Experimental thermal performance study of an inclined heat pipe heat exchanger operating in high humid tropical HVAC systems

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Abstract

In an earlier paper [Y.H. Yau, Application of a heat pipe heat exchanger to dehumidification enhancement in tropical HVAC systems — a baseline performance characteristics study, International Journal of Thermal Sciences 46 (2) (2007) 164–171], the author had established the baseline performance characteristics of the eight-row wickless heat pipe heat exchanger (HPHX) for a vertical configuration under a range of conditions appropriate for a tropical climate. Now, the same basic experimental set-up was to be used in the present research with the HPHX tilted 30°. In this configuration, the gravitational force would be expected to enhance drainage of any condensation forming on the extended fin surfaces of the HPHX evaporator section, and therefore, the effectiveness of the HPHX could be anticipated to be better than the vertical configuration, particularly when processing inlet air with high RH. The investigation has been carried out for 32 experiments with typically high RH and the results are presented in this paper. The results suggested that the possibly adverse influence of condensate forming on the fins of the HPHX was negligible, and therefore the HPHX in a typically-used vertical configuration could perform equally as well as it would if the HPHX was installed in an inclined position.

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Keywords: Air conditioning; Heat exchanger; Air cooler; Heat pipe; Geometry; Experiment; Condensation; Relative humidity; Efficiency

Etude sur la performance thermique d’un échangeur de chaleur à caloduc incliné fonctionnant dans un système de ventilation et de conditionnement d’air utilisé dans une région tropicale à forte humidité

Mots clés : Conditionnement d’air ; Échangeur de chaleur ; Refroidisseur d’air ; Caloduc ; Géométrie ; Expérimentation ; Condensation ; Humidité relative ; Efficacité

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1. Introduction

Condensation forming on the extended fin surfaces of the HPHX evaporator section is a major concern for many tropical HVAC system designers because the surface condensation might prevent this device from working effectively in tropical climates. Wadowski et al. [2] mentioned that the further increase of moisture content caused a rapid drop of total effectiveness value. Hill and Jeter [3] revealed that condensation on the HPHX evaporator led to a more rapid decline in HPHX effectiveness as mass transfer effects further reduced the dry-bulb temperature differential between the return air and the air leaving the conventional cooling coil.

Literature review revealed that there were only three published studies on inclined HPHXs performance, and were conducted by Guo et al. [4] in a Canadian climate (Saskatoon, Canada) and Beckert and Herwig [5] in Chemnitz, Germany, and Foot et al. [6] in Christchurch, New Zealand. Guo et al. [4] claimed that heat pipe inclination did influence effectiveness. All of these investigations were for conditions in which surface condensation was not a concern, and therefore the only effect of any inclination was on the internal condensate return within the heat pipes.

However, based on the study of Incropera and DeWitt [8], the HPHX could be inclined to within ±6° from horizontal and the overall performance was still satisfactory, suggesting that the inclination angle has negligible effect on the performance of an HPHX. Foot et al. [6] further proved that the inclination angle has negligible effect on the performance of a flat plate heat pipe solar panel. In a similar research conducted by Hua [7] on the performance of a flat plate heat pipe solar panel, the inclination angle had no significant effect on the overall performance even if the flat plate heat pipe solar panel was tilted to within approximately 8° from horizontal.

No further independent experimental studies have been conducted to examine the effect of an inclined HPHX on the sensible and total effectiveness operating in tropical HVAC systems where inclination has an additional external effect through its influence on surface condensate run-off. Therefore, this investigation is required to be carried out and the major aim is to examine the combined internal (heat pipe) and external (fin surface) effects of inclining an HPHX.

2. Theory relevant to the present research

The theory relevant to the testing of an HPHX for energy balance analysis has been described in Ref. [1]. The same theory has been applied in the current investigation with the exception that in the present research, the HVAC system was tested with the HPHX in an inclined position. Also, it should be noted that in Ref. [1], the sensible heat ratio (SHR), i.e. the sensible load divided by the total load, was used to determine the dehumidification enhancement capability of the HVAC system. In the present research, the

![Fig. 1. Schematic of the counter-flow HPHX for effectiveness ratings.](image)
extended fin surfaces of the HPHX evaporator. However, again, it was clear that the influence of the condensation layer thickness was negligible for this HPHX design (eight-row HPHX), running under even higher mass flux rate (see Figs. 7–10).

For all cases examined, the total effectiveness was much lower than the sensible effectiveness. In addition, the present research added support to the view that the inclination angle had negligible effect on the internal performance of the HPHX as suggested by all previous researchers [6–8] with the exception of the research work conducted by Guo et al. [4].

4.2. Error analysis

It should be noted that the objective of the present research is to examine the influence, if any, of condensate forming on the fins of the HPHXs and possibly causing a drop in effectiveness, and therefore, highly precise data were not considered necessary. However, a full set of reliable data to examine the performance characteristics of the HPHX itself installed in an inclined position is needed in this research. Therefore, a partial error analysis on effectiveness studies was conducted to prove whether or not the errors present in the results were inside the acceptable limit.

