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A New Horizon with Enhance Heat Transfer Rate Using Heat Pipe for Compact Thermal System - A Review

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ABSTRACT

Due to larger amount of heat transfer and compact system requirement in modern industries, there should be such a device with enhanced heat transfer rate. Heat pipe with proper working medium is modern trends to enhance heat transfer coefficient. This article mainly deals with cylindrical heat pipe of different wick structures, different types of working medium and recent development. Major three wick structures namely screen mesh, sintered and grooved types were discussed. Detailed analysis of various working mediums were carried out. Recently heat pipes were widely using in various applications like electronic item cooling, refrigeration system, aerospace, compact heat exchanges, phase change material (PCMs) with heat pipe, micro reactor etc.

Keywords : Heat Pipe, Cylindrical, Wick Structure, Working Medium, Heat Transfer Rate.

I. INTRODUCTION

The heat pipe is one of the remarkable achievements of thermal physics and heat transfer engineering in this century because of its unique ability to transfer heat over large distances without considerable losses. The main applications of heat pipes deal with the problems of environmental protection and energy and fuel savings.

It is a simple closed-loop device that can quickly transfer heat from one point to another using a two phase flow. It is a high thermal conductance device as well which transfers heat by two-phase fluid circulation.

In a simple form of its structure, this device is transporting heat from one point to another via evaporation and condensation, and the heat transport fluid is recirculated by capillary forces which automatically develop as induction of the heat transport process.

This closed loop of heat pipe is consisting of a sealed hollow tube with two zones, namely, evaporator and condenser, in a very simple case of such device whose inside walls are lined with a capillary structure known as wick. A thermodynamic working fluid having a substantial vapor pressure at the desired operating temperature saturates the pores of the wick. When heat is applied to any portion of the heat pipe evaporator, this fluid is heated and it evaporates, readily filling the hollow centre of the pipe. The vapor then diffuses throughout the heat pipe. Condensation of the vapor occurs on the pipe wall whenever the temperature is even slightly below that of the evaporation area. As it condenses, the liquid gives up the heat it acquired and returns to the evaporator section or heat source by means of capillary action within the wick. This tends to produce isothermal operation and a high effective thermal conductance. When a heat sink is attached to a portion of the heat pipe, condensation takes place preferentially at this point of heat loss, and a vapor flow pattern is then established. [01]

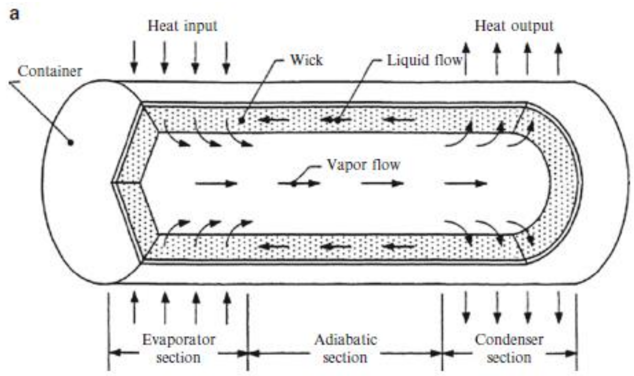

Figure 1. Different sections of heat pipe [01]

WORKING MEDIUM

A first consideration in the identification of a suitable working fluid is the operating vapor temperature range. Within the approximate temperature band, several possible working fluids may exist, and a variety of characteristics must be examined in order to determine the most acceptable of these fluids for the application considered. The prime requirements are

- ✓ Compatibility with wick and wall materials
- ✓ Good thermal stability
- ✓ Wettability of wick and wall materials
- ✓ Vapor pressure not too high or low over the operating temperature range
- ✓ High latent heat
- ✓ High thermal conductivity
- ✓ Low liquid and vapor viscosities
- ✓ High surface tension
- ✓ Acceptable freezing or pour point

The selection of the working fluid must also be based on thermodynamic considerations which are concerned with the various limitations to heat flow occurring within the heat pipe like, viscous, sonic, capillary, entrainment, and nucleate boiling levels. In heat pipe design, a high value of surface tension is desirable in order to enable the heat pipe to operate against gravity and to generate a high capillary driving force. The resistance to fluid flow will be minimized by choosing fluids with low values of vapor and liquid viscosities. [01]

