A Survey On Heat Pipe Heat Recovery Systems

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Abstract: The development of heat pipe arrangements has been accelerated by advances in computer research, which have shown multiphase flow regimes and highlighted the vast potential of the respective technology for passive and active applications. This analysis aims to assess the utility of contemporary heat pipe systems for heat recovery and renewable applications. Regarding the operational temperature profiles of the evaluated industrial systems, fundamental characteristics and constraints are explained together with theoretical comparisons. Working fluids are compared using the figure of merit for the temperature range. The analysis determined that typical tubular heat pipe systems offer the broadest operational temperature range compared to other systems and, as a result, offer optimization and integration opportunities for renewable energy systems.

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1. Introduction

A heat pipe is a simple device with extremely high thermal conductivity and no moving parts that can carry huge amounts of heat efficiently across long distances at a constant temperature without the need for an external source of electricity. A heat pipe is essentially a short, slender tube lined with a wick structure and containing a little amount of a saturated fluid, such as water. It consists of three sections: an evaporator section at one end, where heat is absorbed and the fluid is vaporised; a condenser section at the other end, where the vapour is condensed and heat is rejected; and an adiabatic section in the middle, where the vapour and liquid phases of the fluid flow in opposite directions through the core and the wick, respectively.

The operating pressure and type of fluid inside the heat pipe are heavily dependent on its operating temperature. For instance, if a heat pipe containing water as its working fluid is intended to remove heat at 343 K, the pressure inside the heat pipe must be maintained at 31.2 kPa, which is the pressure at which water boils at this temperature. Although water is a viable fluid for usage in the mild temperature range seen in electronic equipment, different fluids are utilised in the production of heat pipes to enable their use in cryogenic and high-temperature applications. Surface tension must be high to improve the capillary effect, and the working fluid must be compatible with the wick material, chemically stable, readily available, non-toxic, and cost-effective [1]. Figure 1 depicts the fundamental functional portions of a heat pipe.

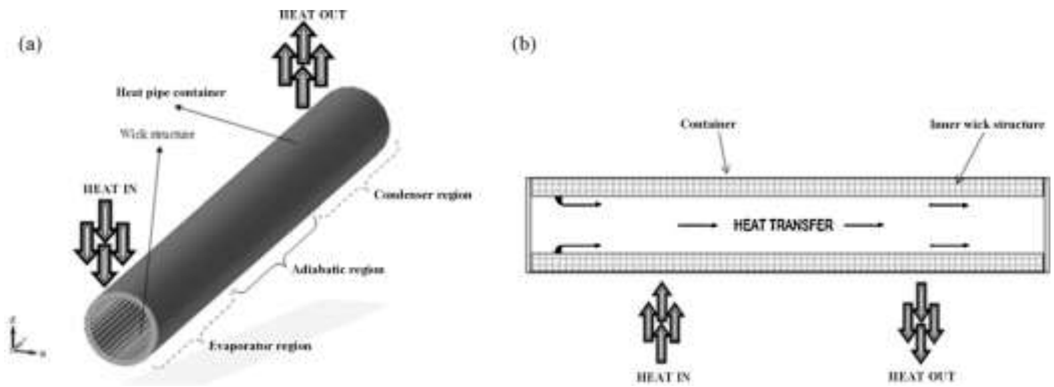

Fig. 1. Basic working principle associated with a heat pipe (a) isometric view and (b) sectional view.

Heat pipes are utilized in a range of applications that include a heat transmission procedure with temperature changes. The effective thermal conductivity of a heat pipe enables the efficient movement of heat across great distances. As a result of their adaptability in the roles of heat transport and passive operation, heat pipes have been widely implemented in numerous energy storage systems. In significant processes, such as temperature stratification in hot water storage tanks, heat pipes with phase change materials (PCMs) operate more efficiently than traditional heat exchangers due to their distinct mode of operation. Another typical application of heat pipes is in solar collectors, which allow static or moving water to be heated through the direct transfer of solar thermal energy [2].

2. The Function Of Heat Pipes In Energy Conservation And Heat Recovery

Heat pipe utilization in renewable energy systems and building heat recovery, highlighting fresh concepts and needs, is gaining in popularity. Several terrestrial applications, ranging from solar concentrators to heat exchangers, utilize heat pipes for more efficient and rapid heat transfer. Heat pipes offer distinct advantages over other thermal transfer devices due to their passive and compact operation, as well as the vast array of commercially available sizes ranging from micro to large, making the device suitable for the majority of applications requiring a temperature differential.

