging with water-SiO_2 nanofluid at different concentrations and from experiment it can be concluded that the thermal resistance of the PHP increased to maximum value of 23.7% in comparison to using pure water as the working fluid. They repeated the same experiment at the same operating situation but with different working fluid (i.e. water-Al_2O_3 nanofluid0. But in this case thermal resistance was reduced to a maximum value of 25.7%

Mohammadi et al. [10] in 2012, Tested two different concentrations of ferrofluid in presence and absence of magnetism in a PHP. They showed that, lower concentration (2.5%) has a better thermal performance in absence of magnetic field, And larger concentration (7%) has a better thermal performance in presence of magnetic field, due to its larger magnetism effects. Their results are presented in Fig 7.

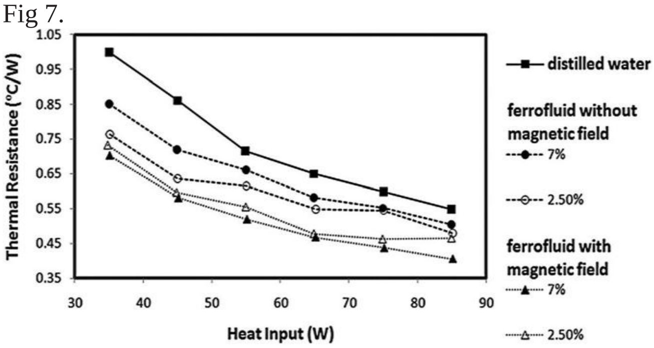

Fig. 7: Thermal resistance as a function of heat input for two different concentrations of ferrofluid (Mohammadi et al., 2012)[10]

Tanshen et al (2013)[4] investigated multi-loop oscillating heat pipe (OHP) charged by water based nanofluids with multi wall carbon-nanotubes (MWCNT) loadings of 0.05 wt.%, 0.1 wt.%, 0.2 wt.% and 0.3 wt.%. The multi-loop OHP with 3 mm inner diameter at 60% filling ratio. The investigation shows that the 0.2 wt % MWCNTs based aqueous nanofluids gives low thermal resistance at any evaporator power input.

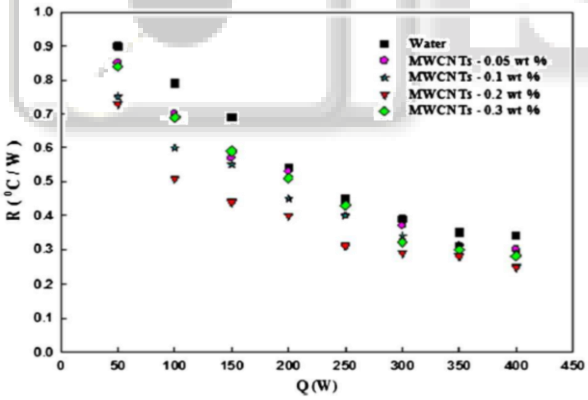

Fig. 8: Thermal resistance with different concentrations of the nanofluids at 60% filling ratio[4]

Wang et al. [12] investigate the pulsating heat pipe with Al_2O_3/water nanofluid and compared the performance of base fluid water with nanofluid. Copper tube PHP with a filling ratio 50% is used. result show that, above 40 W heat input the heat transfer rate of PHP with Al_2O_3 was better than pure water irrespective of the position of PHP. Qu et al. [13] also studied the effect of concentration of Al_2O_3 nanoparticles in water on the thermal resistance of PHP. 56 nm size nanoparticle is used with 0.1%, 0.3%, 0.6%, 0.9% and 1.2% weight concentration with70% filling ratio. Result shows that, from 0% to 0.9% thermal resistance decreased but it increased for 1.2% concentration of nanofluid. The maximum decrease in thermal resistance was about 0.14°C/W (32.5%) obtaine at 0.9% concentration and power input 58.8 W.

Bhawna et al.[8] investigated the effect of concentration of Al_2O_3 nanofluid on thermal resistance of PHP. Copper PHP with filling ratio of 50% and varying concentration from 0.25% to 2.5% (Fig. 9) is used for investigation

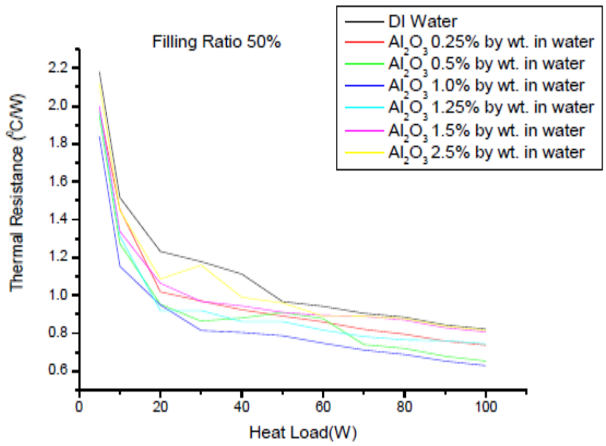

Fig. 9: Effect of concentration of Al2O3 on thermal resistance of PHP at FR 50% [8]

From the result, it was found that a minimum resistance is obtained at 1.0% concentration. Varying concentration of nanofluid from 0.25% to 1.25% give reduction in thermal resistance at constant heat load. above 1.25% concentration thermal resistance of PHP is increase.

