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Heat Pipes Heat Exchanger for HVAC Applications

Anwar Barrak

Abstract

With increasing global demands for energy (especially in developing countries), energy production will increase, the wasted energy will increase, and the emission and pollution will increase also. That makes the researchers focus on recovering the wasted heat and enhancing the recovery devices to improve the energy-saving amount. Heat pipe technology is one of the promising methods of transfer heat efficiently between two species. There are three common types of heat pipe; conventional heat pipe, thermosyphon, and oscillating heat pipe. Each type contains three sections: evaporator, adiabatic, and condenser section. The heat pipe as a heat exchanger was investigated and experimentally used by many authors to recover the wasted energy in many engineering applications.

Keywords: heat transfer, heat exchanger, heat recovery, heat pipe, pulsating heat pipe

1. Introduction

The energy consumption of many countries has been increased mostly in growing countries. A rise in energy-consuming has been recognized because of the main developments in different sectors [1]. It is expected that energy-consuming even has a quicker increase in equatorial (hot) countries in comparison with the other countries. The energy side and global warming are the principal matters now and one of the main challenges for scientists and policymakers. One of the main processes that participate in the emissions lowering is an application of a heat recovery system to improve the thermal performance in the expression of energy-consuming. Air conditioning units are one of the important energy consumers, and commonly the running electrical cost of air conditioning systems accounts for about 50% of whole energy bills [2]. The heat will recover if the energy recovery applications are combined with air conditioning units to decrease the energy required of air conditioning units [3].

Figure 1 shows the use of a heat recovery device in the HVAC system, a high temperature (hot) and humid inlet air is required in an occupied building. The return air (cold) can be used to precool the incoming outdoor (hot) air by employing a heat recovery coil. Conventional heat recovery coils include stationary finned or plate-type air-to-air heat exchangers or rotary heat wheels [4]. Heat pipe heat exchanger (HPHX) suggested as an efficient heat exchanger is for this purpose [3].

The advantages of using the heat recovery device in HVAC systems are:

1. Energy reduction and, thus, primary energy consumption, which led to reduce emission production.

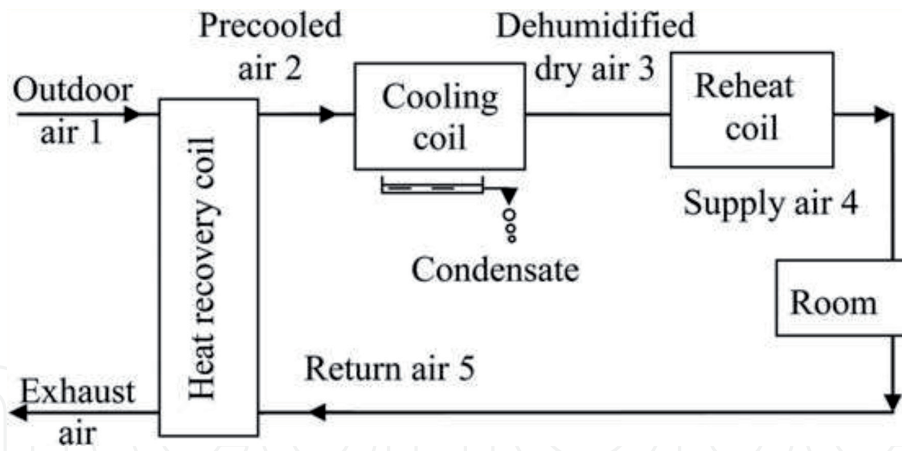


Figure 1.
Air conditioning system with precool and reheat coils [4].

2. Reduction in energy requirements and amounts of coolants used for the air conditioning system.
3. The operating costs are reduced [5].

The purpose of a heat pipe heat exchanger for heat recovery in hot and cold climates is widely known. The heat pipe exchanger offers a low air pressure drop, related to possible by loop configurations, and heat recovery applications can be extended to milder climates and still pay for themselves. A new possibility is 'cooling' recovery in the summertime, which is now economical enough to be considered. The application of heat pipe as a heat exchanger to recover wasted heat is participated to enhance the dehumidification capacity of a conventional cooling coil is one of the most attractive applications. The used heat pipe heat exchanger in HVAC systems as a dehumidifier device can decrease 10% the air relative humidity that leads to resulting in a remarkable enhancement of the quality of fresh air and a decrease in power demand. The heat pipe is a promising technology to enhance the quality of fresh air, and at the same time help save energy.

The objectives of this chapter are to view heat pipe technology, the mechanism of heat and mass transfer, and assess the performance of heat-pipe heat recovery units for the HVAC system. This chapter presents the updated development status of the heat pipe used as a heat exchanger used in the HVAC system to recover the wasted heat. In this chapter, the experimental and theoretical investigations of the heat pipe, Thermosyphon, and OHP are systematically summarized.

2. Heat pipe (HP)

The heat pipe is a very efficient passive device used to transfer heat. Heat pipes let height transfer rates over large space, with minimum temperature differences, simple structure, and easy control, and no required to pump [6]. Heat pipes consist of locked channels that are partially filled by a suitable working fluid. Heat pipes classify as a traditional heat pipe (HP), Thermosyphon heat pipe, and a pulsating/oscillating heat pipe (OHP) [7].