El-Baky and Mohamed [3] examined the effectiveness of using heat pipe heat exchangers for heat recovery through external air conditioning systems in buildings in order to lower the cooling load. The thermal performance of the system was studied for varied mass flow rates and temperatures of the fresh air inlet stream. On the basis of the experimental setup consisting of two air ducts with sectional areas of 0.3 m and 0.22 m, as well as a heat pipe arrangement containing 25 copper tubes with evaporator and condenser sections of 0.2 m and adiabatic sections of 0.1 m, a mathematical model was built. Working fluid R-11 was employed at a saturation temperature of 303 K. According to the results of the study, the efficacy and heat transfer rates improve as the fresh air inlet temperature rises. The study also found that the mass flow rate ratio has a significant effect on the change in temperature of fresh air and that the heat recovery rate increases by approximately 85 percent as the temperature of the fresh air input rises. Figure 2 depicts a diagram of the heat exchanger.

Noie-Baghban and Majideian [4] worked on the design and construction of a heat pipe arrangement to be inserted in a heat pipe heat exchanger for the purpose of heat recovery in hospital and laboratory buildings with a primary demand for high air exchange. The testing apparatus consists of a test rig with two fans delivering a flow rate of 0.103 m3/s through the evaporator and condenser. Eight copper pipes with an exterior diameter of 15 mm, an interior diameter of 9 mm, and a length of 600 mm were used, along with three types of wicks: 50 mesh nickel, 250 mesh nickel, and 100 mesh stainless steel. The merit figure for the type of working fluid was determined. Thermocouples of the K type were employed to measure temperatures. To verify the experimental findings, a mathematical model was developed. Regarding the heat transfer rate in the 100 W evaporator section, a strong correlation was found between the mathematical and experimental data. In addition, the study emphasized the significance of deploying finned heat pipes and increasing the number of rows, as well as the insulation capabilities, in enhancing the overall performance of the system.

In order to gain a broader understanding of the function of heat pipes, this article highlights a variety of sustainable applications. A gas–gas heat pipe heat exchanger consists of a collection of similar heat pipes lined either vertically, horizontally, or at an angle in a tubular arrangement. The device's evaporation and condensation operating principle affects the heat transfer from the countercurrent gas stream, which recovers the heat and transfers it to the preheated air stream. Heat pipe heat exchangers are valuable in industrial heat recovery applications because to its static operation, low auxiliary power needs, and fully reversible process.

Yau and Ahmadzadehtalatapeh [5] examined the effectiveness of horizontal pipe heat exchangers as an energy recovery unit in air conditioning systems in tropical regions. The literature review included previously published work on the vertical and horizontal orientations of heat pipes. As a highly efficient heat recovery unit, the deployment of horizontal heat pipe heat exchangers for both orientations is recommended for tropical regions for dehumidification and energy savings purposes. Figure 3 illustrates the transient simulation of adding double heat pipe heat exchanger units in heating, ventilation, and air-conditioning systems in order to reduce energy consumption rates in tropical climates.

One of the most common commercial applications of heat pipes involves solar collectors to transport direct and diffuse solar energy to the water stream. In Cairo, Egypt, Hussein et al. [6] compared three cross-sectional geometries of wickless heat pipes with varied fill ratios in order to determine the effect of their performance on flat plate solar collectors. The manufacturing group consisted of heat pipe cross-sections arranged circularly, elliptically, and semi-circularly. Experiments were conducted on the group by integrating heat pipes into the solar collector array, and comparing findings revealed that the elliptical design provided superior performance at 10% water fill ratios, while the circular cross-section design proved optimal at 20% water fill ratios.

Rittidech and Wannapakne [7] conducted considerable research to determine the total performance capability of a system that integrated a Closed-End Oscillating Heat Pipe (CEOHP) with a flat plate solar collector. The 18-degree inclined

thermocouple-based experimental test setup consisted of a 2 m zinc sheet linked to 70 m of CEOHP copper tubes. The working fluid consisted of R134a at a 50 percent initial fill ratio. A1–A6 represents the thermo-junction on the collecting plate, and G1–G2 represent the thermo-junction location on the glass plate, respectively. A computational model was developed to calculate the system's performance in relation to the plate temperature and ambient temperature, and an overall thermal efficiency of 62% was determined. The study demonstrated the advantages of employing a CEOHP system on solar collectors in compared to traditional heat pipe systems in terms of minimum corrosion rate and elimination of freezing during the winter.