WICK OR CAPILLARY STRUCTURE

It is a porous structure made of materials like steel, aluminium, nickel, or copper in various ranges of pore sizes. They are fabricated using metal foams, and more particularly felts, the latter being more frequently used. By varying the pressure on the felt during assembly, various pore sizes can be produced. The prime purpose of the wick is to generate capillary pressure to transport the working fluid from the condenser to the evaporator. It must also be able to distribute the liquid around the evaporator section to any area where heat is likely to be received by the heat pipe. Often these two functions require wicks of different forms. The selection of the wick for a heat pipe depends on many factors, several of which are closely linked to the properties of the working fluid. The most common types of wicks that are used are as follows.

(a) Sintered Powder

This process will provide high power handling, low-temperature gradients, and high capillary forces for anti-gravity applications. The Figure 1.2 shows a complex sintered wick with several vapor channels and small arteries to increase the liquid flow rate. Very tight bends in the heat pipe can be achieved with this type of structure.

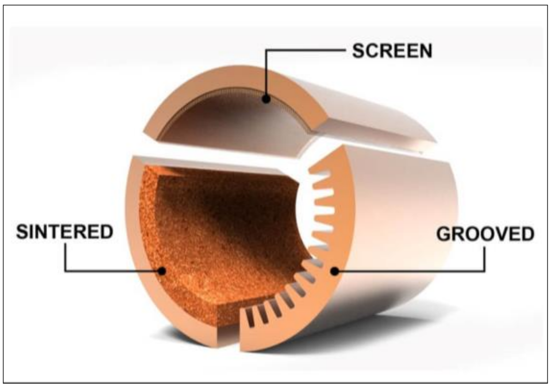

Figure 2. Different Wick Structures (Google image)

(b) Grooved Tube

The small capillary driving force generated by the axial grooves is adequate for low power heat pipes when operated horizontally, or with gravity assistance. The tube can be readily bent. When used in conjunction with screen mesh the performance can be considerably enhanced.

(c) Screen Mesh

This type of wick is used in the majority of the products and provides readily variable characteristics in terms of power transport and orientation sensitivity, according to the number of layers and mesh counts used.

Heat transfer in a heat pipe is limited by: the rate at which liquid can flow through the wick; "choking" (the inability to increase vapor flow with increasing pressure differential, also called "sonic limit"); entrainment of liquid in the vapor stream, such that liquid flow to the evaporator is reduced; the rate at which evaporation can take place without excessive temperature differentials in the evaporator section. [01]

II. LITERATURE STUDY

(a) Heat pipe with screen mesh wick structure

Wang et al. [02], performed an experimental study on thermal performance of an inclined miniature mesh heat pipe using water based CuO nanofluid as working medium. Cylindrical copper heat pipe with 350mm length, 8mm diameter and 0.6mm thickness was used which contains 100mm evaporator section length, 100mm adiabatic section length and 150mm condenser section length. Evaporation section was heated using electric heater and condenser section was cooled by water cooling. Temperature and pressure were recorded using 09 nos thermocouples and pressure transducer respectively. Experiment was conducted for different inclination angles (0, 300, 450, 600, 900) and 0.5wt% to 2.0wt% CuO nanoparticles concentration using operating temperatures (400C, 500C, 600C). Heat transfer coefficient will increase with increasing concentration up to 1.0wt% and then it will gradually decrease by increasing concentration. Heat removal capacity of heat pipe was increased 40% by substituting nanofluid in place of water in. Inclination angle had great effect on evaporator section but it does not much affect on condenser section. Result show enhancement in thermal performance at 450 inclination angle with 1.0wt% CuO nanofluid concentration.

