A review on the application of horizontal heat pipe heat exchangers in air conditioning systems in the tropics

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ABSTRACT

A literature review on the application of horizontal heat pipe heat exchangers for air conditioning in tropical climates was conducted. This paper focused on the energy saving and dehumidification enhancement aspects of horizontal heat pipe heat exchangers. The related papers were grouped into three main categories and a summary of experimental and theoretical studies was made. It was revealed that although there are a number of valuable researches on the impact of heat pipe heat exchangers on the energy consumption and dehumidification enhancement of air conditioning systems in the tropics, but only limited research work on the application of horizontal configuration heat pipe heat exchangers in air conditioning systems has been carried out in these regions. Therefore, it needs more research to deepen the understanding of the benefits of this heat recovery device in the air conditioning systems. On the basis of results obtained from the reviewed research studies, the application of horizontal heat pipe heat exchangers in terms of energy saving, dehumidification enhancement and condensate drainage is recommended for the tropics.

1. Introduction

As an efficient heat exchanger, heat pipe heat exchangers (HPHXs) are playing a considerable role in different fields including air conditioning systems. A heat pipe heat exchanger is a heat transfer device in which the latent heat of vaporization is utilized to transfer heat over a long distance with a corresponding small temperature difference. It consists of individual closed tubes that are filled with a proper working fluid. In operation, the working fluid evaporates at the evaporation section and condenses over the other end of the tube as shown in Fig. 1. The condensed fluid returns back to the evaporator section through the capillary action of the wick or gravitational force in the thermosyphon heat pipes.

The advantage of using a heat pipe over the other ordinary methods to heat transfer is that a heat pipe can have an extremely high thermal conductance in steady state operation. Hence, it can transfer a high amount of heat over a relatively long length with a comparatively small temperature difference. A heat pipe with liquid metallic working fluid can have thermal conductance much more than the best solid metallic conductor such as silver and copper. Moreover, simplicity of design and manufacturing, small temperature drops, wide temperature application range and the ability to control and transport high heat rates at various temperature levels are the unique characteristics of heat pipes.

In recent times, HPHXs in different forms and designs have found a wide variety of application including the heating, ventilation and air conditioning (HVAC) systems. There is considerable literature on the application of HPHXs, but only literatures on the application of horizontal HPHXs in air conditioning systems in

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In recent times, HPHXs in different forms and designs have found a wide variety of application including the heating, ventilation and air conditioning (HVAC) systems. There is considerable literature on the application of HPHXs, but only literatures on the application of horizontal HPHXs in air conditioning systems in
tropical climates are reviewed in the present paper. This literature survey has been separated into three sections, which focused in turn on the application of horizontal configuration HPHXs for energy recovery purposes, application of HPHXs in tropical, subtropical, hot and humid climates and the studies on the influence of inclination angle on the HPHXs performance in tropical HVAC systems.

2. Application of horizontal configuration HPHXs for energy recovery purposes

Since 1970, HPHXs have been extensively applied in many industries including HVAC systems. There are several types of heat exchangers available for heat recovery in the HVAC systems, but HPHXs have a number of significant advantages over the other type of heat exchangers such as lower initial cost, lower maintenance costs, and lower operating costs. The application of HPHXs in cold climates was widely recognized and by improving heat pipes, it is possible to use heat pipes in different climates such as in the tropical climates.

One of the most interesting functions of HPHXs is to increase the dehumidification capacity of the conventional air conditioning systems. In a conventional air conditioning system, the humidity is controlled by cooling the supply air stream below its dew point temperature. The cold air is then reheated to a temperature that is suitable for the conditioned space. An experimental investigation was carried out by McFarland et al. [1] to determine the effect of a heat pipe on the performance of a conventional residential air conditioning system as illustrated in Fig. 2. In this study, the influence of heat pipe on the moisture removal, the amount of auxiliary reheat required to maintain the room conditions, and the latent energy efficiency ratio of the air conditioning system were examined. The system was operated at three configurations: with the heat pipe installed, a conventional system without the heat pipe and the air flow subject only to typical restrictions, and a dampered system with the heat pipe removed but dampering added to return the airflow to the same value as when the heat pipe was installed. It was demonstrated that for the nominal room conditions of 22°C and 50% relative humidity, the heat pipe increased the moisture removal by 62%, decreased the amount of reheat energy required by 20%, and increased the latent energy efficiency ratio by 90%. He declared that the application of HPHX in the conventional air conditioning system could be an efficient technique to control the humidity and reduce the amount of reheat energy required.