2.1 Conventional heat pipe (HP)

A heat pipe is a tube containing a wick structure filled partially with fluid at the saturated state is lined on the inner surface. It is divided into three sections,

as shown in **Figure 2**. An evaporator portion, where the heat is added and the liquid phase changes to vapor phase, a condenser region at the other end, where the heat is dissipated, and the condensation process occurs, and an adiabatic (insulated) zone in between, where no heat in or out in this section of the heat pipe and the two phases of working fluid (liquid and vapor) flow in contrary directions through the core and the wick [8].

In the conventional heat pipe (HP), the condensed (liquid phase) goes back to the evaporator region by the capillary effect of the wick in the HP [7]. **Figure 3** shows the operation of a conventional heat pipe (HP).

1. Heat pipes have some advantages features compared to other conventional approaches to transfer heat like a finned heat sink.
2. In steady-state operation, a heat pipe can have an extremely high thermal conductance.
3. A heat pipe can transfer a high amount of heat over a relatively long distance with a comparatively small temperature differential.
4. Heat pipe with liquid metalworking fluids can have a higher thermal conductance in comparison to the best solid metallic conductors, silver or copper.

2.2 Thermosyphon heat pipe

Thermosyphon is a simple two-phase closed heat pipe but an effective heat transfer device. It is a wickless heat pipe with a small amount of liquid reservoir at the bottom. The best description of Thermosyphon is by dividing it into three sections, as shown in **Figure 4**. Heat input through the evaporator section will convert the liquid into vapor. The vapor rises and moves across the adiabatic region to the condenser section. The vapor condenses and gives up its latent heat in the condenser section. The liquid was then forced to back to the evaporator section as a liquid film by gravity force [10].

Thermosyphon is a wickless heat pipe, therefore gravity is the major driving force for condensate to return to the evaporator section, so the capillary limit is generally of no concern in the operation of the Thermosyphon. **Figure 4** shows the closed two-phase heat pipe (thermosyphon) [9].

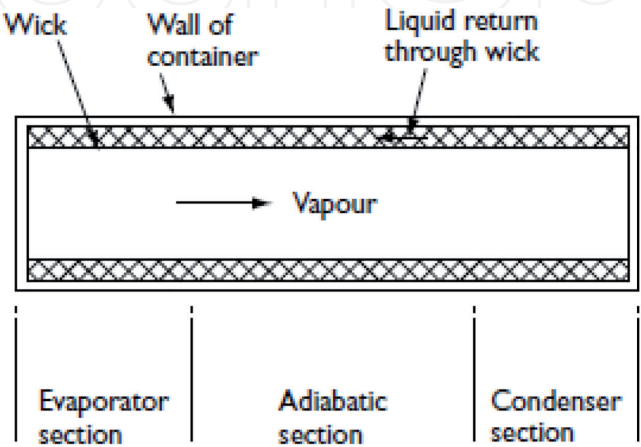


Figure 2.
Conventional heat pipe [7].

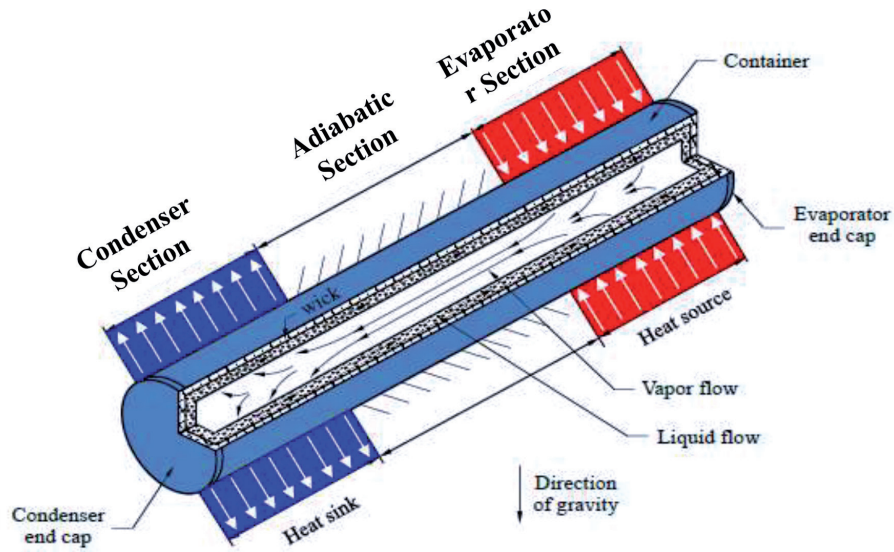


Figure 3.
Schematic operation of a conventional heat pipe [9].

