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DESIGN AND APPLICATIONS OF HEAT PIPE: A REVIEW

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Abstract

Heat pipe is a heat transfer device which transports large quantities of heat with minimum temperature gradient without any additional power. In this review paper various design parameters which affect the performance of heat pipe as well as various applications of heat pipe are discussed. Heat pipe performance is affected by orientation of heat pipe, heat input, heat pipe material, wick structure, working fluid etc. Heat pipe technology has found wide applications in enhancing the thermal performance of heat exchangers in energy savings in heating, ventilating, and air conditioning systems, surgery centres, hotels, clean rooms etc. From literature it is concluded that heat pipe have large heat transfer capacity with varieties of application in cooling as well as heating.

Keyword- *Heat pipe, Application of heat pipe, Loop heat pipe, Nano-fluid, Inclination, Filling ratio, Synergistic coupling.*

I. INTRODUCTION

Heat pipes have been considered as promising means for effective heat transfer in energy transport and storage systems in medium-high temperature range. Heat pipes are two-phase flow heat transfer devices where processes of liquid to vapor and vice versa circulate between evaporator to condenser with high effective thermal conductivity. As its operation involves phase changes (i.e., evaporation and condensation) large amounts of heat can be transferred. Due to the high heat transport capacity, heat exchangers with heat pipes have become much smaller than traditional heat exchangers in handling high heat fluxes [1]. The heat pipe is a self-contained structure that achieves very high thermal energy conductance by means of two-phase fluid flow with capillary circulation. Heat added to the evaporator is transferred to the working fluid by conduction and causes vaporization of the working fluid at the surface of the capillary structure. Vaporization causes the local vapor pressure in the evaporator to increase and vapor to flow toward the condenser thereby transporting the latent heat of vaporization [2].

Heat pipe technology has found increasing applications in enhancing the thermal performance of heat exchangers in microelectronics; energy savings in heating, ventilating, and air conditioning (HVAC) systems for operating rooms, surgery centres, hotels, clean rooms etc.; temperature regulation systems for the human body; and other industrial sectors including spacecraft and various types of nuclear reactor technologies as a fully inherent cooling apparatus [3].

II. DESIGN PARAMETERS OF HEAT PIPE

Theoretical and experimental studies have been conducted to investigate the effect of various parameters on performance of heat pipe and based on that performance characteristics of various heat pipes are evaluated.

Eui Guk Jung et al. conducted study on thermal numerical model of a heat pipe under radiation [4]. In this study, a thermal analysis model was developed by the nodal approach and used to predict the thermal performance of a high-temperature HPHEX (Heat Pipe Heat Exchanger). The numerical thermal model was useful for determining not only the temperature distribution of the fluid in each row but also the temperatures at various points of the HP (Heat Pipe). It is concluded that an increase in H*(ratio of evaporator length to total length) narrowed the range of Re*(Reynolds number) values that could satisfy the minimum operating temperature of the HPs, although it also reduced the inlet temperature and pressure drop on the cold-side. The effectiveness of the HPHEX was strongly dependent on H* and Re*, the values of which could be adjusted to the required operating condition.

Senthilkumar R. et. al. conducted study on effect of inclination angle in heat pipe performance using copper nanofluid [5]. An experiment was carried out to study the thermal efficiency enhancement of the heat pipe using copper nanofluid as the working fluid. In this study copper heat pipe with stainless steel wick is used. The copper nanoparticles are uniformly suspended with the de-ionized (DI) water. The experiments are conducted using two identical heat pipes. One of the heat pipes is filled with de-ionized water and another one with copper nanofluid. It is found that the thermal efficiency of copper nanofluid is higher than the base fluids like DI water and the thermal resistance is also considerably less than the DI water. Pramod R. Pachghare et. al conducted study on effect of pure and binary fluids on performance of closed loop pulsating heat pipe [6]. This paper presents experimental results on thermal performance of closed loop pulsating heat pipe (PHP) using copper tube. For all experimentation, filling ratio (FR) was 50 %, ten turns and different heat inputs of 10 to 100W was supplied to PHP. Working fluids are selected as Methanol, ethanol, acetone, water and different binary mixtures. From the experiments it is found that for pure and binary working fluids of PHP, thermal resistance is decreases with the increasing heat inputs. In this PHP, pure acetone gives best thermal performance in comparisons with the other pure and binary mixtures working fluid. No measurable difference has been recorded between the PHP running with pure and binary mixture working fluids, in terms of overall thermal resistance.