Abd El-Baky and Mohamed [2] also stated that by the application of a HPHX between two streams of fresh and return air in an air conditioning system, the incoming fresh air could be cooled down. Ratios of mass flow rate between return and fresh air of 1, 1.5, and 2.3 were tested to validate the heat transfer and the temperature change of fresh air as shown in Fig. 3. During the tests, fresh air inlet temperature was controlled in the range of 32–40°C, while the inlet return air temperature was kept constant at about 26°C. The optimum effectiveness evaluated in accordance to thermo-economical optimization method found in Soylemez [3] and compared with the experimental data. According to the experimental results, the temperature changes of fresh and return air were increased with the increase of fresh air inlet temperature. The effectiveness and heat transfer of both the evaporator and condenser sections were also increased up to 48%, while the inlet fresh air temperature was increased up to 40°C. Furthermore, the enthalpy ratio between the heat recovery and conventional air mixing was increased to about 85% with the increase of fresh air inlet temperature. Optimum effectiveness was obtained at fresh air inlet temperature near the fluid operating temperature of the heat pipes.

As a heat exchanger, the horizontal HPHXs were also used in naturally ventilated buildings. For example, Rifat and Gan [4] explored the effectiveness of HPHXs for the naturally ventilated buildings. In this research, the performance of three types of heat pipe heat recovery units was tested in a two-zone chamber with a horizontal partition. The first heat recovery consisted of a bank of seven externally finned heat pipes, the second had cylindrical spine fins and the third was made of 2-rows of staggered heat pipes. The CFD modeling was used for pressure loss characteristics of the units. According to the experimental results, the air velocity had a significant influence on the effectiveness of heat pipe heat recovery units. It was also found that at the same velocity, the heat

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### Nomenclature

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>AC</td>
<td>air conditioner</td>
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<tr>
<td>ET</td>
<td>effective temperature</td>
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<tr>
<td>HP</td>
<td>heat pipe</td>
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<tr>
<td>HVAC</td>
<td>heating, ventilation and air conditioning</td>
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<tr>
<td>HPHX</td>
<td>heat pipe heat exchanger</td>
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<tr>
<td>PMV</td>
<td>predicted mean vote</td>
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<tr>
<td>SIECHP</td>
<td>semi-indirect evaporative cooler and heat pipe</td>
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<tr>
<td>SHR</td>
<td>sensible heat ratio</td>
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<td>TRNSYS</td>
<td>transient systems simulation program</td>
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on the heat transfer rate of an air-to-air HPHX applied in an air conditioning system. A set of two-phase closed thermosyphons was investigated to find out how far they can be inclined without considerable decrease in the heat transfer rate. It was found that even in a nearly horizontal position (up to ±6° with the horizontal) the overall performance is still good enough. It was observed that turning the set of pipes by an angle of about 12° from −6° to +6° with respect to the horizontal will switch the overall heat transfer from one direction to the other. It was also observed that in an air conditioning system, where the thermosyphon heat pipes operate as a heat exchanger between the outside channel and the exhaust air, it can be used in a position of −6° to preheat the fresh air in winter and in a position of +6° to pre-cool the fresh air in summer. Similarly, the effect of tilt angle on the overall heat transfer of two types of heat pipes, one with wick and another with no wick was studied by Said and Akash [48]. The heat pipes were positioned at different tilt angles of 30°, 60°, and 90° with the horizontal. It was revealed that for all the cases, the performance of the heat pipe was improved when wick was used. In terms of overall heat transfer coefficients, the wickless heat pipes had a value in the range of 4000–5000 W/m²°C and for wicked heat pipes it was improved to the range of 6000–7000 W/m²°C. For the tilt angles of 30°, 60°, and 90° (with respect to the horizontal), the amount of enhancement, when wick was used in a heat pipe, was about 55%, 25%, and 70%, respectively. Loh et al. [49] also investigated the effect of orientation angle on the performance of three heat pipes wick structure. It was found that heat source orientation and gravity had less influence on sintered powder metal heat pipes. According to the experimental results, employing the mesh and groove heat pipe with evaporator is on the top of the condenser was not suggested. Furthermore, Foot et al. [50] explained that inclination angle had no significant effect on the performance of a plate heat pipe solar panel. In contrast, Guo et al. [51] studies showed that heat pipe effectiveness can be affected by inclination angle. All of these investigations were for conditions in which the surface condensation was not a concern.