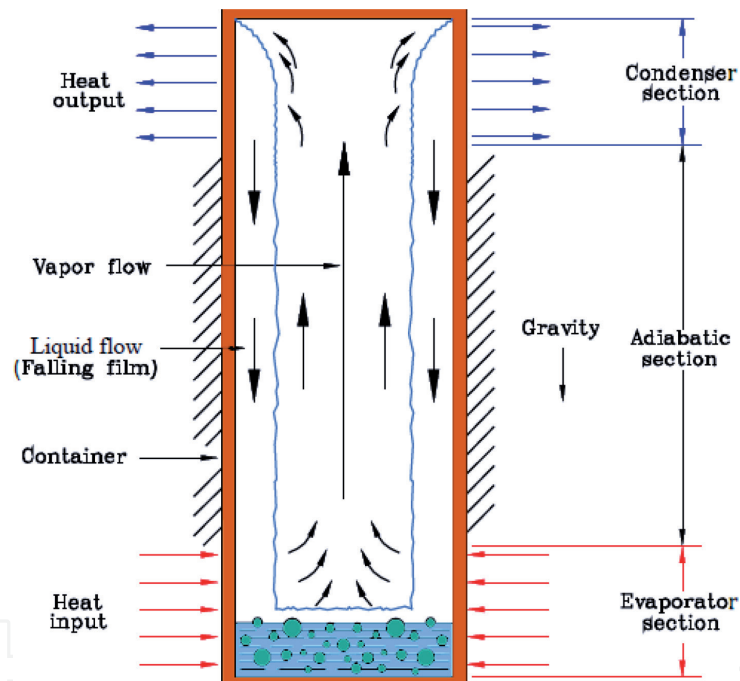


Figure 4.
Schematic operation of a thermosyphon heat pipe [9].

3. Oscillating heat pipe (OHP)

Oscillating heat pipe (OHP) or pulsating heat pipe (PHP) is a relatively new development that was proposed by Akachi in the field of the heat pipe in cooling technology [11].

OHP is characterized by the following basic features (see **Figure 5**):

1. The structure of OHP is manufactured from a bending tube comprised of serpentine channel capillary dimensions with many turns, filled partially by a working fluid [13].
2. The OHPs are classified into three main types. **Figure 5a** illustrates the first type of OHP, which is a closed-loop oscillating heat pipe (CLOHP). The name

became from its long capillary tube forming a closed loop. While **Figure 5b** depicts the second type, which is a CLOHP with check valves; it is manufactured from a long capillary pipe with the joining ends to configure a closed loop. The closed-loop heat pipe/check valves contain one or more direction-control one-way check valves in the loop to make the working fluid circulate in one direction only. A closed-end oscillating heat pipe is a third type of heat pipe, which is manufactured from a long capillary tube with closed at both ends, as shown in **Figure 5c** [12].

3. No internal wick structure (simple manufacturing).
4. At least one heat-receiving section (evaporator), heat-dissipating section (condenser), and an optional in-between adiabatic section are present [13].

3.1 Operation of oscillating heat pipe (OHP)

When the evaporator section receives heat, the temperature in the evaporator region increases, which will lead to a rise in the vapor pressure in the channel, and causes the growth of bubbles size in the evaporator section, then bubbles move to the condenser zone by the difference between the pressure of the evaporator and condenser. During the movement of the vapor plug to the condenser section, which is under low temperature, so the condensation process occurs, and the vapor plug collapses. Then, the slug-train in the condenser section is pushed to the adjoining vapor plug, and the liquid slug moves to the evaporator section for nucleation.

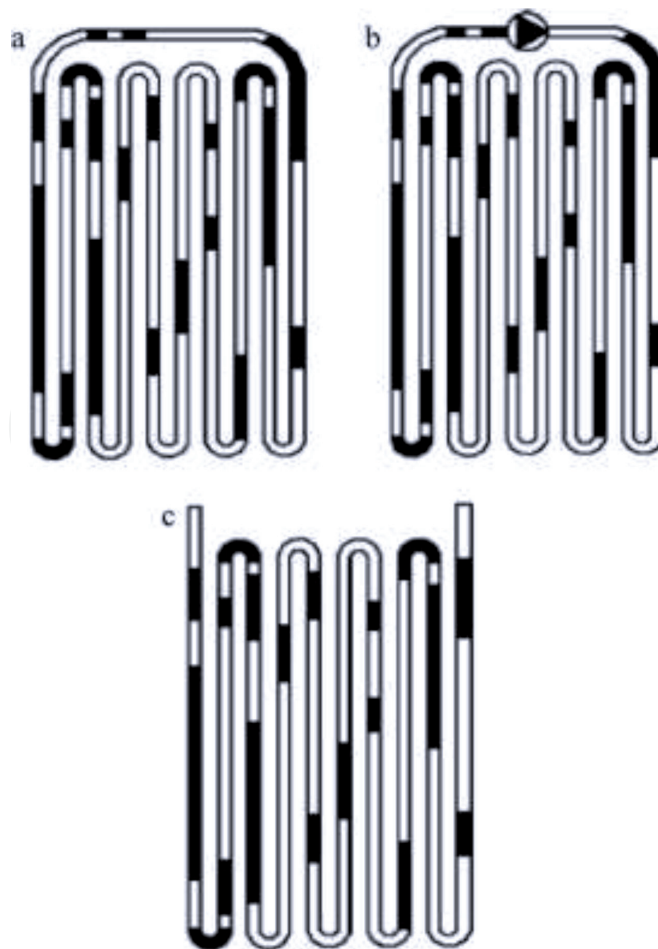


Figure 5.
 Types of oscillating heat pipes [12].