3. Standard Heat Pipe Systems

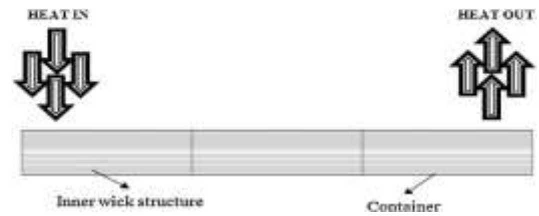

Fig. 2 Schematic of a tubular heat pipe.

Commercially available heat pipes vary in terms of the technique of liquid transport from the condenser to the evaporator and their functionality. This review provides a source of information on the numerous types of existing heat pipes used for a variety of applications needing moderate to high temperature fluctuations, based on the current published literature.

3.1.1 Tube heat exchangers

Conventional tubular heat pipes, are the simplest and most widely used passive heat transfer systems commercially for heat transport over varied distances in numerous terrestrial applications. The typical operating principle relies on capillary action, and performance is measured in terms of equivalent thermal conductivity. These materials can also be utilized as heat spreaders to isothermalize equipment where uniform temperature patterns are desired.

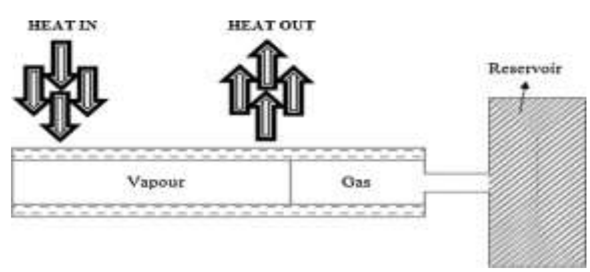

Fig. 3. Schematic of a cold-reservoir variable conductance heat pipe.

Liao et al. [8] compared the thermal performance of a smooth carbon steel-water heat pipe to its equivalent with internal fins. The investigation was based on many influencing aspects, including the inclination angle, working temperatures, and heat flux. The experimental apparatus consisted of a carbon steel pipe covered with fibre glass and a flat band heater for providing heat flux to the evaporator part. The apparatus was mounted on an adjustable workstation so that the inclination angles could be altered, and thermocouples were connected to the data logging system so that the results could be produced. Under experimental conditions, the work revealed that the heat transfer coefficient of the internally finned heat pipe was 50–100% greater than that of the smooth heat pipe.

Joudi and Witwit [9] improved the thermal efficiency of gravity-assisted traditional wickless heat pipes. With the addition of an adiabatic separator, the modified cop- per heat pipe was the subject of an experiment. Several measuring equipment, including a digital ammeter and voltmeter, were attached to the test heat pipe in order to calculate the input power. To reduce heat losses to the environment, the heat pipe was insulated with glass wool. The condenser flow rate was maintained at a steady rate, the temperature was monitored at 23.2 degrees Celsius, and the input power was gradually increased to get gradual thermocouple readings. The study resulted in beneficial findings regarding the addition of an adiabatic separator to the heat pipe. The research indicated a roughly 35% increase in heat transmission coefficient compared to conventional heat pipes. According to the investigation, the addition of an adiabatic separator eliminated the influence of inclination angles greater than 45 degrees and decreased the working temperature of the heat pipe.

3.2 Variable-conductivity heat pipes

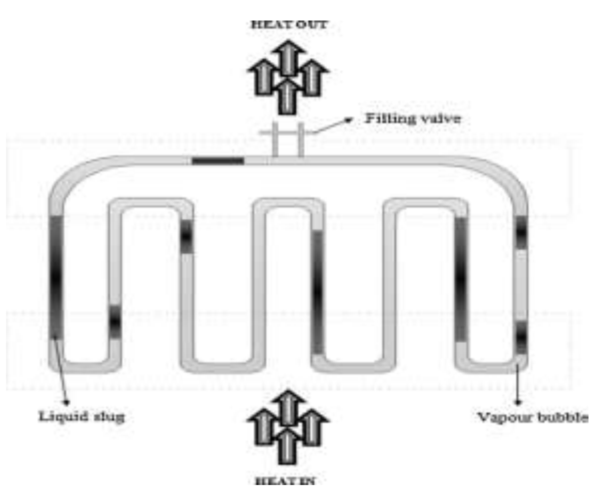

Fig. 3. Schematic of a Variable-conductivity heat pipes

Variable Conductance Heat Pipes (VCHPs) are widely used in a variety of applications, including traditional temperature control in electronics. A variable conductance heat pipe or gas-loaded heat pipe has the ability to maintain a device positioned at the evaporator at a temperature that is nearly constant, regardless of the amount of power provided by the device. Both passive and active feedback-controlled systems have the ability to control the source of heat at the evaporator end and are therefore the most common VCHP systems. However, the active system provides superior temperature management compared to the passive method. Fig. 6 displays