Putra et al. [03], manufactured and tested thermal performance of screen mesh wick heat pipes with nanofluid. Investigated the thermal resistance of screen mesh wick heat pipe using nanofluid such as Al2O3-Water, Al2O3-ethylene glycol, TiO2-water, TiO2-ethylene glycol and ZnO-ethylene glycol. Thermal conductivity test was carried out for the nanofluid. Thermal conductivity increases with increasing volume fraction of particles. Thermal conductivity of Al2O3 with 5% volume fraction nanofluid was increased by 13%. Sedimentation test was conducted to study the dispersion characteristics. There was 5% separation observed after 64 days in Al2O3-Water but sedimentation was observed in Al2O3-ethylene glycol after 67 days, TiO2-water after 53 days, TiO2- ethylene glycol after 55 days and ZaO nanofluid after 32 days. Heat pipe was fabricated using copper tube of 8mm dia and 200 mm long using 4 layer screen mesh of stainless steel wire (dia-56.5un). SEM and Energy Dispersive X-ray Analysis (EDAX) were performed to examine wick screen mesh before and after. Result shows thin layer coating on weak structure when Al2O3- water was used as nanofluid where as a very thin and smooth coating also occurs when other nanofluids were used. Straight copper heat pipe with screen mesh wick perform best using Al2O3-water nanofluid with 5% volume concentration.

Hajian et al. [04], had carried our experimental study on effect of nanofluid on thermal performance with response time on heat pipe. Test was carried out with medium size circular, mesh type heat pipe and silver nanofluid using 300-500W heat load. Nanofluids with small nanoparticles have higher thermal resistances without encountering clogging and sedimentation problem. Nanofluid with 50 ppm particle size was most dilute working fluid and shown best performance. If concentration of nanoparticles exceeds the optimum value then more collisions and contact among particles occurs and the probability of particles conglomeration and sedimentation increase.

Senthilkumar et al. [05], experimented the effect of inclination angle in heat pipe performance using copper-Di water nanofluid. Copper container with two layer stainless steel screen wick material was used for heat pipe. Nanofluid was prepared using ultrasonic homogenizer with 6 hr time duration. Experiments were conducted for different heat loads (20, 40, 50, 60 and 70W) and different inclination angles (00, 150, 300, 450, 600, 750 and 900) of heat pipe. Results show that 300 for DI water and 450 for nanofluid is optimum angles for better heat transfer characteristics. Furthermore, efficiency of heat pipe was 10% increased by using nanofluid in place of DI water.

Mousa [06], experimentally studied the effect of nanofluid concentration on the performance of circular heat pipe. Pure water and Al2O3-water based nanofluid were used as working fluid for the study of heat performance under different operating conditions like filling ratio, volume fraction, heat input rate. Evaporator section was heated by electric heater and condenser section was cooled by air. Heat pipe was evacuated up to 0.01 bar vaccum pressure. The filling ratios used were 0.2, 0.4, 0.45, 0.50, 0.55, 0.60, 0.65, 0.70, 0.80 and 1.0. the volume fractions used were 0.25%, 0.4%,0.5%, 0.6%, 0.75%, 1.0% and 1.5% respectively. Obtained data shows 0.45 as optimum filling ratio and 1.2% as optimum volume fraction for better thermal performance of heat pipe.

Liu and Zhu [07], had carried out experimental study to investigate the effect of aqueous CuO nanofluid performance in a horizontal mesh heat pipe. Average nanoparticles diameters were 50 nm. The heat transfer increase with decreasing of pressure but this change of pressure may be negligible. TEM test was conducted on nanofluid. The test was conducted under three pressure 19.97kPa, 12.38kPa and 7.45kPa respectively. Heat pipe was undistributed for a week and same test were conducted but there wasn't any noticeable change in observations. Nanoparticles concentration significantly decreases the wall temperature of evaporator and increase the wall temperature of condenser. 1.0wt% mass concentration is optimum value for better performance of heat pipe. Maximum heat flux was enhanced by 24% and average heat resistance was decreased by 60% using nanofluid in place of deionized water.

Hung et al. [08], demonstrated the thermal performance enhancement of heat pipe using alumina nanofluids. Copper tubes with outer diameter 9.52 mm and three different lengths (0.3m, 0.45 m and 0.6m) were used for study. Nanofluids were prepared using homogenizer, electromagnetic agitator and ultrasonic vibrator. Working medium was characterized using TEM and XRD technique. The thermal performance was enhanced by 22.7%, 56.3% and 35.1% by using nanofluids in place of DI water for 0.3m, 0.45m and 0.6m length respectively.