At nucleation locations, dispersed bubbles generate and coalesce to grow in size as bubbles are continuously heated. The formation and growth of dispersed bubbles happen continuously when supplying the heat at the evaporator zone because the temperature of the inner wall of the tube was higher than the saturated temperature of the working fluid [11].

As the condenser cools, the pressure reduces, and a condensation process of bubbles accrues. This process pumps the working fluid again to the evaporator region and continuous between both sections and resulting in oscillating motion. The cycle gets completed in this way, and the same cycle is repeated again and again for heat transportation from the evaporator region to the condenser region.

3.2 Advantages of oscillating heat pipe (OHP)

OHP is a highly effective thermal conductivity, thus resulting in a high level of temperature uniformity from the evaporator to the condenser. The operation of OHP can start at a low temperature to a high temperature, where the liquid and vapor phases can coexist. The manufacturing of OHP is almost by any shape. The OHP has some advantages and unique operating characteristics in comparison to a traditional heat pipe:

1. Part of the heat input at the evaporator zone of OHP will convert to the kinetic energy of the working fluid to maintain the oscillating/pulsating motion.
2. The liquid and vapor phases move in the same direction, and both phases do not interfere inside the OHP.
3. The evaporating and condensing heat transfer is significantly enhanced because liquid plugs that thermally driven in capillary tubes or channels that effectively produce thin films.
4. Oscillating/pulsating flows of working fluid inside capillary tubes/channels significantly improve the heat transfer by forced convection and the phase change (mass transfer).
5. The heat transferability of the OHP dramatically grows as the input power increases.
6. Wickless formations and low manufacturing expense.
7. The design of OHP can be independent of gravity [14].

4. Heat pipe heat exchanger (HPHX)

A wide range of research investigations had been done to explain and understand the thermal performance and operational behavior of heat pipes technology when it is used as a heat exchanger for recovering the heat that is wasted in HVAC and other engineering applications. The literature studied many factors that affected the operating behavior and thermal performance of heat pipe heat exchanger (HPHX) like working fluid, heat input, inlet air temperature, and velocity, pipes geometry, and arrangement style.

4.1 Review of heat pipe heat exchanger (HPHX)

This part will review the literature that investigated the recovering heat by using HPHX.

The heat pipe heat exchanger with staggered and inline arrays arrangement was investigated [15]. The heat pipe included sections with a height of 150 mm for the evaporator and condenser and 50 mm for the adiabatic zone. The heat pipe was fabricated from steel with a 20 mm inner diameter. They used 48 heat pipes put in an arrangement of eight rows. The results showed the effect of tube configuration, and the rate of heat transfer will increase by using a staggered configuration.

Noie [16] study experimentally and theoretically the influence of heat input, air temperature, and velocity on the performance of thermosyphon HPHX under steady-state operating conditions. The heat exchanger is comprised of six rows of 90 finned thermosyphon. The heat pipe had a length of 600 mm for the evaporator and condenser section and 100 mm for the adiabatic section and filled partially with water by 60% (from evaporator volume) filling ratio. The evaporator section was heated by air with temperature (100–250) °C & velocity (0.5–5.5) m/s, and the air was used to cool the condenser section at 25°C. The effectiveness-NTU method was used in the simulation program was developed to predict the outlet temperature. The results showed that the experimental and theoretical results were close. The results suggested avoiding the equal air velocity at the evaporator and condenser zones due to the minimum effectiveness of heat pipe [16].

By using a heat exchanger with eight rows of thermosyphon in an HVAC system, Yau (2007) investigated experimentally the effect of the inlet air conditions on the sensible heat ratio (SHR). The results concluded that the SHR decreased by using HPHX with the HVAC system. These meant that the cooling coil capability for removing moisture with HPHX was enhancing, and it strongly recommended to install heat pipe heat exchangers with an HVAC system for moisture removal enhancement [17].

El-Baky and Mohamed [18] examined a heat pipe heat exchanger to recover heat by connecting it with ducts of inlet and return air streams. They investigated the influence of flow rate ratio, and inlet air temperature (32–40) °C. To help the liquid back from the condenser to the evaporator section, the heat pipes have 4 layers of the brass screen with a 0.125 mm wire diameter. The findings manifest that the effectiveness will be high as the inlet air temperature was near to the operating temperature of working fluid inside the heat pipe. The results revealed that increasing the inlet air temperature led to enhance the heat transfer rate and effectiveness for the evaporator and condenser section.

A loop type of heat pipe (LHP) was integrated into the window type air-conditioning system [19] to introduce and perform a possible reheat process in the system. This configuration presented an enhancement in the COP of the system with a reduction in energy consumption. The author concluded that the loop heat pipe could de enhance the thermal performance for the large capacity units due to the double effect LHP in the system.

Yau and Ahmadzadehtalatapeh [20] carry out an experimental investigation to study the thermal performance of a horizontal heat pipe heat exchanger. They used two rows of copper heat pipe filled partially with R134a as working fluid. They examined the influence of the inlet air velocity and variation of inlet air temperature (27–35°C). The mathematical simulation was used to predict the thermal resistance for one heat pipe and then compared with experimental findings that gave a good agreement between the experimental and theoretical results with increasing air velocity. The findings deduced that the sensible effectiveness for heat pipe decreased with increasing air velocity.

