

Performance of revolving bent heat pipe heat pump system

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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 were applied and positioned oppositely as centrifugal forces worked. Extra normal fan blades were required to improve the fan performance. Tests of fan performance were carried out, followed by the thermal performance, within which eight pieces of thermoelectric devices were applied. The results showed that the system can handle airflow of up to $168.7 \text{ m}^3/\text{hr}$ with the revolving speed of 600 RPM, and maximum static pressure is up to 37 Pa. The system can supply the heat of up to 257.1 W with the coefficient of performance (COP) of up to 1.96.

Key words: heat pipe; thermoelectric device; heat pump

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1. Introduction

The awareness of the environmental protection, global warming and energy use for built environment introduced the novel heat pumping system using thermoelectric coolers (TEC) rather than the traditional air-compressed systems to recover the thermal energy from the exhaust air from building and increase the indoor air quality [1-3]. The newly developed system mainly comprises of heat pipes and thermoelectric device. The Effective heat transfer from/to the thermoelectric modules can be achieved by the use of revolving heat pipes as both a heat exchanger and an air impeller [4]. Normal cylindrical straight heat pipes without wick were used and their smooth parts were inserted into heat sinks. But the limited interface between the smooth 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 thick heat sink will cause the massive mass increase, which will store more thermal energy and therefore reduce thermal output. It also would require more power to drive the system.

This paper will propose to apply a bent heat pipe to maximize the interface area. Sintered copper powder is used as a wick to increase heat transfer efficiency within the heat pipe [5, 6]. Fan performance, followed by the thermal performance, will be investigated. The performance will be justified as a whole.

2.0 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 thermoelectric devices; while hot side is the one attaching to the hot surfaces of TECs. In the cold side, the finned part worked as evaporator section; while 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 inverted as shown in the Fig.1 and Fig. 2 because the centrifugal force assists the condensate to flow back to the evaporator section of heat pipes. This consequently caused the less fan performance in the hot side because of the

less distance from heat pipe to the centre revolving axe, unless some extra fan blades are installed in the hot side to make sure that both sides have the same or similar fan performance.

Eight pieces of thermoelectric device of UT8-12-40-RTV were used to generate the temperature difference. They abstract the heat from exhaust air through the bent heat pipes and heat sink on the cold side, and then release the upgraded heat to the fresh air via heat sink and bent heat pipes as well in hot side. A DC power supply was used in the laboratory work. It could be replaced by solar powered PV system.

A Duct heater and air-cooled condenser were used to simulate both inlet airflows. Two ducting subsystems with a damper for each were connected with 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 system was pictured as Fig.3.