Sauciuc et al. [10] examined the operation of a VCHP for controlling the temperature of an arrangement of solar collectors in a closed system. The experimental equipment utilised air as the Non-Condensable Gas and featured a copper/water heat pipe fitted with a cold reservoir (NCG). The respective thermodynamic properties of water were investigated, and the investigation was conducted at the interface between water vapour and non-condensable gas at different operating pressures. The results suggested that the beginning point of the VCHP function is significantly influenced by the amount of NCG in the heat pipe and the required superheat for boiling.

3.3. Pulsating heat pipes

A pulsating (oscillating) heat pipe is composed of a channel that has been emptied and filled with working fluid. The transfer of heat occurs via the latent heat of vapour and the sensible heat transferred by the liquid droplets. When the tube on the evaporator section of the heat pipe is subjected to thermal load, the working fluid evaporates, resulting in an increase in vapour pressure and the formation of bubbles. The liquid is then transferred to the condenser section, where cooling causes a decrease in vapour pressure and the condensation of bubbles. The growth and decrease of bubbles in the two parts of the capillary tube produce an oscillating or pulsing motion. Qu and Ma [15] investigated the primary factors involved in the initiation of oscillating motions in a pulsating heat pipe, including the superheat and heat flux level on the evaporator section and the cavity size on the inner surface of the capillary. The experimental research included a 300 mm long glass prototype and a 90 mm long evaporator portion with a constant inlet temperature of 296 K. The results of the theoretical research confirmed that the performance at startup can be enhanced by adjusting the type of vapour bubbles and employing a surface with a coarser texture. The results also demonstrated that the globe-type vapour bubble requires less superheat than the Taylor-type vapour bubble.

Wang et al. [12] analysed the thermal performance of heat transmission in a four-turn pulsing heat pipe by comparing different working fluids to pure water. The experimental evaluations were based on two operational orientations (vertical and horizontal) of a 2.5 mm-diameter copper tube in vertical and horizontal positions. For the test, FS-39E microcapsule and Al2O3 nanofluid were utilised. In comparison to pure water, the functional working fluids boost the heat-transporting capacity of the heat pipe, with the FS-39E microcapsule proving to be the most effective fluid in the horizontal orientation. Yang et al. [13] conducted experiments on copper tubes with differing inner diameters and filling ratios to estimate the thermal performance of closed-loop pulsating heat pipes. The system consisted of 40 copper tubes with 1 mm and 2 mm inner diameters, and the vertical bottom heated, vertical top heated, and horizontal orientations were evaluated. The analysis found that the closed loop pulsing heat pipe with vertical bottom heating provides the highest performance with a 2 mm inner diameter and a 50% fill ratio, whereas the orientation effects for the 1 mm inner diameter tube were negligible.

3.4 Loop heat pipes (LHPs) and capillary pumped loops

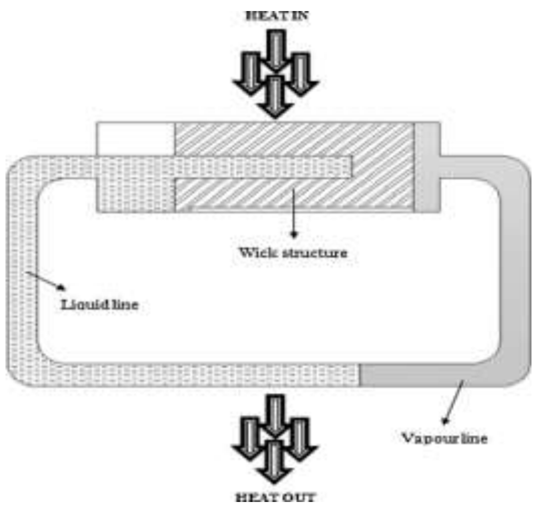

Fig. 4. Schematic of a loop heat pipe arrangement.

