NTU Journal of Engineering and Technology (2025) 4 (1) : 1-9
DOI: https://doi.org/10.56286/ntujet.v4i1

IRAQI Academic Scientific Journals

P-ISSN: 2788-9971 E-ISSN: 2788-998X
NTU Journal of Engineering and Technology
Available online at: https://journals.ntu.edu.iq/index.php/NTU-JET/index

Enhancement for Heat Pipe Using Different Configurations: Review Study

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Article Informations

Received: 16-03- 2024,
Revised: 10-09-2024,
Accepted: 01-11-2024,
Published online: 22-03-2025

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Key Words:
Heat Pipe,
Heat Recovery,
HVAC,
Heat Exchanger.

A B S T R A C T

The majority of the energy utilized in systems is transformed into heat energy, making the world's constantly rising rate of energy consumption one of the most significant challenges of our day. Heat pipe heat exchangers, or HPHEs, are used in many different fields, such as air conditioning, electronics, aerospace, and aircraft. With the inclusion of HPHE, this article seeks to physically modify the HVAC system of the all rooms in order to enhance its dehumidification capabilities, which are used to remove contaminated air. The overall goal of the study was to increase people's comprehension of heat pipes through the collection and organization of readily available data in a range of formats across the material spectrum, its presentation in an orderly fashion ranging from rudimentary to sophisticated understanding of heat pipes, and the provision of further information regarding the quality of considerations made in the design and construction of heat pipes as well as the examination of the effects of altering heat pipe parameters on performance. This paper covers the research that has been done on heat pipes in terms of design and analysis HPHE succeeded in reducing the energy consumed by the precooling and reheating processes of the HVAC system, enhancing its dehumidification capability.

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Nomenclature

U-HPHE	U shape heat pipe heat exchanger
PHP	Pulsing Heat Pipe
PCM	Phase Change Material
PHP	Performance Heat Pipe
EER	Energy Efficiency Ratio
FR	Filling Ratio
CLPHP	Closed Loop Pulsing Heat Pipe
Cp	Specific heat in the ambient air, J/ kg k
m_h	Mass flow rate of hot air, kg/s
m_c	Mass flow rate of cold air, kg/s
Q	Heat transfer rate, Watt
HR	Heat Recovery, Watt
T	Temperature, °C
m_w	Mass flow rate of water, kg/s
Greek letters	
ε	Effectiveness
Subscripts	
act	actual
max	maximum
c	condenser
e	evaporator
i	inlet
o	outlet
h	hot

1. Introduction

In 1942, Richard S. Gaugler of the General Motors Corporation created the concept of the heat pipe. In order to feed heat to energy conversion systems and remove waste heat from them, the Los Alamos Scientific Laboratory designed the contemporary heat pipe in 1963. Heat pipes started to be employed extensively in space components in the 1970s. Metals were employed in the design of heat pipes at the time as a working fluid and to achieve higher operating temperatures. They were suitable for use as components in spacecraft and other non-gravity scenarios. Up until Deverall and Kemme's discovery of water-based low-temperature heat pipes [1], [2], [3]. Heat Pipe Science and Technology). The basic principles of a "...novel, relatively simple structure of a loop-type heat pipe in which a heat carrying fluid, circulates in a loop form in itself under its own vapor pressure at high speed within an elongate pipe so as to repeat vaporization and condensation, thus carrying out a heat transfer" were described in two patents issued in 1990 and 1993 by the Japanese inventor Akachi. This is the first description of the wickless two-phase passive heat transfer device, also referred to as a pulsing heat pipe (PHP), that has been published in the literature [4], [5].