(b) Heat Pipe with Sintered wick structure

Vijaykumar et al.[09], investigated the thermal characteristics of cylindrical sintered wick heat pipe using CuO and Al_2O_3 nanofluids. The size and morphology of the nanoparticles are maintained as constant to analyse the distinctive performances of nanoparticles on the thermal enhancement of heat pipe. The effect of inclination angle and heat input on the thermal performance of heat pipe is also studied. The addition of nanoparticles has a notable influence in surface temperature of heat pipe and it is gradually reduced with increasing concentration. The reduction for 0.5 wt.%, 1.0 wt.% and 1.5 wt.% of CuO nanofluids are 2.1°C, 5.9°C and 4.7°C respectively, whereas for the same concentrations Al_2O_3 nanofluids obtain only 0.9°C, 3.6°C and 5.3°C respectively compared with DI water at horizontal position. Thermal resistance of heat pipe is dramatically reduced with increasing heat flux at low heat input and the reduction is diminished for peak loads. The optimum performance is attained for both CuO and Al_2O_3 nanofluids at 45° inclination angle. In contrast, the optimum concentration is varied i.e., 1.0 wt.% for CuO and 1.5 wt.% for Al_2O_3 nanofluids. The evaporation and condensation HTC is increases about 32.99% and 24.59% respectively for CuO and Al_2O_3 nanofluids at 45°.

Kang et al. [10], performed an experiment to measure the temperature distribution and compare the heat pipe temperature difference using nanofluid and DI-water. The tested nano- particle concentrations ranged from 1, 10 and 100 mg/l. The condenser section of the heat pipe was attached to a heat sink that was cooled by water supplied from a constant temperature bath maintained at 40°C.At a same charge volume, the measured nanofluids filled heat pipe temperature distribution demon- strated that the temperature difference decreased 0.56–0.65°C compared to DI-water at an input power of 30–50 W. In addition, the nanofluid as working medium in heat pipe can up to 70 W and is higher than pure water about 20W.

Kumaresan et al. [11], experimentally studied the enhancement in heat transfer characteristics of a copper sintered wick heat pipe with surfactant free CuO nanoparticles dispersed in DI water. The effect of heat input, tilt angle and weight fractions of nanoparticles on the heat pipe thermal resistance, heat transfer coefficient in evaporator and condenser sections, thermal conductivity and thermal efficiency were investigated. The experimental results were evaluated for the vapor temperatures directly measured at the center core of heat pipe. Interestingly, a temperature difference of 5.1°C was observed between the heat pipe surface and the vapor core in the evaporator section. Results showed a reduction in the thermal resistance of 66.1% and enhancement in the heat transfer coefficient and thermal conductivity of 29.4% and 63.5% is respectively, observed for 1.0 wt.% of CuO/DI water nanofluid at 45° tilt angle compared with heat pipe kept at horizontal position. Similarly, the thermal efficiency is also improved by 24.9% for the same tilt angle and weight fraction of CuO nanofluid. The use of nanoparticles and tilt angle enhances the operating range and thermal performance of heat pipe when compared with that of the heat pipe with DI water.

(c) Heat pipe with grooved wick structure

Yang et al.[12], carried out an experiment to study the heat transfer performance of a horizontal micro-grooved heat pipe using CuO nanofluid as the working fluid. CuO nanofluid was a uniform suspension of CuO nanoparticles and deionized water. The average diameter of CuO nanoparticles was 50 nm. Mass concentration of CuO nanoparticles varied from 0.5 wt% to2.0 wt%. The experiment was performed at three steady operating pressures of 7.45 kPa,12.38 kPa and 19.97 kPa, respectively. Effects of the mass concentration of CuO nanoparticles and the operating pressure on both the heat transfer coefficients of the evaporator and the condenser sections, the critical heat flux (CHF) and the total heat resistance of the heat pipe were discussed.

Mehrali et al. [13], published a paper in which he analysed thermal performance of a grooved heat pipe using aqueous nitrogen-doped graphene (NDG) nanofluids.It was in particular focused on the effect of varying NDG nanosheets concentrations, heat pipe inclination angles and input heating powers. The results indicated that the inclination angle had a major influence on the heat transfer performance of heat pipes and the inclination angle of 90° was corresponded to the best thermal performance. The maximum thermal resistance reduction of 58.6% and 99% enhancement in the evaporator heat transfer coefficient of the heat pipe were observed for NDG nanofluid with concentration of 0.06 wt%, inclination angle of h ¼ 90° and a heating power of 120 W in comparison to DI-water under the exact same condition. Additionally, the surface temperature distribution was decreased by employing NDG nanosheets, which can in return increase the thermal performance of a grooved heat pipe. The present investigation indicated that the thermal performance of the grooved heat pipe can be improved significantly by using NDG nanofluids.

