Experimental study of a thermoelectric heat pump system utilizing bent heat pipes for heat transfer

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Abstract

This paper presents the study of the novel thermoelectric heat pipe heat pumping system. Bent heat pipes with sintered powder wicks were utilized in a configuration which used centrifugal forces, due to rotation, to enhance heat transfer. The revolving heat pipes worked both as a fan and as a heat exchanger; however, extra fan blades were required to improve the fan performance. Fan performance tests were carried out, followed by the thermal performance, within which eight pieces of thermoelectric devices were applied to provide the heat pumping. The results showed that the system could provide airflows of up to 168.7 m³/h with the revolving speed of 600 RPM, and maximum static pressure was up to 37 Pa. The system could supply the heating of up to 257.1 W with the coefficient of performance of up to 1.96. Comparisons were made between the revolving and stationary systems, and the results showed that the former increased the thermal performance by up to 10% in heating and up to 20% in cooling.

Keywords: revolving heat pipe; thermoelectric device; COP; fan performance

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1 INTRODUCTION

The awareness of the environmental protection, global warming and energy use in the built environment has encouraged scientists and engineers to seek novel heat pumping systems. Investigations have looked at the use of thermoelectric coolers (TECs) rather than the traditional vapour-compression heat pump systems to recover the thermal energy from the exhaust air from building and at the same time increase the indoor air quality [1–3]. This paper describes a newly developed system which mainly comprises of heat pipes and thermoelectric devices. Effective heat transfer to and from the thermoelectric modules can be achieved by the use of revolving heat pipes as both a heat exchanger and an air impeller [4]. Conventional cylindrical straight heat pipes without a wick were used and their un-finned sections were inserted into aluminium heat sinks. However, the limited interface between the un-finned part of heat pipe and heat sink restricted the further improvement of the heat transfer, therefore the thermal performance was low [3]. Increasing the contact area by using a thicker heat sink would result in a significant increase in rotating mass, with a larger thermal resistance. It would also require more energy to drive system.

This paper will propose to apply bent heat pipes to maximize the interface area between the heat sink and the evaporator/condenser sections of the heat pipes. Sintered copper powder was used as a wick to increase the heat transfer efficiency within the heat pipe [5, 6]. Testing was undertaken to establish both fan performance and the thermal performance of the system.

2 EXPERIMENTAL SETTING UP

To simplify the description of the system, it is defined that cold side of system is the part that attaches to the cold surfaces of TECs, whereas hot side is the one attaching to the hot surfaces of the TECs. In the cold side, the finned part of heat pipe worked as evaporator section, whereas, in the hot side, the finned part worked as a condenser section. Both smooth
parts were attached firmly within the slots of two heat sinks, respectively, between which the thermoelectric devices were sandwiched. The bent heat pipes were positioned on the hot and cold sides conversely one to another as shown in Figures 1 and 2. This was to capitalize on the centrifugal forces due to rotation which assists the condensate to flow back to the evaporator sections of heat pipes. This consequently caused a drop in fan performance on the hot side because of the smaller distance between the heat pipe and the centre of rotation. Consequently, additional fan blades were installed on the hot side to make sure that both sides could deliver the same or similar fan performance.

Eight pieces of thermoelectric device of UT8-12-40-RTV were used to generate the temperature difference. They absorb the heat from warm exhaust air through the bent heat pipes and heat sink on the TEC cold side, and then release the upgraded heat to the fresh air via a heat sink and bent heat pipes on the hot side. A DC power supply was used in the laboratory work to power the TECs. The system lends itself to the potential of being powered solely by photovoltaic without incurring transformer losses.

A Duct heater and an air-cooled condenser were used to simulate both inlet airflows. Two ducting subsystems with a damper on each were connected on both outlets in order to measure the airflow rate and static pressure. The location of measuring points for pressure can be referred to Gillott’s work [7]. The whole assembly of the system is shown in Figure 3.

3 EXPERIMENTAL RESULTS AND DISCUSSION

3.1 Fan performance
The fan performance test was carried out according to the British Standard [8]. This was done without any power supplied to the TECs. Different rotating speeds were achieved by a motor controller, PowerFlex 40 Drive. Different cases, listed in Table 1, were tested separately. Due to the limited space for blades on both sides, only straight blades were applied. The blades on both sides were placed with the same distance from central axis, and therefore on the hot side, there was more space for blades when compared with the cold side. The test using eight heat pipes with 32 blades on the hot side was undertaken only to investigate the fan performance.

Figure 1. Schematic diagram of the system.
Figures 4 and 5 show the characteristics of the fan with different numbers of blades on the hot and cold sides, respectively. The results show that the heat pipes with blades had better fan performance than those without blades. On the hot side, maximum flow rate increased by 105–138% when the rotating speed increased from 400 to 800 RPM with up to 32 straight blades; while the maximum static pressure increased by 233–477%. On the cold side with up to 16 straight blades, maximum flow rate and maximum static pressure increased by 34–67% and by 138–86.6%, respectively.

The results shown in Figures 4 and 5 suggest that the case of eight heat pipes with eight blades on the cold side can match the case of eight heat pipes with 16 blades on the hot side in terms of fan performance. The arrangements of heat pipes and straight blades are illustrated in Figures 6 and 7, and were used for the following thermal performance tests.