Heat pipes were only used for certain purposes, such as water heaters, electronic component cooling, and automobile engine cooling. The ETEKINA project (heat pipe Technologies for Industrial Applications) began in 2017 with the goal of employing heat pipe heat exchangers (HPHE) in a number of energy intensive industries for waste heat recovery and targeted recovering 57–70% of the waste heat stream in those industries. The need for such increases in efficiency is pressing and will allow for both financial and environmental savings in the industrial and manufacturing sectors, which contribute 26.2% and15.6% to global GDP , respectively [6], [7]. In order to lower the energy consumption of air conditioning systems, engineers are searching for new environmentally friendly energy-saving technologies and devices. This is due to the global emphasis on energy conservation brought about by the depletion of energy resources like gas and oil as well as environmental protection. HPHE, or heat pipe heat exchangers, have the ability to achieve this goal[7], [8]. In essence, heat pipes are passive heat transfer devices that transmit heat by the evaporation and condensation of a two-phase working fluid. The evaporating, insulating, and condensing sections make up the three components of the heat pipe. The heat pipe experiences a temperature differential when heat is applied at one end[6], [9] The liquid along the evaporator tube wall heats and vaporizes in response to external heat, creating vapor pressure, which is a higher pressure. The force that propels the vapor to the condensing end is this vapor pressure. The vapor will condense and release latent heat as it enters the condensing region. Ultimately, the structure's capillary force will cause the liquid to return to the evaporator[10]. Notably, heat pipes have the ability to transfer heat with relatively little temperature difference between the two ends. One advantage of heat pipes is that they facilitate the quick passage of heat through the utilization of latent heat. A circulating pump is not necessary for this technology to work. They don't have any moving components that need upkeep[11]. Heat pipes are employed in many different cooling applications these days, including space exploration, medical, electronic, and aircraft applications, among many others [12]. Influence of binary fluid on the pulsating heat pipe's thermal efficiency studies by Barrak, et al.[13]. The objective of this research is to examine how working fluids affect the PHP's thermal performance. In order to conduct research, a mixture of water and methanol with a mixing ratio of 0.5:0.5 by volume was chosen as the pure working fluids. Examining the PHP's effective thermal conductivity and thermal resistance through the use of various working fluids, this investigation illustrates how well the system operates. In this work, the effective thermal conductivity and thermal resistance of the PHP were investigated under a range of input air temperatures and velocity ranges, with a binary fluid serving as the working fluid. It was observed that for all working fluids, the relationship between the heat input and the thermal resistance and effective thermal conductivity. Also we found after applying the binary fluid, the PHPs' thermal resistance and effective thermal conductivity increased, improving their thermal performance.

2. Application of Heat Pipe

Currently, integrated circuit packages, transistors, and other semiconductor devices are the electronic components that heat pipes are most frequently employed to cool. Heat rejection is essential to the dependable operation of all electronic components, ranging from sophisticated power converters to microprocessors. For high-end cooling applications, heat pipes are reliable and fairly priced options [14]. The many benefits of heat pipe covers include increased heat recovery effectiveness, less pressure drop, lighter weight, and the ability to separate hot and cold fluids[15], [16], An HPHE is a heat exchanger consists of externally finned sealed pipes with a working fluid. The heat exchanger is divided into two sections, namely the evaporator and condenser sections Compared to traditional heat exchangers, HPHE offer a variety of benefits. One of the primary benefits is that HPHE don't need outside electricity to function[17] . HPHE is an effective heat transfer device that may be used in air conditioning systems to recover energy. It is also simple to manufacture and maintain, and there is no cross-contamination between two air flows [18], [19],but the electronic industry has only lately come to recognize this. They work well to cool the high-power transistors found in laptops. An apparatus with heat pipes embedded in phase change material (PCM) has been created for a novel application in the low-energy cooling of buildings, such as offices[20], [21], [22].One of the most significant challenges of our day is the world's fast rising rate of energy use. As a result, developing new energy technologies is just as crucial as making better use of the energy systems that already exist. Heat energy is produced when most of the energy used in systems is transformed. Heat exchangers are used to either remove this heat energy from systems or convert it into energy that may be used for various purposes, like cooling and heating. Thermosiphon heat pipes are the most popular type of heat exchanger in many technological domains because of their low cost, simple structure, high heat transfer capacity, and energy-free operation[23], [24], the Thermosyphon has been a highly-efficient passive cooling device to solve thermal issues due to its superior performance[25].It is widely utilized in all fields of engineering that involve heat transmission, such solar water heaters. geothermal systems, nuclear reactor cooling systems, energy conversion in HVAC systems, spacecraft cooling applications, electric machine rotor cooling, gas turbine blade cooling, and cooling of electronic components generating high heat flux[25], [26], [27] ,Space electronics are always becoming more potent, intricate, and compact. Thus, there is a need for high performance, efficient systems, and low A range of cutting-edge solid conduction heat pipe and loop heat pipe technologies can be used to meet bulk requirements and requirements for no moving parts [27]. Axially grooved heat pipes are more dependable and simpler to construct than alternative wick forms, such as artery heat pipes[28]. Probably more than any other sector, heat pipes have profited from findings pertaining to spacecraft applications, particularly at vapor temperatures as high as 200°C. Loop heat pipes offer highly dependable electro-optic cooling for target acquisition systems, remote wing electronics, and navigational avionics onboard fighter aircraft, even in the face of intense temperatures and up to 9g of force.