(d) Recent development in heat pipe areas

Shukla et al. [14], carried out an experiment to study the thermal efficiency enhancement of the heat pipe using copper nanofluid as the working fluid. The copper nanoparticles are uniformly suspended with the de-ionized water using ultrasonic homogenizer to prepare the copper nanofluid. The average particle size of the copper is 40 nm and the concentration of copper nanoparticle in the nanofluid is 100 mg/lit. The study discusses about the effect of heat pipe inclination, type of working fluid and heat input on the thermal efficiency and thermal resistance. The experimental results are evaluated in terms of its performance metrics and are compared with that of DI water.

Mohamed et al. [15], conducted a literature review to evaluate current heat pipe systems for air conditioning and personal computers applications utility. In air conditioning systems, the research mainly focused on the use of heat pipe heat exchanger as a unit for humidity control and heat recovery. The review shows that by the application of a heat pipe heat exchanger in air conditioning systems, the moisture removal capability and energy saving were increased in addition to the environmental impact. In personal computers application, the use of heat pipes makes it possible to create low-noise and effective systems for cooling of personal computer components under high thermal load.

Roman et al. [16], submitted research papers that dealt with the use of loop thermosyphon heat pipe to transfer heat from electrotechnical box. The loop heat pipe is very good cooling device which requires no mechanical parts in their design. Loop heat pipe uses only phase change during heat transfer, without a compressor, fan or pump. Loop heat pipe is more energy saving compared to conventional cooling systems with forced convection. The main advantage of cooling by loop heat pipe is that electrotechnical box can be hermetically closed, because dust reduces the life time of electrotechnical box.

Yang et al. [17], summarized a paper in which the recent developments of lightweight, high performance heat pipes were discussed. Various methods or approaches to achieve the requirements of lightweight and high performance were introduced. The applications of lightweight materials can help reduce by up to 80% the weight of conventional copper heat pipes; however the lightweight material often has problems of corrosion. Although improving the design of wick structures and changing the size of conventional heat pipe assemblies can help to reduce weight and achieve high heat flux, there are still some limitations to the applications of lightweight materials such as magnesium due to its incompatibility with some working fluids.

Narendra et al. [18], summarized a paper in which the recent developments of lightweight, high performance heat pipes are discussed. The applications of lightweight materials can help reduce by up to 80% the weight of conventional copper heat pipes. However the lightweight material often has problems of corrosion. There are still some limitations to the applications of lightweight materials such as magnesium due to its incompatibility with some working fluids. To use water (the most desirable working fluids for normal heat pipes) as a working fluid, aluminum alloys, titanium alloys and magnesium alloys must have additional protection incorporated during the production process in order to avoid non-condensable gas generation.

III. RESULTS AND DISCUSSION

There are different types of heat pipes which are most commonly used in various industries for heat transfer purpose.

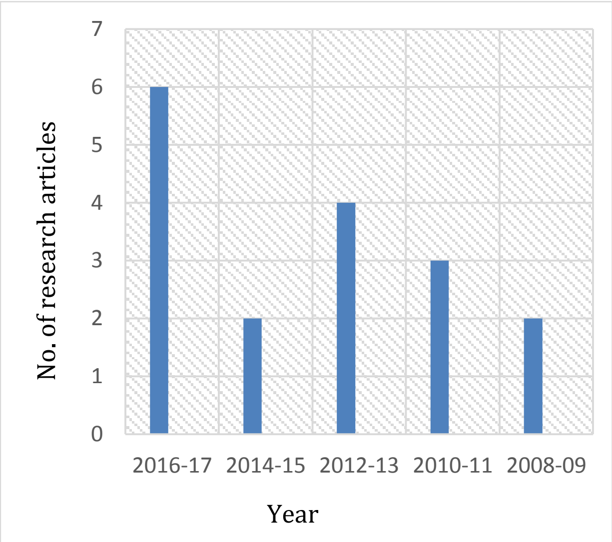

Figure 3. Analysis of research articles: Year wise

As per Figure 3, analysis shows that heat pipe is recent trends and researcher are most commonly focusing on it for the purpose of heat transfer enhancement.