VI. CONCLUSIONS

From the above discussion it is concluded that working fluid play an important role in operation of PHP, but PHPs with nanofluids as working fluid have proven to be high performance thermal devices. Presence of nano size particles of metal or nonmetals can improve thermal performance and affect the startup temperature of the PHP. However, the startup temperature depends on the size of nanoparticle, as the size of nanoparticle reduced, the thermal conductivity of the nanofluid increases.the only disadvantage with nanoparticles is that it may agglomerate, settle, or coalesce to the walls with long-term operation of the nanofluid PHP. There is an optimum concentration for nanofluid charged PHPs. Every nanofluid charged PHP has its own optimum charging ratio.

Until now, there are too many nanoparticles is available which is not tested in PHPs and their performance is unpredictable. Examples of these nanoparticles are CNT, SiC, Fe, Ni, Zn, Zr, ZnO, CeO_2, etc. Plus, the type of base fluid has a considerable impact on thermal behavior. Effect of changing the base fluid (alcohols, refrigerants, oils, and etc.) is not considered so much and most of the studies are focused on water as the base fluid up to now.

REFERENCES

[1] Akachi, H., “Structure of a Heat Pipe”, US Patent, Patent Number 4921041, 1990.

[2] K. Rama Narasimha, S.N. Sridhara, M.S. Rajagopal and K.N. Seetharamu, “Influence of Heat Input, Working Fluid and Evacuation Level on the Performance of Pulsating Heat Pipe”,

Journal of Applied Fluid Mechanics, Vol. 5, No. 2, 2012, pp. 33-42,

[3] Mameli Mauro, Khandekar Sameer, Marco Marenga, "An Exploratory Study Of A Pulsating Heat Pipe Operated With A Two Component Fluid Mixture", Proceedings of the 21st National and 10th ISHMT-ASME Heat and Mass Transfer conference, December 27-30, 2011, IIT Madras, India

[4] Tanshen Md. Riyad, B. Munkhbayar, Md. J. Nine, Hanshik Chung, Hyomin Jeong, "Effect of functionalized MWCNTs/water nanofluids on thermal resistance and pressure fluctuation characteristics in oscillating heat pipe", International Communications in Heat and Mass Transfer, 2013

[5] Wannapakhe S., Rittidech S., Bubphachot B. and Watanabe O.,"Heat transfer rate of a closed-loop oscillating heat pipe with check valves using silver nanofluid as working fluid", Journal of Mechanical Science and Technology 23, 2009, pp. 1576~1582

[6] Pramod R. Pachghare, Ashish M. Mahalle, "Effect of pure and binary fluids on closed loop pulsating heat pipe thermal performance", Chemical, Civil and Mechanical Engineering Tracks of 3rd Nirma University International Conference, Procedia Engineering 51, 2013, pp.624 – 629

[7] Yu-Hsing Lin, Shung-Wen Kang, Hui-Lun Chen, "Effect of silver nano-fluid on pulsating heat pipe thermal performance", Applied Thermal Engineering 28, 2008, pp. 1312–1317

[8] Bhawna Verma, V.L.Yadav, K.K.Srivastava, "Nano fluid- An alternative fluid in Pulsating Heat Pipe/Oscillating Heat Pipe", Journal of Electronics and Communication Engineering, Volume 3, Issue 3, Sep-Oct. 201, pp. 28-37

[9] Mohammadi, maziar mohammadi, mohammad behshad shafii, "A review of nanofluidic pulsating heat pipes: suitable choices for thermal management of electronics, frontiers in heat pipes (fhp)", 3, 2012

[10] Mohammadi Niloofar , Mazir, Mohammadi, Mohammad, Ghahremani, A.R., and Shafii, M.B., "Experimental Study of the Effects of Ferrofluid on Thermal Performance of a Pulsating Heat Pipe", Proceedings of 9th International Conference on Nanochannels, Microchannels, and Minichannels, University of Alberta in Edmonton,Canada. 2011

[11] Yulongji, hongbinmaa, Fengmin Su, Guoyou Wang, "Particle size effect on heat transfer performance in an oscillating heat pipe", Experimental Thermal and Fluid Science 35, 2011, pp.724–727.

[12] Wang S., Lin Z., Zhang W. & Chen J., "Experimental study on pulsating heat pipe with functional thermal fluids", International Journal of Heat and Mass Transfer 52, 2009, pp.5276-5279.

[13] Qu Jian, Hui-ying Wu, Ping Cheng, "Thermal performance of an oscillating heat pipe with Al2O3-water Nanofluids", International communications in Heat and Mass Transfer 37,2010, pp. 111-115.

[14] Khandekar Sameer, Groll Manfred, "Closed loop and open loop pulsating eat pipe", 13th International Heat Pipe Conference, Shanghai, China, September 21-25, 2004.

[15] Qu, J., and Wu, H., 2011, "Thermal Performance Comparison of Oscillating Heat Pipes with SiO2/Water and Al2O3/Water Nanofluids", International Journal of Thermal Sciences, 50(10), pp.1954–1962.

[16] Piyanun Charoensawan, Sameer Khandeka, Manfred Groll, Pradit Terdtoon, "Closed loop pulsating heat pipes Part A: parametric experimental investigations", Applied Thermal Engineering 23, 2003, pp.2009–2020.

[17] Pramod R. Pachghare, Ashish M. Mahalle, Shekhar Khedkar, "Effect of Working Fluid on Thermal Performance of Closed Loop Pulsating Heat Pipe: A Review", National Conference on Innovative Paradigms in Engineering & Technology (NCIPET-2012) Proceedings published by International Journal of Computer Applications® (IJCA).