The creation of extremely effective radar electronics and power supply cooling for next-generation navy destroyer radar systems is the area of expertise for heat pipes and cold plates. For high heat efficiency and low mass, thermal cycling between 40°C and 75°C[29]. Electronic cooling for nuclear submarine power conversion is provided underwater by embedded heat pipe assemblies and vapor chamber assemblies .Because of its efficiency in heat transport, the heat pipe is a great choice for applications demanding energy conservation [30]. It has been successfully applied in energy conversion devices and heat recovery systems. In order to keep the occupants comfortable in cold weather, heat pipes may be utilized to transfer heat from the exhaust gas inside the car to the cabin. In order to dry tobacco, the tobacco industry uses heat pipe heat recovery systems[31]. The most common and widely used thermal device is the heat exchanger, which converts heat from a hot fluid to a cool one. Heat exchangers are needed for a variety of thermal equipment, such as residential air conditioning and heating systems and contemporary power generating systems like nuclear reactors[27], [32].

3. Literature Review

Heat pipes have substantially higher thermal conductivity than thermally conductive materials like copper or silver, they are frequently referred to as superconductors. During the phase change, the working fluid in heat pipes either releases or absorbs a sizable quantity of latent heat while keeping its temperature constant[33]. Nowadays, vapor compression refrigeration is widely employed in many different applications, including electronic cooling, food processing, air conditioning, and cold storage. Maintaining and regulating the air temperature is the goal of vapor refrigeration. This suggests that the energy consumption of air conditioners has increased. Among all the devices in a home, an air conditioner consumes the most energy. Research on the use of heat pipes in air conditioners can be divided into two categories: heat recovery and dehumidification[34], [35]. One of the most efficient waste heat recovery technologies available. The advantage of using a heat pipe over other methods is that it can transport large amounts of heat over a tiny cross-sectional area. Using a heat pipe heat exchanger minimizes primary energy use and thus carbon dioxide emissions. In the mid-1970s, commercial manufacture of heat pipe heat exchangers began. They have numerous applications in a range of industries. The use of heat pipes for waste heat recovery in hospitals was tested in 2000. They concluded that more rows of heat pipe, full insulation, and good pipe sealing were necessary to improve the efficiency and efficacy of heat pipe heat exchanger finned pipes .This will be an important factor in increasing the heat pipe heat exchanger and consequently heat recovery[36], [37] . The COVID-19 epidemic caused widespread worry. The airborne infection isolation all rooms in a hospital is critical for preventing virus transmission to patients and medical personnel. All rooms with HVAC systems for evacuating impure air, combined with (CHP) as show in figure 1, lowered HVAC system energy consumption. Before it enters the cooling coil device, fresh air is pre-cooled.

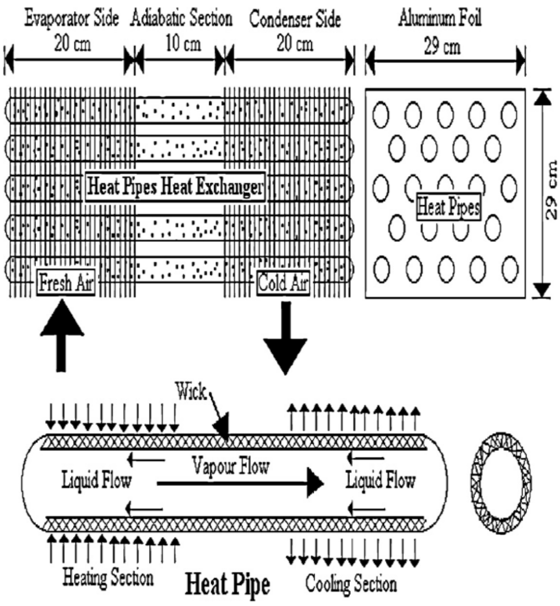

Figure 1. The CHP heat exchanger for heat recovery [37].