Xiao-Dong Wang et. al. Conducted study on experimental investigation of cooper grooved micro heat pipes (MHPs) [7]. In this study two types of microgroove is investigated, first is silicon microgroove and second is copper microgroove. The rectangular ambulatory structures was designed and fabricated between copper and silicon. An experiment was conducted to measure the hydrophobicity

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between the fabricated silicon microgrooves and copper microgrooves. The drop shape analyzer measuring instrument was used to measure the contact angle of the fabricated microgrooves. Since the copper microgrooves had a smaller contact angle, as well as better capability of capillary traction, the copper-grooved MHPs showed a 17% higher equivalent thermal conductivity than that of silicon-grooved MHPs. The copper-grooved silicon based MHPs were proved to be feasible in heat transfer for HP LEDs.

Jorge Bertoldo Junior et. al. conducted study on dynamic test method to determine the capillary limit of axially grooved heat pipe [8]. The dynamic method proposed in this paper to detect dry out in heat pipes consists in applying a given heat load on the heat pipe, which is initially kept in a horizontal position on a rotary table equipped with motor with reducer gearbox and digital inclinometer. The heat pipe used as test specimen is a two-core aluminium axially grooved heat pipe filled with ammonia. After steady state is reached on the heat pipe, which is leveled horizontally, the table is driven causing the pipe to adverse tilt slowly until the dry out occurs. Once dry out initiates, detection of the dry out event by a temperature sensor was investigated. The pipe is then placed back in the horizontal position. From Experiments it is found that this method allows to reduce the performance tilt test time necessary to obtain the characteristic curve of HP heat transfer capability over the whole range of adverse tilts and to increase the detection accuracy of the point where the dry out occurs.

Jianhong Liu et. al. investigates synergistic coupling between the pulsating heat pipes [9]. Using a constant temperature water bath as heat source, experiments are performed to investigate the heat transfer characteristics of the coupled pulsating heat pipe (PHP), which consists of the main PHP filled with distilled water and the synergistic oscillating PHP filled with ethanol. The heat transfer characteristics and the wall temperatures of the coupled PHP are analysed and compared with the single PHP only made of the main PHP under the same condition. From the experiments it is concluded that, in the same heat source temperature, the heat absorption and the heat release of the coupled PHP are both greater than the single PHP's, and the heat transfer is better in the case of small temperature difference.

M.A. Chernysheva et. al. describes study on effect of external factors on the operating characteristics of a copper–water loop heat pipe [10]. From experimental study it is concluded that for higher heat input the Loop Heat Pipe operates in constant-conductance condition at all slopes but slop dependency of heat transfer capacity was decrease.

III. APPLICATION OF HEAT PIPE

M. Ahmadzadehtalatapeh conducted study on air conditioning application of heat pipe [11]. Based on field measurements, it was found that air conditions provided by the existing AC system are not within the thermal comfort zone recommended by the ASHRAE. In order to achieve more reliable simulation results, the effectiveness of three fabricated HPHEX was experimentally obtained under conditions similar to actual conditions. TRNSYS software was employed to simulate the performance of existing AC systems and the system equipped with the HPHEX for the entire year. The results showed that the system equipped with the HPHEX could keep the library space approximately at 22.4 °C and 54.5% RH. In addition, it provides the supply duct air RH at 68.3%. Energy consumption of the systems was also investigated. It was shown that the HPHEX caused the total amount of 15% energy could be saved in a year. Mostafa A. Abd El-Baky et. al. conducted study on use of heat pipe for heat recovery in air conditioning [12]. Two streams of fresh and return air have been connected with heat pipe heat exchanger to investigate the thermal performance and effectiveness of heat recovery system. The results showed that the temperature changes of fresh and return air are increased with the increase of inlet temperature of fresh air. The effectiveness and heat transfer for both evaporator and condenser sections are also increased to about 48%. The results showed that the effectiveness is close to the optimum effectiveness at fresh air inlet temperature near the fluid operating temperature of heat pipes.

Wei Jieting et. al. conducted study on thermoelectric power generation in vibration heat pipe [13]. Based on the combination of Solar Energy with thermoelectric power generation, there are design a test system of Solar Thermoelectric Power Generation in that paper. In order to obtain greater a temperature gap between hot and cold side of thermoelectric electricity generator, focused on the cold-side in the case of fin cooling and Vibration heat pipe cooling. From experimental result it is found that Vibration heat pipe is better than the fin in the selection of cooling mode of cold-side. Under the cooling mode of Vibration heat pipe, when Semiconductor power chip are set to series-parallel-connection, the power that the unit generates is enough to light LED energy saving lamps.