Jouhara and Merchant [21] preferred an experimental and theoretical study of the performance and saving energy of a tilted heat pipe heat exchanger (thermosyphons) in the HVAC system. The heat exchanger consisted of nine thermosyphons in arrangement inline configuration with fins at evaporator and condenser sections and filled partially with water. The investigation showed the impact of the heat input and inclination angles on the thermal performance of the system. They developed a simulation model to predict the thermal performance of the heat pipe. At 90 tilt angle, the results depicted that the HPHX had high performance and optimum effectiveness.

An experimental and theoretical analysis of heat pipe heat exchanger is presented [22]. The horizontal heat exchanger consisted from 6-row of finned heat pipe aimed to heat recovery in HVAC system. The experimental test examined friendly substitutes as working fluid, and the results presented the alternative working fluid HFC152a had interesting heat transfer capabilities.

A study was conducted to investigate the effect of heat pipes rows on the thermal performance of heat exchanger experimentally and theoretically [23]. The heat exchanger was with three, six, and nine rows of the heat pipe, with four heat pipes in each row. The authors arranged heat pipes as a staggered configuration, and they investigated the effect of variation of inlet air temperature and velocity. In the theoretical part, the ϵ -NTU method applied to estimate the temperature of air exiting the evaporator and the effectiveness and heat recovery. The results showed that the maximum effectiveness was 62.6% and achieved at the maximum number of rows 9 with inlet air conditions 45°C and 2 m/s.

4.2 Review of oscillating heat pipe heat exchanger (OHPHX)

An oscillating heat pipe (OHP) is one of the promising heat pipe technologies. Compared with a traditional heat pipe, no wick structure inside the heat pipe, low cost, sensitive to low-temperature difference, and fast thermal response.

The operation of OHP does not need any power and there is no pump, so OHP considers as a passive device. The capillary effect plays an important role in the circulation fluid inside OHP between the evaporator and condenser section of OHP.

The principle of heat transporting by oscillating heat pipe depends on the pulsation phenomenon and the oscillation movement of working fluid in OHP. This phenomenon occurred because of the evaporation and condensation process (phase change) in the heat source (evaporator) and heat sink (condenser).

An OHP is a vacuum closed and a serpentine capillary tube (turns) and divided into the evaporator section (where the heat is added), condenser (where heat is rejected) section, and in-between adiabatic section. The OHP must have enough small inner diameter to let the liquid columns and vapor bubbles to coexist. The operation of an OHP begins when the evaporator section of OHP is subjected to heat, therefore, the evaporation process of working fluid starts, and the pressure of the vapor phase increases. So, the vapor bubble grew and pushed liquid plugs toward the condenser section (low-temperature region).

The condensation process at the condenser section induced a rise in the pressure variation between the evaporator section and the condenser section of OHP. Thus, the working fluid motion increased between hot and cold ends that lead to the heat transfer increased [24].

S. Rittidech et al. [25] used a prototype closed-end OHP made from copper with an inner diameter of 2 mm and 6 m total length of the tube. The eight turns OHP comprised only evaporator and condenser sections with a height of 190 mm for each one. They used 32 rows of OHP and used water and R123 as working fluid. The hot gas produced by a burner at a controlled velocity of 3.3 m/s with temperature

60, 70, 80°C. They noticed that the heat transfer rate and the thermal effectiveness increased by using R123 as a working fluid.

Oscillating heat pipe with check valve (OHP/CV) used in drier system [26]. CLOHP/CV with 20 turns made from copper filled partially by R134a with inner diameter 2 mm, evaporator, adiabatic, and condenser are 0.19 m, 0.08 m, and 0.19 m, respectively. The results showed that air humidity could be reduced from range (89–100) % to range (54–72) %.

An OHP was used to extend the tube surface of the heat exchanger instead of wire metal to overcome this limitation problem [27]. The copper OHP with 17 turns and 2.5 mm inner diameter is attached to both sides of the tubes. The working fluids were Acetone, R123, and Methanol by a 30% filling ratio. Furthermore, OHP with no working fluid was investigated to be a reference case that gives the same effect of wire metal features. The wind tunnel used to supply air at 25°C & rang (0.2–1.5) kg/s and the inlet temperature of water range (45 to 85) °C. The results revealed that the heat transfer and thermal performance of the OHPHX increased when the temperature of the inlet air increased. The using Methanol, R123, and acetone working fluids had higher thermal performance than the reference case by 10%.

Pracha et al. [28] used closed-loop OHP as the condenser for the vapor compression refrigeration system. The copper OHP was used with inner diameter 2.03 mm, the number of turn 250, and 80, 90, 100 mm as a length of the evaporator, condenser, and adiabatic sections respectively, and water as working fluid. The experimental work consists of two parts; the condenser unit and the OHP condenser part. For the same heat condition, the results showed that the OHP condenser system saved more electrical power, and the energy efficiency ratio (EER) increased by 18.9, 6.1, 13.4%, respectively. While for all cases, the coefficient of performance (COP) of the conventional condenser system is higher than the OHP condenser.