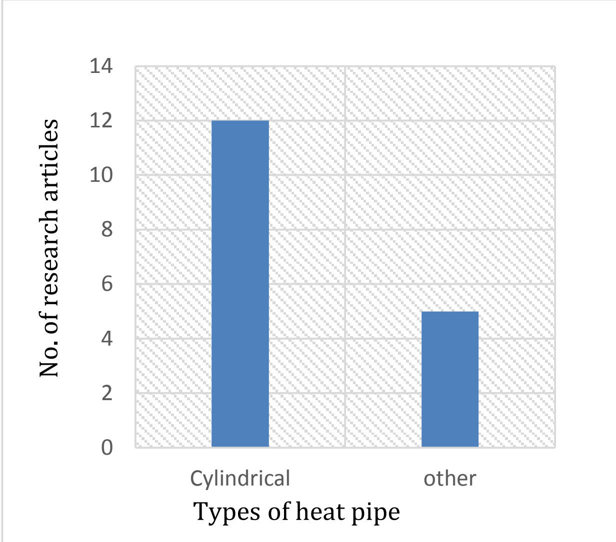

Figure 4. Analysis of research articles: heat pipe type wise

Figure 4 shows that major investigations had been carried out on cylindrical shaped heat pipe which is most commonly used heat pipe in industrial applications.

Figure 5 show that screen mesh wick structure is most common due to easy construction, assembling and financially.

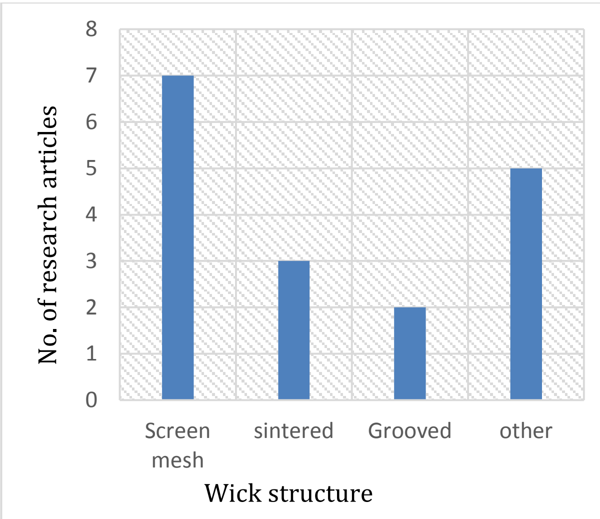

Figure 5. analysis of research articles: wick structure wise

As shown in Table 1, Nanofluid is the relatively recent practice to enhance the heat transfer rate. There are different types of nanofluid which can be used to enhance heat transfer rate. Many researchers have carried out numerical and experimental analysis on application of different types of nanofluid in enhancement of heat transfer rate under different conditions.

Table 1. Use of Different working mediums in heat pipe

Researcher (s)	**Types of wick structure**	**Working medium**
Wang et al. [02]	Screen mesh	CuO/Water Nanofluid
Putra et al. [03]	Screen mesh	Al2O3-water Nanofluid
Hajian et al. [04]	Screen mesh	Silver-DI water Nanofluid
Senthilkumar et al. [05]	Screen mesh	Cu-DI water Nanofluid
Mousa [06]	Screen mesh	Al2O3-water Nanofluid
Liu and Zhu [07]	Screen mesh	CuO-water Nanofluid
Hung et al. [08]	Screen mesh	Al2O3-water Nanofluid
Vijaykumar M. et al.[09]	Sintered	CuO-water and Al2O3-water Nanofluids
Kang et. al [10]	Sintered	Silver-water Nnaofluid
Kumaresan et. al. [11]	Sintered	CuO-DI water nanofluid
Yang et. al.[12]	Grooved	CuO-water Nanofluid
Mehrali et al. [13]	Grooved	Aqueous Nitrogen Dropped Graphene(NDG)
Shukla et al.[14]	Grooved	Silver-water and CU-water Nanofluids
Roman B et al.[16]	Other	Methanol-water and acetone

IV. CONCLUSION

A novel idea which has been suggested to utilize nanofluid as working medium in cylindrical screen mesh wick heat pipe to enhance thermal performance of any cooling system which is critically exposed with heat load.