HPHE recovered energy ranging from 82 to 767 W, which can improve HVAC system performance and contribute to better energy efficiency[38]. Not only does the U-shaped heat pipe precool the new air by absorbing and distributing heat into the environment, but it also recovers the released heat for reheating. When the air is precooled, the quantity of energy needed by the cooling coil is lowered. Furthermore, the ability to reheat is advantageous. The dehumidification function of an HVAC system [39]. According to the data, it has the potential to enhance the COP by 39.9% when compared to HVAC without HPHE. The greatest efficiency of the two-row U-shaped HPHE was 12.4%. The biggest energy savings for pre-cooling and reheating were 288.1 and 340.2 W, respectively, at 0.080 m3 /s air volume. According to the results of the trial, the U-shaped as show in figure 1 HPHE was successful in lowering the energy required by the HVAC system's pre-chilling and warming procedures, therefore enhancing its dehumidification performance[40] Based on a study of their use in air conditioning applications, heat pipes are highly excellent heat transfer devices that may easily be used as heat exchangers in air conditioning systems to ensure energy savings and environmental preservation[41] .

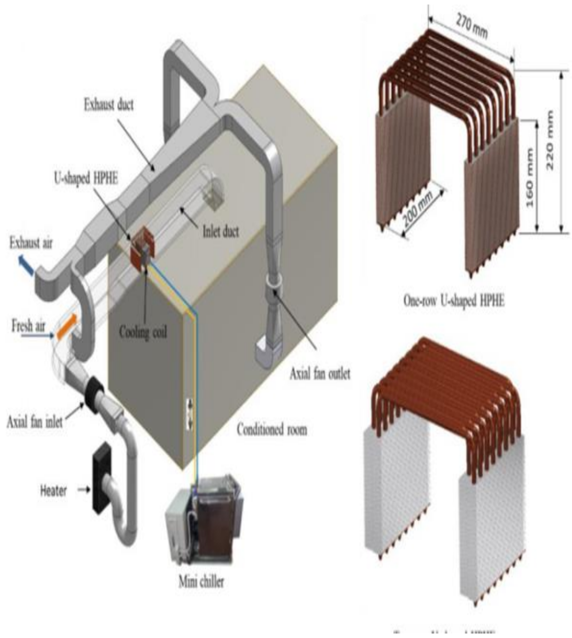

Figure 2. Prototype test model and design of U-shaped HPHE [40].

A vapor compression refrigeration system can benefit from the usage of a heat pipe set. The Reynolds numbers, the number of heat pipes, and the temperature of the heater surface all influence the increase in heat transfer rate. The energy efficiency ratio (EER) of an air conditioner can be improved with heat pipe sets[42]. Starting and operational performance were both enhanced with a recovery efficacy of roughly 50%, the best performance occurred at an installation angle of 60. The recovery efficacy rose considerably as the temperature of the fresh air input increased. This meant that in the summer, the hotter the outside air was, the easier it was for the HPHE to start and run, and the larger the Potential for energy savings. There was promise. Recovery capacity increased approximately linearly with increasing wind speed (air volume), however recovery efficacy decreased gradually as pressure drop increased rapidly[43].

For evaluating the sensible effectiveness value of the HPHE model, equations 1 to 11 have been used [44].