An OHP/CV is used as a heat recovery device in the drying chamber [29]. The cooper OHP/CV with inner diameter 2 mm, the length of the evaporator, adiabatic, and condenser section are 180, 200, and 180 mm, respectively. The working fluid was water by a 50% filling ratio. The result observed that the ratios of energy-saving were 56.66% and 28.13% for thermal and electrical energy, respectively.

Supirattanakul et al. [30] tested the different inlet air temperature at 50% relative humidity for the system with and without OHP/CV. The OHP/CV is made from copper with 56 turns, 2.03 mm inner diameter, and 220, 190, and 220 mm as a length of the evaporator, adiabatic, and condenser section, respectively, and the working fluid was R134a. The results revealed that energy is saved by 3.6% when OHP/CV was used in the system.

Pramod R and Ashish M [31] developed a closed-loop oscillating heat pipe by using a copper tube with a 2 mm inner diameter and bent to 10 turns. The lengths of the evaporator section, adiabatic section, and condenser section were 50 mm. The evaporator zone is heated by the oil path, while the condenser zone is cold by the water tank. Water, Acetone, Methanol, and Ethanol used as pure working fluids, and binary mixtures of (water/Acetone, water/Methanol, and Water/Ethanol) working fluids used by a filling ratio of 50%. The results of the study indicated that the thermal resistances smoothly decreased with rising heat input for both pure and binary (1:1 by volume) working fluid. The study also revealed that the temperature of working fluid (water/Methanol) at the evaporator section is low in high input heat, which gives a better performance of OHP than other binary working fluids.

The effects of putting fins in OHP were investigated [32]. They tested the finned and unfinned structure of OHP. The copper OHP was manufactured from a meandering tube by eight turns with a 2.5 mm inner diameter, and the lengths of the evaporator, adiabatic, and condenser sections were 50, 120, and 80 mm, respectively. They used copper wires by a 1 mm as fins, and the working fluids were

Methanol and Ethanol with a 50% filling ratio. The results revealed that Methanol had better thermal performance (lower thermal resistance) than Ethanol, and finned – inserted OHP presented lower thermal resistance than unfinned one.

The effect of using OHP/CV as a heat exchanger on energy-consuming in the split air unit was investigated [33]. They used HPHX to recover the wasted heat in an HVAC system. The authors made the ten turns OHP from copper tube with 1.65 mm inner diameter, and tested the OHP dry and with n-pentane by 70% filling ratio. At the evaporator section, the heat input was at a constant temperature of 45°C, while at the condenser section, the dissipation at 6°C with a constant volumetric ratio of 0.19 m³/s. The finding concluded that the OHP was able to regain wasted heat up to 240 W.

A. S. Barrak et al. [34] examined experimentally and theoretically the thermal performance of the oscillating heat pipe (OHP). The copper OHP had seven turns with 3.5 mm an inner diameter, and 300 mm as the lengths of the condenser and evaporator, and 210 mm for adiabatic section. The water was working fluid of the OHP a filling ratio of 50%. The evaporator region is heated by hot air (35, 40, 45, and 50) °C with various face velocity (0.5, 1, and 1.5) m/s. The condenser section is cold by air at a temperature of 15°C. They developed a turbulent approach based on the k- ϵ model by using the volume of fluid (VOF) method to simulate heat and mass transfer inside OHP. The results revealed that the minimum thermal resistance was 0.2312°C/W at maximum heat input 107.75 W and maximum thermal resistance was 1.036°C/W at lower heat input 13.75 W. The simulation model showed a good agreement with experimental results with a maximum deviation of 15%.

Three working fluids (water, methanol, and binary solution) were used in OHPHX to improve the humidity removal of the cooling coil [35, 36]. They mixed water with methanol (binary fluid) by a ratio of 50:50 by volume and used it as working fluid in the OHP. The findings revealed that the dehumidification process was enhanced by 17% for water, 25% for methanol, and 21% for binary fluid. Authors notice 16% an enhancement in energy-saving ratio and an improvement in the thermal effectiveness of the OHPHX about 14% by using the binary fluid as a working fluid instead of water.

OHP was proposed as fins on the heat exchanger to enhance the heat transfer rate by increasing the surface area [37]. OHP was manufactured from copper with 3 mm inner diameter and R 134 s as a working fluid. The results showed 310 and 263% the enhancement by using OHP in the overall heat transfer coefficient for natural and forced convections.

The thermal effectiveness and thermal resistance of OHPHX were investigated [38]. The inner diameter of OHP was 5 mm and filled by HFE-7000 with a 35% and 50% filling ratio. The results presented that the behavior of OHP as a thermosiphon due to the inner diameter was not small enough to form the oscillating phenomena by vapor plugs and liquid slugs.

5. Conclusions

Heat pipe heat exchanger is a new member of the heat recovery device in the HVAC system. The heat pipe has many advantages make it one of the promising device to enhance the value of energy saving in many engineering system and important research topics in the heat transfer area like simple structure, low cost, high heat transferability. The heat transfer performance of heat pipe is greatly influenced by many parameters, such as inner diameter, tilt angle, working fluids and filling ratio, and a turn's number for OHP, and many kinds of research have been done by investigating the heat transfer characteristics of the heat pipe.