V. REFERENCES

[1]. Bahman Zohuri, 2016, "Heat Pipe Design and Technology, A Practical Approach", CRC Press.

[2]. Ping-Yang Wang, Xiu-Juan Chen, Zhen-Hua Liu, Yi-Peng Liu, 2012, "Application of nanofluid in an inclined mesh wicked heat pipes", Thermochimica Acta,539, 100-108.

[3]. Nandy Putra, Wayan Nata Septiadi, Haolia Rahman, Ridho Irwansyah, 2012, "Thermal performance of screen mesh wick heat pipes with nanofluids", Experimental Thermal and Fluid Science, 40, 10–17.

[4]. Ramin Hajian, Mohammad Layeghi, Kamal Abbaspour Sani, 2012, "Experimental study of nanofluid effects on the thermal performance with response time of heat pipe", Energy Conversion and Management, 56, 63–68.

[5]. Senthilkumar R*a, Vaidyanathan Sb, Sivaraman B, 2012, "Effect of Inclination Angle in Heat Pipe Performance Using Copper Nanofluid", Procedia Engineering, 38, 3715 – 3721.

[6]. M.G. Mousa, 2011, "Effect of nanofluid concentration on the performance of circular heat pipe", Ain Shams Engineering Journal, 2, 63–69.

[7]. ZhenHua Liu, QunZhi Zhu, 2011, "Application of aqueous nanofluids in a horizontal mesh heat pipe", Energy Conversion and Management, 52, 292–300.

[8]. Yi-Hsuan Hung, Tun-Ping Teng, Bo-Gu Lin, 2013, "Evaluation of the thermal performance of a heat pipe using alumina nanofluids", Experimental Thermal and Fluid Science, 44, 504–511.

[9]. M. Vijayakumar, P. Navaneethakrishnan, G. Kumaresan, 2016, "Thermal characteristics studies on sintered wick heat pipe using CuO and Al2O3 nanofluids", Experimental Thermal and Fluid Science, 1-34.

[10]. Shung-Wen Kang, Wei-Chiang Wei, Sheng-Hong Tsai, Chia-Ching Huang, 2009, "Experimental investigation of nanofluids on sintered heat pipe thermal performance", Applied Thermal Engineering, 29, 973–979.

[11]. G. Kumaresan, S. Venkatachalapathy, Lazarus Godson Asirvatham, 2014, "Experimental investigation on enhancement in thermal characteristics of sintered wick heat pipe using CuO nanofluids", International Journal of Heat and Mass Transfer, 72, 507–516.

[12]. Xue Fei Yang, Zhen-Hua Liu and Jie Zhao, 2008, "Heat transfer performance of a horizontal micro-grooved heat pipe using CuO Nanofluid", J. Micromech. Microeng, 18,1-7.

[13]. Mohammad Mehrali, Emad Sadeghinezhad, Reza Azizian, Amir Reza Akhiani, Sara Tahan Latibari, Mehdi Mehrali, Hendrik Simon Cornelis Metselaar, 2016, "Effect of nitrogen-doped graphene nanofluid on the thermal performance of the grooved copper heat pipe", Energy Conversion and Management, 118, 459–473.

[14]. K. N. Shukla, A. Brusly Solomon, B. C. Pillai, Mohammed Ibrahim, 2010, "Thermal Performance of Cylindrical Heat Pipe Using Nanofluids", JOURNAL OF THERMOPHYSICS AND HEAT TRANSFER, Vol. 24, No. 4, 796-802.

[15]. A.S.A.Mohamed, M.salem Ahmed, 2017, "A REVIEW: ON THE HEAT PIPE AND ITS APPLICATIONS", Proceedings of 4th International Conference on Energy Engineering, Faculty of Energy Engineering, Aswan University, Aswan , Egypt, December 26-28.

[16]. Banovcan Roman, Puchor Tomas, Kapjor Andrej, Malcho Milan, 2017, "Optimization of loop heat pipe for cooling of electrotechnical box,", AIP Conference proceedings.

[17]. X. Yang, Y.Y. Yan, D. Mullen, 2012, "Recent developments of lightweight, high performance heat pipes" Applied Thermal Engineering, 33-34, 1-14.

[18]. Narendra Babu Na, Kamath HC, 2015, "Materials Used in Heat Pipe", Materials Today: Proceedings 2, 1469 – 1478.