Loop heat pipes (LHP) utilise the features of a conventional heat pipe but have the advantage of being able to transport thermal energy across a larger area without any constraints on the path of the liquid or vapour lines, as well as having a higher heat flux potential and resilient operation [2]. As a result, LHPs are quickly becoming standard devices to address the global demand for thermal control of high-end electronics. The operation of the LHP is driven by capillary force in the evaporator part and requires no further power input.

Wang et al. conducted experiments on a flat LHP with a modest heat power input in order to comprehend the control of the compensation chamber and the evaporator on the start-up behaviour. For experimentation, the appropriate testing system included standard K-type thermocouples, a DC-stabilized power supply, and an isothermal cooling water tank. The outcomes indicated that the LHP is capable of starting with a low heat power of 6 W. With increasing thickness of the capillary interlayer, the LHP has a higher start-up performance under low power, as confirmed by the results.

Zhao et al. [11] developed an innovative LHP solar water heating system for a typical Beijing residence in order to facilitate the efficient transfer and conversion of solar heat to hot water. To monitor the total thermal performance of the system, a numerical model was constructed, and various parameters, such as the heat pipe loop and the facade integrated solar absorber, were evaluated to influence the results. The findings indicate that system efficiency falls with increasing mean water flow temperature, but thermal system efficiency increases with increasing ambient temperature. The results confirmed that the ideal working temperature for the heat pipe is approximately 345 Kelvin.

Kaya and Goldak studied heat and mass transmission to examine the capillary porous nature of the LHP. The mass and energy equations were solved using a finite element approach for the evaporator cross-section-based numerical code, and the answers encompassed all-liquid and vapor–liquid wick situations. The results demonstrated that under high heat loads, the onset of boiling under the evaporating meniscus is highly improbable since liquid contact with the fin drops significantly. The investigation indicated that the elimination of non-condensable gases and a very good contact at the fin–wick interface are required to raise the boiling heat transfer limit.

3.5 Microscopic heat pipes

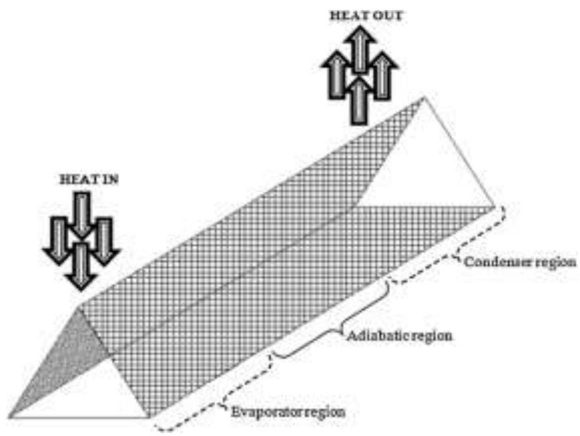

Fig. 5. Schematic of a micro heat pipe.

Micro heat pipes (MHPs) are utilised in applications requiring low to moderate heat transfer rates. Compared to forced convection systems, the rate of cooling produced by the MHP is significantly lower. The capacity to manage temperatures in situations with changing heat loads, coupled with its small size, enables its use in a variety of applications [2]. The thermal performance of a micro heat pipe with a rectangular grooved wick structure was predicted by Do et al. [21]. Taking into account the contact angle, liquid–vapor interfacial shear stress, and liquid charge, a mathematical model was built. Solution of the one-dimensional conduction equation for the wall and the augmented Young–Laplace equation. The studied data suggested that the rate of heat transport rises diffidently with increasing liquid charge. The results demonstrated the optimization of the grooved wick structure by highlighting the maximum heat transfer rate of 128 W under the optimal circumstances of height and groove width, respectively. Figure 10 depicts the diagram of a tiny heat pipe.

Hung and Seng [22] studied the thermal performance in terms of the heat transfer capacity of star-groove micro-heat pipes under the influence of their geometric design. The continuity, momentum, and energy equations of the liquid and gas phases have been solved using a one-dimensional steady state numerical model. Due to its capacity to deliver a higher capillary rate by reducing the corner apex angle, the star-groove micro-heat pipe has a better performance characteristic than the traditional polygonal micro-heat pipe, as determined by the study's comparison results. Lefèvre and Lallemand [23] studied the heat transport capacity of a flat MHP in relation to the position of heat sources and heat sinks. A hydrodynamic 2D model incorporating a porous wick as a capillary-like media was combined with a 3D thermal model to investigate the heat conduction of both the liquid and vapour phases. The thermal model assessed the ability to determine the heat flux generated by the wall heat conductance alone.