Many experimental and theoretical investigations were conducted to study the heat and mass transfer in the heat pipe, and the thermal performance for the heat pipe and the system. The experimental part focused on the effect of certain parameters on the thermal performance and operation of the heat pipe heat exchanger, while the theoretical part focused on simulation and modeling the mechanism of mass and heat transfer operations.

From all those studies, the following conclusions are obtained:

1. The heat pipe heat exchanger as a heat recovery device has been successfully applied in conjunction with the HVAC system to enhance the energy-saving, cooling coil capacity, and dehumidification capability.
2. Despite the achievements gained from the theoretical studies, the mechanism of mass and heat transfer in the operation of OHP still has not been fully understood.
3. There are some questions and subjects that still need more investigations like; the chaotic behaviors in the OHP, the hydrodynamic and thermodynamic effects on the thermal performance, and the formation mechanism and transfer of heat and mass between the liquid plugs and vapor slugs. Finally, the Design techniques for the OHP heat exchange at present there is no reliable method.

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References

- [1] Hunt, V. D., 'Handbook of conservation and solar energy, trends and perspectives', Van Nostrand Reinhold Company, 1982.
- [2] Yau, Y. H., 'The use of a double heat pipe heat exchanger system for reducing energy consumption of treating ventilation air in an operating theatre – A full year energy consumption model simulation', *Energy and Buildings*, Vol. 40, pp. 917-925, 2008.
- [3] M. Ahmadzadehtalatapeh, and Y. H. Yau, 'Energy Conservation Potential of the Heat Pipe Heat Exchangers: Experimental Study and Predictions', *IJE TRANSACTIONS B: Applications* Vol. 25, No. 3, pp. 193-199, 2012.
- [4] K. S. Ong, 'Review of Heat Pipe Heat Exchangers for Enhanced Dehumidification and Cooling in Air Conditioning Systems', *International Journal of Low-Carbon Technologies*, 11, pp. 416-423, 2016.
- [5] ASHRAE Handbook HVAC Applications, SI Edition, 2011.
- [6] Amir Faghri, 'Review and Advances in Heat Pipe Science and Technology', *Journal of Heat Transfer*, Vol. 134, 2012.
- [7] Reay D, and Kew P. 'Heat pipes: theory, design and applications', fifth ed. Butterworth-Heinenmann, 2006.
- [8] Hassam Nasarullah Chaudhrya, Ben Richard Hughesa, and Saud Abdul Ghanib, 'A review of heat pipe systems for heat recovery and renewable energy applications', *Renewable and Sustainable Energy Reviews*, 16, pp.2249-2259, 2012.
- [9] Amir Faghri, 'Heat Pipes: Review, Opportunities and Challenges', *Frontiers in Heat Pipes (FHP)*, 5, 1, 2014.
- [10] A. Faghri, M.-M. Chen, and M. Morgan, 'Heat Transfer Characteristics in Two-Phase Closed Conventional and Concentric Annular Thermosyphons', *Journal of Heat Transfer*, Vol. 111/6, 11, 1989.
- [11] S. Thongdaeng, S. Rittidech and B. Bubphachot 'Internal flow patterns behavior of a top heat mode closed-loop oscillating heat pipe with check valves (THMCLOHP/CV)', *International Journal of the Physical Sciences* Vol. 7(29), pp. 5097-5105, 26 August, 2012.
- [12] W. Srimuang, and P. Amatachaya, 'A review of the applications of heat pipe heat exchangers for heat recovery', *Renewable and Sustainable Energy Reviews* 16, pp.4303-4315, 2012.
- [13] Khandekar S., Schneider M. and Groll M., 'Mathematical Modeling of Pulsating Heat Pipes: State of the Art and Future Challenges', *Heat and Mass Transfer Conf.*, pp. 856-862, Kolkata, India, 2002.
- [14] Hongbin Ma 'Oscillating Heat Pipes', Springer New York, Media New York 2015.
- [15] Yodrak L, Rittidech S, Poomsaad N. and Meena P., 2010, "Waste Heat Recovery by Heat Pipe Air-Preheater to Energy Thrift from the Furnace in a Hot Forging Process", *American Journal of Applied Sciences*, Vol.7, pp.675-681
- [16] Noie S. H., 2006, "Investigation of Thermal Performance of an Air-to-Air Thermosyphon Heat Exchanger Using e-NTU method, *Applied Thermal Engineering*, Vol.26, pp.559-567
- [17] Yau Y. H., 2007, "Application of a heat pipe heat exchanger to dehumidification enhancement in a HVAC system for tropical climates a baseline performance characteristics study", *International Journal of Thermal Sciences*, Vol.46 (2007), pp.164-1714.