$$\varepsilon = \frac{q_{actual}}{q_{max}} \quad (1)$$

An overall energy balance for the two streams of the HPHE model will get:

$$q_{act} = C_h \left(T_{e,i} - T_{e,o}\right) = C_c \left(T_{c,o} - T_{c,i}\right) \quad (2)$$

$$(T_{e,i} - T_{e,o}) > (T_{c,o} - T_{c,i}) \quad (3)$$

$$C_h \leq C_c \quad (4)$$

Where

$$C_h = m_h \, C_{p,h} \quad (5)$$

$$C_c = m_c \, C_{p,c} \quad (6)$$

$$C_{min} = C_h \quad (7)$$

$$q_{max} = C_{min} \left(T_{e,i} - T_{c,i}\right) \quad (8)$$

$$Q_{act} = m_h \, C_{p,h} \left(T_{e,i} - T_{e,o}\right) \quad (9)$$

$$Q_{max} = m_h \, C_{p,h} \left(T_{e,i} - T_{c,i}\right) \quad (10)$$

$$\varepsilon = \frac{(T_{e,i} - T_{e,o})}{(T_{e,i} - T_{c,i})} \quad (11)$$

The percentage of energy saving by the evaporator (Se)

$$Se = \frac{ma\ cp\ (Tei - Teo)}{ma\ cp\ (Tei - Ta) + mw\ (h2 - h1)} \quad (12)$$

Where Ta temperature of the air after cooling coil and h1& h2 (kJ/kg) enthalpy of water inlet and outlet cooling coil respectively.

3.1. Pulsating heat pipe & factors affecting its performance

With its high performance, variety, and ease of construction, the pulsating heat pipe (PHP) has emerged as one of the most innovative, effective, and more convenient passive two-phase heat transfer systems since the early 1990s[45]. Visual examination of ammonia PHP was tested by for startup performance. Through experimentation, they found that with a 70% filling ratio (FR), the start-up power needed is extremely low because of the characteristics of ammonia. Furthermore, the ongoing oscillation results from the interaction of the forces that propel and restore heat transport. To determine the PHP factors that influence performance, experiments are conducted. These kinds of studies are done to understand how different operating conditions affect PHP's thermal performance. Working fluid is referred to as Ethanol and distilled water as working fluids with 50% FR and 100, 120, and 140 watts are among the operating conditions. As the heat input rises, distilled water's thermal resistance decreases. The thermal resistance of ethanol deviates from a predetermined trend line. Ethanol has a temperature resistance that first drops and then rises from 100 to 140 watts. Ethanol begins to pulse at 47°C and 50°C. The temperature range for water pulsation is 50°C to 52°C[46].

3.2. Work principle of heat pipe

Standard closed two-phase gravitational heat pipe is called heat pipe thermosyphon and the main regions of the heat pipe are shown in Figure 3. A small quantity of working fluid is placed in a tube from which the vapor is then evacuated and the tube sealed. The vapor is moving from lower end of the tube which is heated to the cold end of the tube where it is condensate. The condensate is returned to the hot end by gravity. Since the latent heat of evaporation is large, considerable quantities of heat can be transported with a very small temperature difference from end to end. Thus, the structure will also have a high effective thermal conductance