4 Computational simulation pertaining to heat pipes

Computational studies done on various heat pipe arrangements, depicting two-phase flow patterns, demonstrate the broad applicability of the relevant technology to a variety of passive and active applications, as previously discussed. Viable numerical codes have evolved into a valuable instrument for determining specific and accurate outcomes for the overall performance of diverse multiphase flow patterns and phase change behaviours, respectively.

Alizadehdakhel et al. [25] investigated the functioning of a thermosyphon by simulating two-phase flows with a commercial CFD code, FLUENT 6.2, and validating the results with an experimental set-up employing a variety of operational settings. A two-dimensional geometry was designed using the Gambit software, with the domain containing a total of 47,124 grids for the fluid region and 14,361 grids for the solid region. The Volume of Fraction (VOF) [26] approach was developed for modelling two-phase flow. Various experimentally determined heat flux values were used as the energy input to the evaporator, and a vapour pressure of 1.72 kPa at 288 K was applied to gaseous water. Along the length of the pipe, the CFD and experimental temperature profiles were in good agreement. The experimental results confirmed that raising the inlet heat flow from 350 to 500 improves the thermosyphon's overall performance significantly. This study confirmed that complex heat and mass transfer phase shifts may be efficiently predicted and that CFD provides a superior understanding of the phase transition.

In order to obtain a detailed understanding of the two-phase behaviour within a heat pipe, a variety of numerical codes have been implemented. Lin et al. [27] evaluated the potential usage of heat pipe heat exchangers in dehumidification operations in order to comprehend the system's performance. For CFD simulation of a drying cycle in the dehumidification process using characteristic air properties with an inlet temperature variation between 308 and 321 K along with a relative humidity of 100% and a volume flow rate variation between 6 and 8 L/s, the FLOTHERM numerical code was coupled with the Microsoft Excel commercial package. For the simulation's calculation of fluid parameters and properties, the heating and condensation zones of the domain were defined. It was determined what the thermal conductivity, specific heat capacity, and density of heat pipe cuboids should be. The projected results demonstrate that a significant improvement in the dehumidification process is attainable employing a heat pipe system with greater condensate rates attained at higher intake flow rates and temperatures. However, the results confirm that the heat transport in the heat pipe reduces as the flow rate increases, indicating that a heat exchanger utilising auxiliary power may be more efficient at greater flow rates.

Ranjan et al. [28] performed numerical analysis on the study of flat heat pipes or vapour chambers by solving the vapour and liquid flow utilising three-dimensional Navier–Stokes continuity, momentum energy equations in order to comprehend the effect of varying wick microstructure on the evaporation and condensation sections of the heat pipe. Using the commercial FLUENT solver, temperature and flow contours were computed independently by a device-level numerical macro-model and combined with wick-level micro-model to account for the evaporation heat transfer rate in the pores of general sintered-powder wick structures. Based on the local contact angle of liquid in the wick, the coupled model includes modifications to the evaporative mass flow rates at the liquid–vapor interface. To explore the liquid meniscus between copper wires, an effective conductivity value of 40 W/(m K) was assumed for the macro-model, while the convective heat transfer boundary conditions for the micro-model consisted of a constant inlet temperature and pressure. Based on the results of the two models (coupled and uncoupled), the thermal resistance of the liquid–vapor interface increases with decreasing device size, negatively impacting the performance of the vapour chamber.

Shao and Riffat [29] examined the efficacy of a heat recovery system based on a heat pipe configuration at various places within passive stacks for natural ventilation systems. CFD coding utilised the FLUENT solver to simulate flow losses in the ventilation stack by solving the mass and energy conservation equations. The domain mapped by a consistent 50 x 100 Cartesian grid consisted of the two-dimensional geom- etry of the exhaust stack and building space in order to comprehend the buoyancy flow in the room. The boundary conditions included an external and interior stack wall temperature of 288 and 293 K, respectively. The results of the computational simulation indicated that the average vertical velocity in the stack is 0.222 m/s and that the pressure differential between the inlet and outflow is greater than 29 Pa. In addition, the analysis demonstrated that the insertion flow loss is greater when the heat pipes are positioned at the bottom of the vertical stack than at the top, and that it is inversely related to the insertion pressure loss. It was determined that the heat pipes did not significantly reduce stack flow.