- [18] El-Baky M. A. and Mohamed M. M., 2007, "Heat pipe heat exchanger for heat recovery in air conditioning", *Applied Thermal Engineering* Vol.27, pp.795-801
- [19] Alklaibi A. M., 2008, "Evaluating the possible configurations of incorporating the loop heat pipe into the air-conditioning systems" *international Journal of Refrigeration*, Vol. 31, pp.807-815.
- [20] Yau Y. H. and M. Ahmadzadehtalatapeh, 2010, "Experimental Investigation of the Thermal Performance of an Air-To-Air Horizontal Heat Pipe Heat Exchanger", *International Journal of Mechanical and Materials Engineering (IJMME)*, Vol. 5 (2010), No. 1, pp.29-35.
- [21] Jouhara H. and Merchant H., 2012, "Experimental investigation of a thermosyphon based heat exchanger used in energy efficient air handling units", *Energy* Vol.39, pp. 82-89.
- [22] G. Righetti, C. Zilio, S. Mancin & G. A. Longo (2018) Heat Pipe Finned Heat Exchanger for Heat Recovery: Experimental Results and Modeling, *Heat Transfer Engineering*, 39:12, 1011-1023, DOI: 10.1080/01457632.2017.1358483
- [23] Ragil Sukarno, Nandy Putra, Imansyah Ibnu Hakim, Fadhil Fuad Rachman, Teuku Meurah Indra Mahlia, 'Multi-stage heat-pipe heat exchanger for improving energy efficiency of the HVAC system in a hospital operating room', *International Journal of Low-Carbon Technologies*, ctaa048, <https://doi.org/10.1093/ijlct/ctaa048>
- [24] Reay D, and Kew P. 'Heat pipes: theory, design and applications', fifth ed. Butterworth-Heinenmann, 2006
- [25] S. Rittidech, W. Dangeton, S. Soponronnarit, "Closed-ended oscillating heat-pipe (CEOHP) air-preheater for energy thrift in a dryer", *Applied Energy*, 81, 198-208, 2005.
- [26] P. Meena, S. Rittiched, N. Poomsaad, "Application of Closed Loop Oscillating Heat Pipe with Check Valve (CLOHP/CV) Air Preheater for Reduced Relative Humidity in Drying Systems), *Applied Energy*, vol. 84, issue 5, pages 553-564, 2007.
- [27] A Nuntaphan, S. Vithayasai, N. Vorayos, N. Vorayos, T. Kiatsiriroat, 'Use of oscillating heat pipe technique as extended surface in wire-on-tube heat exchanger for heat transfer enhancement', *International Communications in Heat and Mass Transfer* (37), 287-292, 2010.
- [28] Pracha Yeunyongkul, P. Sakulchangsattajai, and Afshin J. Ghajar "Experimental Investigation of Closed Loop Oscillating Heat Pipe as the Condenser for Vapor Compression Refrigeration", *International Refrigeration and Air Conditioning Conference at Purdue*, 2010.
- [29] S. Wannapakhe, T. Chaiwong, M. Dandee, S. Prompakdee " Hot Air Dryer with Closed – Loop Oscillating Heat Pipe with Check Valves for Reducing Energy in Drying Process" *Procedia Engineering* 32 (2012) 77-82, 2011.
- [30] P. Supirattanakul, S.Rittidech, B.Bubphachot, "Application of a closed-loop oscillating heat pipe with check valves (CLOHP/CV) on performance enhancement in air conditioning system." *Energy and Buildings journal*, G Model ENB-3133; No. of Pages5, 2011.
- [31] Pramod R. Pachgharea, Ashish M. Mahalle, 'Thermal Performance of Closed Loop of Pulsating Heat Pipe Using Pure and Binary Working Fluids', *Frontiers in Heat Pipes (FHP)*, 3, 033002, 2012.

[32] M Lutfor Rahman, Sumaiya Nawrin, and Rasel A Sultan, Fariha Mir, and Mohammed Ali, 'Effect of fin and insert on the performance characteristics of close loop pulsating heat pipe CLPHP', *Procedia Engineering* 105, 129-136, 2015

[33] Govinda Mahajan, Heejin Cho, Scott M. Thompson, Harrison Rupp, Kevin Muse, "Oscillating heat pipes for waste heat recovery in HVAC systems", *Proceedings of the ASME*, 13-19, 2015.

[34] A. S. Barrak, A. A.M. Saleh and Z. H. Naji, "Experimental and Numerical Simulation for Thermal Investigation of Oscillating Heat Pipe Using VOF Model" *Engineering and Technology Journal*, Vol. 38, Part A, No. 1, pp. 88-104, 2020, [https://doi.org/ 10.30684/etj.v38i1A.286](https://doi.org/10.30684/etj.v38i1A.286)

[35] A. S. Barrak, Ahmed. A. M. Saleh and Zainab. H. Naji, An experimental study of using water, methanol, and binary fluids in oscillating heat pipe heat exchanger, *Engineering Science and Technology, an International Journal*, <https://doi.org/10.1016/j.jestch.2019.05.010>

[36] A. S. Barrak, A. A. M. Saleh and Z. H. Naji, "Energy Saving of Air Conditioning System by Oscillating Heat Pipe Heat Recovery Using Binary Fluid," *2019 4th Scientific International Conference Najaf (SICN)*, Al-Najef, Iraq, (2020), pp. 178-183

[37] H. J. Mosleh, M. A. Bijarchi, M. B. Shafii, 'Experimental and numerical investigation of using pulsating heat pipes instead of fins in air-cooled heat exchangers', *Energy Conversion and Management* 181 (2019) 653-662.

[38] K. Yang, M. Jiang, C. Tseng, S. Wu, and J. Shyu, 'Experimental Investigation on the Thermal Performance of Pulsating Heat Pipe Heat Exchangers', *Energies*, 13, 269, 2020; doi:10.3390/en13010269