### 3.2 Revolving thermal performance

The thermal performance varies upon the rotating speeds, TEC power supply, inlet air conditions, and so on. The system was tested for rotating speeds of 300–600 RPM. The power supply for TEC could be adjusted between 0 and 300 W (0–19 V for voltage). The comfort temperature was chosen to range between 20 and 21°C for both heating and cooling modes [9]. For cooling mode, the temperature of simulated inlet airflow from outside was 28–32°C, whereas for heating mode, the temperature of cold air from outside was 10–16°C.

Coefficient of performance (COP) is used to indicate the thermal performance. It is the ratio of heating/cooling load to the electricity consumption by TECs. Over the range of the conditions, cooling COPs changed from 0.15 to 0.60, while cooling loads changed from 13.0 to 67.5 W (Figures 8 and 9). It can be seen that the more power input for TEC, the more cooling capacity it delivered, while the less COP it had. The maximum cooling capacity occurred when TEC power supply was 248.9 W (i.e. 19 V × 13.1 A). It increased only by 6.6–10.8% with increasing rotating speeds from 300 to 600 RPM.
Therefore, a lower rotating speed is desirable if the requirement of fan performance is satisfied.

From Figures 10 and 11, heating COPs varied from 1.0 to 1.96, and heating load was from 76.8 to 257.1 W. Similarly, the maximum heating load occurred when the TEC power supply was 248.9 W. Its change was <1% when rotating speeds were varied between 300 to 600 RPM, therefore the effect of rotating speeds on the maximum heating load can be ignored.

Both cooling and heating modes did not deliver good thermal performances in terms of COPs, especially when there was a higher level of the TEC power input. Manufacture and assembly of the system were problematic. Not all of the heat pipes had a strict 90° bend. This distortion caused the consequent problem in the assembly which in some cases caused inadequate thermal contact between the heat pipes and the heat sinks. However, this could be improved mechanically, and thermal resistance could have been reduced with application of thermal grease.

Revolving speed contributed little towards the improvement of the thermal performance when the speed was over 300 RPM. The heat transfer limits of heat pipes and thermal resistance between the heat sink and heat pipes were more important factors that affected the whole system's thermal performance. Rotational speeds largely impacted on fan performance.

3.3 Stationary case study and comparison
Tests for stationary conditions were carried out for a comparison. The structure of heat pipes and heat sinks remained the same, while the hollow cylinders were used instead of the fan casing in order to make sure the heat transfer between the air flow and the heat pipes took place effectively. Figure 12 shows the schematic diagram of cross-section of arrangement of heat pipes and cylinders. Figure 13 is the photograph of the test rig for the stationary case studies. The system was arranged...
vertically for testing. The stationary case study focused on the following conditions: TEC power input ranged between 0 and 300 W (0–19 V for voltage). Air flow rate was set up at the level of 58.93 m$^3$/h, which was equivalent to the value with rotating speed of 300 RPM. Inlet air temperature was 16$^\circ$C for heating, and 31$^\circ$C for cooling. Room temperature remained the same, i.e. 20–21$^\circ$C.

The results of heating loads, cooling loads and COPs in the stationary condition against TEC power input show the similar characteristics to those in the revolving cases. Comparisons for heating and cooling modes were made in Figures 14 and 15, and showed that the revolving system with bent heat pipes had a better thermal performance both in heating and in cooling modes. Under the testing conditions, the revolving systems improved the heating load and heating COP by up to 10%, and cooling load and cooling COP by up to 20%, respectively.

4 CONCLUSIONS

This paper investigates the performance of revolving thermoelectric heat pumping system utilizing bent heat pipes as heat exchangers. Laboratory experiments were undertaken including fan performance testing and thermal performance measurements. It can be concluded that the fan performance of the revolving heat pipe system was improved by applying fan blades. Straight blades were used during the experiments due to the consideration of space limits and easy assembly. Eight pieces of straight blades with eight heat pipes on the cold side delivered the similar fan performance with 16 straight blades and eight heat pipes on the hot side. The air handling capacity of the system was shown to reach up to 168.7 m$^3$/h and the static pressure could achieve up to 37 Pa when the rotating speed was kept under 600 RPM.
Figure 10. Heating load and COP against TEC power input.

Figure 11. Heating load and COP against revolving speed.

Figure 12. Schematic diagram of stationary structure.

Figure 13. Picture of stationary testing rig.
Experiments showed that this test rig with eight pieces of TECs (UT8-12-40-RTV) could deliver the cooling capacity of up to 67.5 W, while heating capacity up to 257.1 W. Cooling COP varied from 0.15 to 0.60, while heating COP increased up to 1.96.

Application of bent heat pipes can increase the interface between the heat sink and heat pipes. However, mechanical faults and poor assembly tolerances could be problematic and cause a reduction of thermal performance. This could be improved in the manufacturing process of the heat pipes.

For the same conditions, the revolving system showed it had a better thermal performance than the stationary system. The revolving system had an increased heating load and COP by up to 10% and cooling load and COP by up to 20%.

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