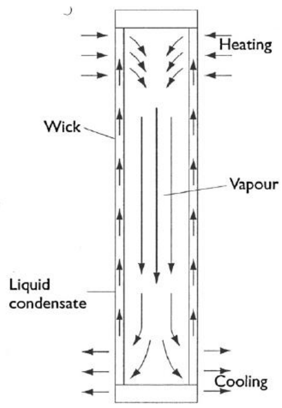

Figure 3. Mechanism of thermal performance of heat pipe

3.3. Pulsating heat pipe & factors affecting its performance

Since the early 1990s, the pulsing heat pipe (PHP) has emerged as one of the most innovative, effective, and convenient passive two-phase heat transfer systems due to its high performance, variety, and ease of construction[47]. conducted a visual examination of ammonia PHP for startup performance. They discovered that the start-up power required for 70% filling ratio (FR) is quite low due to ammonia characteristics. Furthermore, the continuous oscillation is caused by the interaction of the driving and restoring forces of heat transfer. Experiments are carried out to determine the impacting parameters of PHP. Such investigations are carried out in order to comprehend the impact of various operating situations on PHP's thermal performance. One of the operational parameters is the working fluid, which can be ethanol or distilled water with a 50% FR and 100, 120, or 140 watts. The thermal resistance of distilled water diminishes as the heat input increases. Ethanol's thermal resistance does not follow a set trend line. The thermal resistance of ethanol decreases initially and subsequently increases from 100 to 140 watts. The pulse of ethanol begins between 47°C and 50°C. Water pulsation is found at temperatures ranging from 50°C to 52°C [46] . Numerous criteria influence the performance of a pulsing heat pipe, including inner diameter, number of turns, inclination angle, and charge ratio. When they are they attain the highest thermal performance and maximum performance limitation when operating in the vertical bottom heat mode with a 50% FR. Closed loop pulsing heat pipe (CLPHP) with 2 mm ID tubes demonstrated lower thermal resistance, whereas 1mm ID tubes achieved dry out . Because of the effect of gravity on inclination, heat resistance is lowest when angled at 45 degrees. Excellent thermal performance is obtained at a 45-degree inclination angle for high power input, but at a 0-degree inclination angle for low power input[49]. Due to chaotic fluid movement, thermal resistance diminishes as heat input increases. As the heat input is increased while the FR remains constant, more fluctuations are noticed. This tendency is also found for water as a working fluid at FR=60%, but the amplitude is lower than at 40% and 50% FR[50] . Thermal performance improves by raising the evaporator temperature and decreasing the effective length. The best results were obtained using a short evaporator length of 50 mm. For a 2 mm inner diameter, water was the preferred working fluid; however, for a 1 mm inner diameter, both water and ethanol were suitable. Five revolutions were ineffective, and the heat resistance was almost infinite. All CLOHPs perform best when the maximum number of turns is 26[51]. Thermal resistance decreases as heat input increases for pure and binary PHP operating fluids. In terms of thermal performance, the water-methanol binary mixture outperforms other working fluids. Pure working fluids PHP with minor to large thermal resistances are acetone, methanol, ethanol, and water. Thermal resistances in binary mixtures are ordered from small to big, such as water methanol, water-acetone, and water-ethanol. In terms of thermal performance, pure acetone exceeds the other pure and binary mixed working fluids. There is no substantial difference in total heat resistance between PHPs operating with pure and binary mixture working fluids. The term "phase change cold storage technology" refers to a high-tech system that can store heat from chemical reactions, latent heat, and sensible heat in an insulated container. When the condition of the cold storage material changes, the density increases[52]. The phase change cool storage substance is used at a rate of 78.7% when the liquid filling rate is 30%. The real cycle of a pulsing heat pipe cold storage device has a maximum value of net output power and efficiency, and the cycle curve of power and efficiency is compatible with the trend of limited thermodynamic correlation [53], within the restrictions of theoretical analytical value. Improved thermal performance in terms of evaporation section temperatures was found while using a nanofluid in an open loop PHP [54]. Lower temperatures and more apparent pulsations were seen when water copper nanofluid was used. a nanofluid had larger amplitudes on the pulsations, which might be attributable to the nanoparticles acting as nucleation sites, enhancing slug dynamics. Similarly, the nanofluid had a significantly smaller bubble critical diameter than pure water, resulting in better thermal performance[55] Despite this, due to the intricate interaction effect of hydrodynamic and thermodynamic, the operational features and mechanisms of the PHP are not entirely understood. A significant amount of experimental research, as well as credible analytical models, should be conducted in order to improve PHP utilization [56].

4. Conclusion

An overview of study undertaken by different researchers on the construction and modeling effect of heat pipes is given by the development measures. After analyzing Researchers' investigations revealed that a heat pipe is a passive heat transfer mechanism. There are several ways to increase a heat pipe's thermal efficiency, and there are a lot of uses for it. Furthermore, heat pipes can be used for both heating and cooling purposes, as the literature indicates, but there is still a great deal to learn about them. In order to facilitate next studies, the following categories of objectives can be used to improve the heat pipes' thermal performance:

(1) Altering the surface area or pipe dimensions.
(2) Extending the duration of the fluid flow across the evaporator and condenser sections.
(3) Positioning the heat pipe's tubes so that the fluid comes into contact with the evaporator and condenser section.

(4) Taking into account the kinds and characteristics of the working fluid as well as the volumetric filling ratio.
(5) Causing the working fluid to bubble rapidly.
(6) Causing the working fluid to flow in a single direction for the HPHE.

Acknowledgments. The authors gratefully thank the staff of the laboratories of Middel Technical University and Northern Technical University for their support during the realization of the study.

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