Rahmat and Hubert created a triangular two-phase model of a micro-heat pipe in order to analyse heat and mass transmission within the three-dimensional micro channel. The commercial programme Ansys CFX-5.7.1 was used to solve the unsteady flow equations. To accommodate the behaviour of the evaporator and condenser sections, the channel geometry was separated into three similar parts. The evaporator and condenser sections each measured 0.67 cm in length. The mesh model consisted of 560,000 components, with an average working fluid volume of 310 m2 per element. For precise performance, the fluctuation of convergence results with regard to various fill ratios and boundary condition types was explored. At a fill ratio of 25%, the micro channel had an effective thermal conductivity of 3,333 W/C, according to the findings. In addition, the results indicate that an increase in the liquid fill ratio produces an increase in the heat pipe's effective length. The analysis confirmed a good agreement between the computational results and the relevant literature, demonstrating the ability of commercial finite element codes to simulate two-phase flows successfully.

With the emergence of thermal imaging devices, the thermal efficiency of experimental processes involving heat pipes has grown over time. Hemadri et al. completed a comprehensive investigation on the practicability of employing pulsing heat pipes in thermal radiator systems for terrestrial and extraterrestrial uses. Using a high-resolution, forward-looking infrared camera and a variety of thermal and mechanical boundary conditions, an experimental understanding of temperature profiles was developed. The experiment was conducted on radiator plates made of aluminium and mild steel with and without embedded pulsating heat pipe arrangement aligned in three distinct orientations. Surface-mounted, flat mica heaters with known dimensions were used to generate heat with varying thermal inputs of 50 to 150 W. The experiment yielded the results of spatial thermography and orientation effects, respectively. Due to the aluminium plate's strong thermal conductivity at its base, it was noticed that the pulsating heat pipe configuration provided only a little improvement to the isothermalization rate. The results also demonstrated an increase in the dominance of gravitational forces at low heat input for both plates in a vertical orientation with the heater positioned above. With increasing temperature input, the gravitational effects were shown to decrease as the pulsations increased. The experimental results were validated using the FLUENT 6.3.26 commercial code in the computational domain of the three-dimensional tetrahedron. On a unit-cell model, excellent agreement was obtained between the experimental and simulated temperature profiles at various places throughout the plate with a heat input of 55 W. The research demonstrated the potential of pulsing heat pipes in space and terrestrial thermal control.

Savino et al. evaluated the influence of surface tension fluctuation with temperature to highlight the performance of self-rewetting fluids in wickless heat pipe systems in comparison to regular fluids. Laboratory tests on glass tubes containing alcohol and 1-heptanol aqueous solution were conducted to produce temperature profiles utilising thermographic images. The thermal power was set between 4 and 7 W to limit the evaporation phenomenon. The trajectory of the bubble revealed that the linear flow of an ordinary fluid is in the direction of the temperature gradient, whereas the self-rewetting fluid moves in the opposite direction. In order to validate the experimental results, Navier–Stokes equations were solved using the SIMPLE family of methods, and the Volume of Fraction (VOF) model in the FLUENT commercial package was utilised for computational analysis. Additional similar laboratory studies were conducted to establish the relationship between the surface tension gradient and temperature fluctuation. The conventional fluid (ethanol) was discovered to display a decreasing linear dependence on temperature, but the self-rewetting fluid (heptanol) demonstrated a nonlinear dependence. The comprehensive analysis highlighted the potential for efficient heat transmission by developing novel functioning self-rewetting fluids based on Water/Ammonia and Water/Ethylene Glycol combinations for various applications.

5. Conclusion

Utilizing modern calculation and intricate experimentation, research into the use of heat pipes for efficient and passive heat transport is quickly advancing in terms of its technological development. This study examined the general heat pipe systems used in building and ground applications, including heat recovery and renewable energy techniques, in order to determine the usual heat pipe configurations and their working temperature ranges for use in the various applications. The analysis found that heat pipes including the sorption phenomenon had a larger heat transfer capacity, and that tubular heat pipes have the highest working range on average, with a maximum operating temperature of 453 K among all studied systems.

The study's conclusions are based on an analysis of a variety of industrial products employing heat pipe systems for operation. For numerous suitable heat pipe working fluids, important factors, including the merit figure, were calculated and compared. Water displayed the highest average Merit Number compared to ammonia and acetone for the operating temperature range of 293–393 K, according to the results.

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