Condensation forming on the extended fin surfaces of HPHXs is expected in high humid climates. As a result, the performance of the HPHX is expected to be influenced by any condensation forming on the fin surfaces. Literature review revealed that the condensation forming on the fin surfaces of a HPHX in high humid condition and its effect on the HPHX performance has received little attention. Kim et al. [52] carried out a research on the effect of air inlet humidity on the air side heat transfer and pressure drop for an inclined brazed aluminum heat exchanger as shown in Fig. 13. The heat exchanger was studied at three different inclined angles namely 14°, 45°, and 67° (with respect to vertical position). The inlet air temperature was in the range of 60–90°C, while the inlet air humidity was controlled at 12°C. It was observed that the effect of air inlet humidity on the heat transfer and pressure drop characteristics of heat exchanger was negligible for the inclination angle of less than 45°. Similarly, Yau [53] claimed that the impact of condensate layer on the performance of a thermosyphon HPHX operating in a high humid condition was negligible. In the tilted angle of 30° with the horizontal configuration, the gravitational force would be expected to enhance drainage of any condensate on the fin surfaces in evaporator section. Therefore, the effectiveness of the HPHX could be predicted to be better than the vertical configuration, but the results revealed that the condensation forming on the extended fin surfaces has a negligible effect on the effectiveness of the HPHX studied. For instance, for mass flux of 1.3 kg/m²s and nominal evaporative relative humidity of 80%, the sensible effectiveness was in the range of 0.40–0.50 and 0.41–0.49 for the vertical configuration and tilted angle of 30°, respectively.

In terms of condensate layer, because of the fins orientation in the horizontal configuration HPHXs, this configuration HPHXs can be anticipated to lessen negative impact of any condensate layer on the HPHX effectiveness. Moreover, the space that an air conditioning system occupies in a building is one of the major concerns in the building industry. In other words, if the air conditioning system occupies less space, it will be more economical. Nowadays, the building industry focuses on more benefit of spaces in buildings than before, especially in countries with high population density. Since the horizontal configuration HPHXs is smaller in vertical dimension and this could save in space of building when they installed, it seems that the employment of horizontal configuration HPHXs can be more economical than vertical configuration HPHXs from this point of view.

5. Conclusions

A literature review was carried out on the application of HPHXs in HVAC systems in tropical climates. This review testifies that HPHXs in both configurations, i.e., vertical (thermosyphon) and horizontal configuration, can be implemented as an efficient energy recovery unit in air conditioning systems to remove heat or coolness and dehumidification purposes. Moreover, literature review on the application of horizontal configuration HPHXs installed with air conditioning systems in tropical climates reveals that although the humidity control is one of the main concerns in indoor comfort quality in tropical climates, but investigations regarding the application of horizontal configuration HPHXs for dehumidification enhancement and energy saving purposes in air conditioning systems are limited and most of the studies have been carried out in sub-tropical climates. Therefore, further investigations on the subject such as optimization of working fluid, impact of rows on the overall performance, and effect of different indoor temperature and relative humidity on the energy saving and dehumidification enhancement should be made to deepen the understanding of the benefits of this heat recovery device in areas as tropical climates such as Malaysia, Singapore and Thailand. Based on this literature survey, for condensate drainage considerations, the horizontal configuration HPHXs are recommended especially in tropical climates.

References


Fig. 13. Schematic diagram of the heat exchanger installation.