Tawat Samana et.al. conducted study on enhancement of fin efficiency of solid wire fin by oscillating heat pipe [14]. Enhancement of fin efficiency of solid wire fin in a wire-on-tube heat exchanger under forced convection was examined. The solid wire fin was replaced with an oscillating heat pipe filled with R123. The unit was tested in a wind tunnel by exchanging heat between hot water flowing inside the tube and the air stream flowing across the external surface. The results showed that the fin efficiency for the case of oscillating heat pipe fin was higher than that of the conventional fin around 5% depended on the mass flow rate of air stream and the geometrical parameters of heat exchanger surface.

Souad Harmand et. al. conducted study on cooling application of heat pipe in electronic components [15]. In this work a theoretical investigation of a Flat Heat Pipe designed for the cooling of multiple electronic components in transient state. This model is a transient model, coupling 3D thermal model with a 2D hydrodynamic one through the mass flux of evaporation-condensation, which occurs in a mass conservation equation. According to its degree of refinement and complexity, the model proposed here could be used for different electronic component cooling applications. This complex and precise model are able to predict the reliability and quality of electronic cooling.

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Michel Hayek et. al. performed Experimental Investigation of the Performance of Evacuated-Tube Solar Collectors [16]. Experimental investigation of the overall performance of solar collectors is carried out for two kinds of evacuated tube solar collectors, namely, the water-in-glass tubes and the heat-pipe designs. The results show that the heat-pipe-based collectors are better than the water-in-glass designs and their efficiency is almost 15 to 20% higher. Taoufik Brahim et. al. conducted study on theoretical and experimental investigation of plate screen mesh heat pipe solar collector [17]. In this paper the consequence of incorporating fins arrays into the condenser region of screen mesh heat pipe solar collector is investigated. An experimental and a transient theoretical model are conducted to compare the performances of solar heating system at different period of the year. Two working fluids are investigated (water and methanol) and results reveal that water slightly outperforms methanol with a collector instantaneous efficiency of nearly 60%. Compared with conventional flat plate solar water heating systems, the heat pipe flat plate solar collector has the advantage of operating as thermal diode, when the collector temperature is less than the storage water temperature the heat energy will not be lost from storage tank, easy freeze protection and no pumping or control system requirements that means that the system will not require an electrical connection.

Dong Wei et. al. conducted study on Thermo-mechanical analysis of heat pipe cooled leading edge thermal protection structure with thermal contact resistance [18]. The computational model of the heat pipe cooled thermal protection structure is given firstly, then the computational scheme of the thermo-mechanical coupling problem caused by thermal contact resistance is established based on the sequential coupled method. The thermo-mechanical coupling analysis of the computational model under different initial gaps is performed after that, with an emphasize on the effect of thermal contact resistance. Numerical result show that, using heat-pipe-cooled leading edge can greatly reduce the maximum temperature to make sure that the stagnation temperature is in the tolerance zone, which is a very effective thermal protection concept.

Maryline Leriche et. al. conducted an experimental and analytical study of a variable conductance heat pipe (VCHP) for vehicle thermal management [19]. A theoretical model based on a nodal method and an experimental test bench was developed to study the performance of a copper/water VCHP, using nitrogen as a non-condensable gas. For high vehicle velocity, the power is high but the air velocity is also high and the rate of start-up is not important. For low vehicle velocity, the power is low, the air velocity is low, but generally, the rate of start-up is important. So that, the VCHP is an interesting solution for the vehicle thermal management in order to reduce the engine energy consumption after a cold start by controlling heating-cooling cycle of oil.

IV. CONCLUSION

From above literature it is concluded that there are various design parameter which affect the performance of heat pipe. There are two types of parameter, first is internal parameter like property and types of working fluids, types of wick structure, area of wick grooves, material used for wick and container etc.; and second is external parameter like orientation and inclination of heat pipe, heat source temperature and heat sink temperature etc.

From the literature it is also found that there are wide ranges of application of heat pipes. Heat pipe have positive advantages when it is used in energy recovery application. It is also applicable for cooling in automobile, air conditioning, electronic component etc. Heat pipe also used in solar application for power generation or water heating application. It is also concluded that use of heat pipe in any application gives better thermal performance as well as economic benefit.

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