A bias uncertainty analysis on the effectiveness studies was conducted for a representative experimental run for the inlet HPHX evaporator DBT at 29.6 °C, RH at 71.3% and mass flux rate at 2.2 kg/m² s (0.205 kg/s). This representative experimental run was chosen due to the same reasons as mentioned in Ref. [1].

The bias uncertainties for the sensible and total effectiveness are 0.7% and 5.4%, respectively. The main reason for this bias uncertainty difference between the sensible and total effectiveness can be attributed to the fact the sensible effectiveness needs only temperature data but the total effectiveness needs both temperature and humidity ratio data. Because wet-bulb temperature sensors contribute relatively high errors compared to dry-bulb temperature sensors, the bias uncertainty for total effectiveness is slightly larger than for the sensible effectiveness. These results suggested that non-uniform temperature distributions were present during this experimental run (see Table 7). The details of the bias uncertainty analysis for effectiveness studies could be found in Ref. [13].

5. Concluding summary

In this paper, the HVAC system was tested with the wickless eight-row HPHX in an inclined position to examine the influence of condensate forming on the fins of the HPHXs and affecting its effectiveness. The results suggested that the possibly adverse influence of condensate forming on the fins of the HPHX was negligible, and therefore, the HPHX in a typically-used vertical configuration could perform equally as well as it would if the HPHX was installed in an inclined position. This result, obtained under quite high humidity conditions where condensate formation on the HPHX could be expected to be significant, suggests that the more easily incorporated vertical configuration for the HPHX should be satisfactory under all conditions.

<table>
<thead>
<tr>
<th>Mass flux (kg/m² s)</th>
<th>Nominal RH (%)</th>
<th>Sensible effectiveness</th>
<th>Total effectiveness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(Alfa = 30°)</td>
<td>(Alfa = 0°)</td>
</tr>
<tr>
<td>1.3</td>
<td>70</td>
<td>0.48–0.61</td>
<td>0.25–0.34</td>
</tr>
<tr>
<td>1.3</td>
<td>80</td>
<td>0.41–0.49</td>
<td>0.20–0.21</td>
</tr>
<tr>
<td>2.2</td>
<td>70</td>
<td>0.62–0.76</td>
<td>0.38–0.46</td>
</tr>
<tr>
<td>2.2</td>
<td>80</td>
<td>0.50–0.65</td>
<td>0.27–0.30</td>
</tr>
</tbody>
</table>

Table 7
Bias uncertainties for the calibrated temperature sensors

<table>
<thead>
<tr>
<th>Station</th>
<th>Max DBT (°C)</th>
<th>Max WBT (°C)</th>
<th>Min DBT (°C)</th>
<th>Min WBT (°C)</th>
<th>Bias uncertainty max (°C)</th>
<th>Bias uncertainty min (°C)</th>
<th>Error DBT (%)</th>
<th>Error WBT (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>29.7</td>
<td>25.1</td>
<td>29.6</td>
<td>25.0</td>
<td>0.01</td>
<td>0.02</td>
<td>0.0</td>
<td>0.1</td>
</tr>
<tr>
<td>2</td>
<td>23.5</td>
<td>23.5</td>
<td>23.3</td>
<td>23.2</td>
<td>0.10</td>
<td>0.12</td>
<td>0.4</td>
<td>0.5</td>
</tr>
<tr>
<td>3a</td>
<td>21.8</td>
<td>22.0</td>
<td>20.7</td>
<td>20.5</td>
<td>0.53</td>
<td>0.76</td>
<td>2.5</td>
<td>3.6</td>
</tr>
<tr>
<td>4</td>
<td>21.4</td>
<td>21.3</td>
<td>21.2</td>
<td>21.2</td>
<td>0.06</td>
<td>0.02</td>
<td>0.3</td>
<td>0.1</td>
</tr>
<tr>
<td>5</td>
<td>28.3</td>
<td>23.8</td>
<td>27.2</td>
<td>22.3</td>
<td>0.53</td>
<td>0.76</td>
<td>1.9</td>
<td>3.3</td>
</tr>
</tbody>
</table>

a It should be noted that bias uncertainties for Station 3 (consisted of individual DBT and WBT sensors) were assumed to be the same as Station 5 due to the fact that Station 5 had the highest bias uncertainty values.
Neither is it essential to apply higher-than-normal air
face velocities through the HPHX to reduce the thickness
of the condensate film. Both of these conclusions are encour-
aging findings in terms of reducing the payback period for
installing an HPHX in the HVAC systems. An inclined
HPHX configuration would almost definitely increase the
complication and cost of ductwork, especially for a retrofit.
Moreover, that added complication would increase the pres-
sure drop penalty (i.e. the fan penalty), as would any condi-
tion to run the HVAC systems at a higher air velocity than
would be applied otherwise.

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