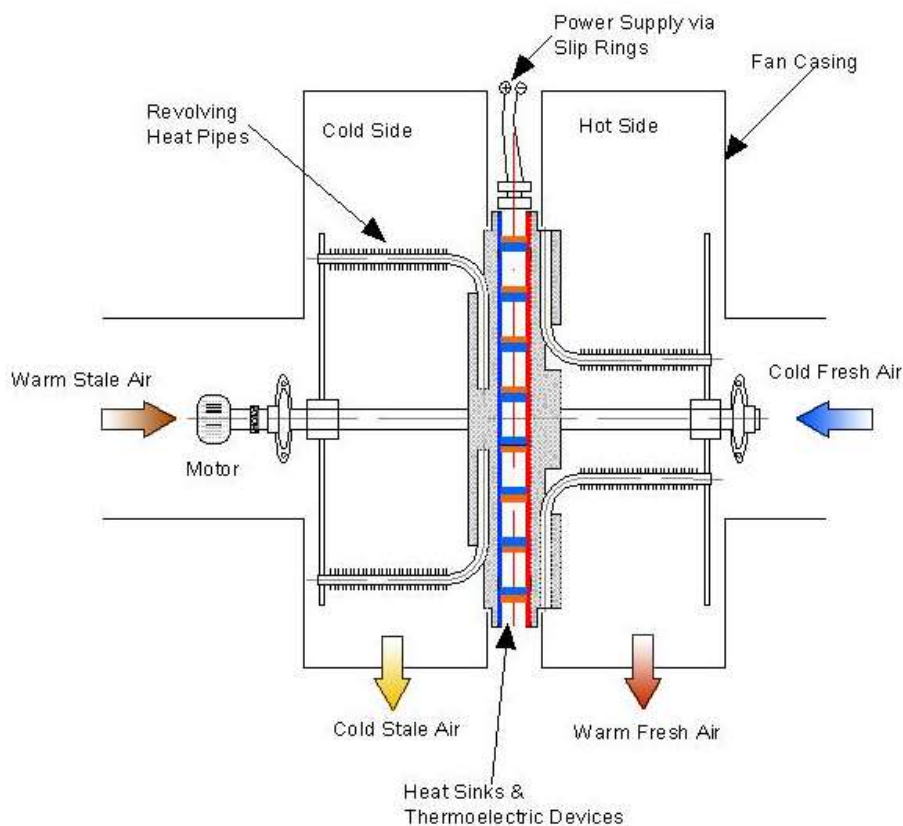


Fig. 1: Schematic diagram of system

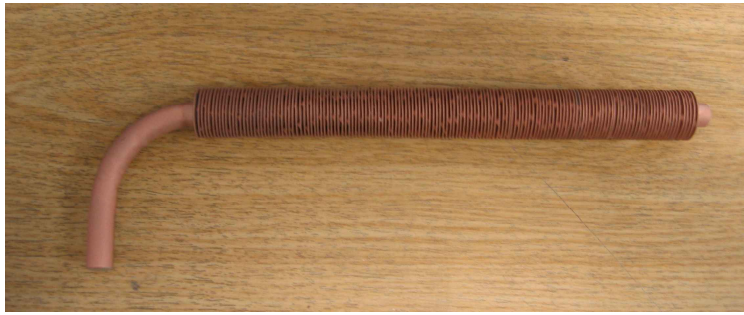


Fig. 2: Picture of bent heat pipe

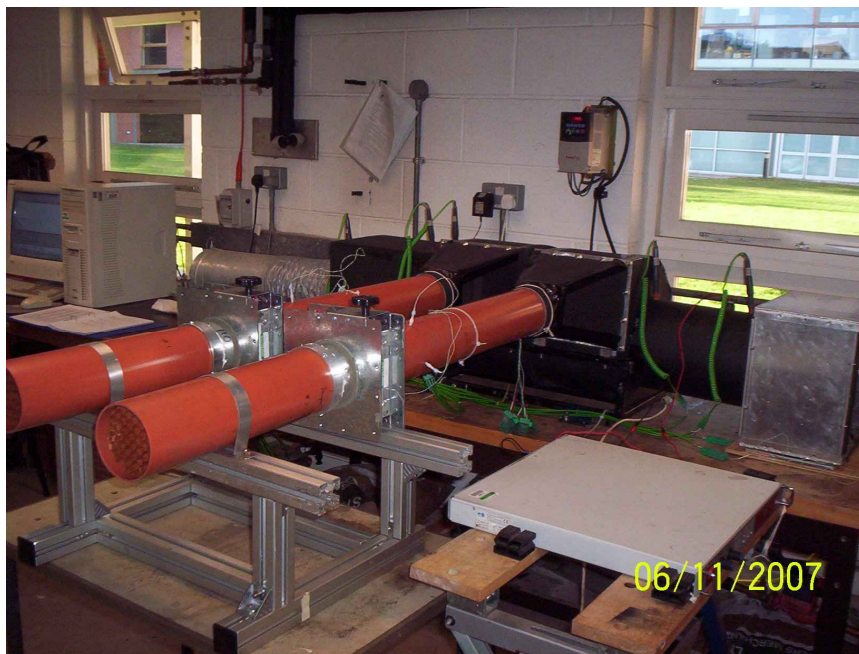


Fig. 3: Picture of test rig

3.0 Experimental results and Discussion

Fan performance was carried out according to the British Standard [8]. It can be done without power supply for TECs. Different rotating speed can be 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 axe, and therefore on hot side, there is

more space for blades compared to the case on the cold side. And an extra case of eight heat pipes with thirty-two blades on hot side only was tested to investigate the fan performance.

Table 1: Cases for fan performance test

Cases	Cold Side	Hot Side
8 heat pipes only	√	√
8 heat pipes with 8 straight blades	√	√
8 heat pipes with 16 straight blades	√	√
8 heat pipes with 32 straight blades		√

Fig.4 and Fig. 5 show the fan characteristics with different numbers of blades on hot and cold sides respectively. The results show that cases of heat pipes with blades have better fan performance than those without blades. On hot side, maximum flow rate increases by 105—138% when rotating speed increases from 400 RPM to 800 RPM with up to 32 straight blades; while maximum static pressure increases by 2.33 – 4.77 times. On cold side with up to sixteen straight blades, maximum flow rate and maximum static pressure increase by 34 -- 67% and by 138 – 86.6 % respectively.

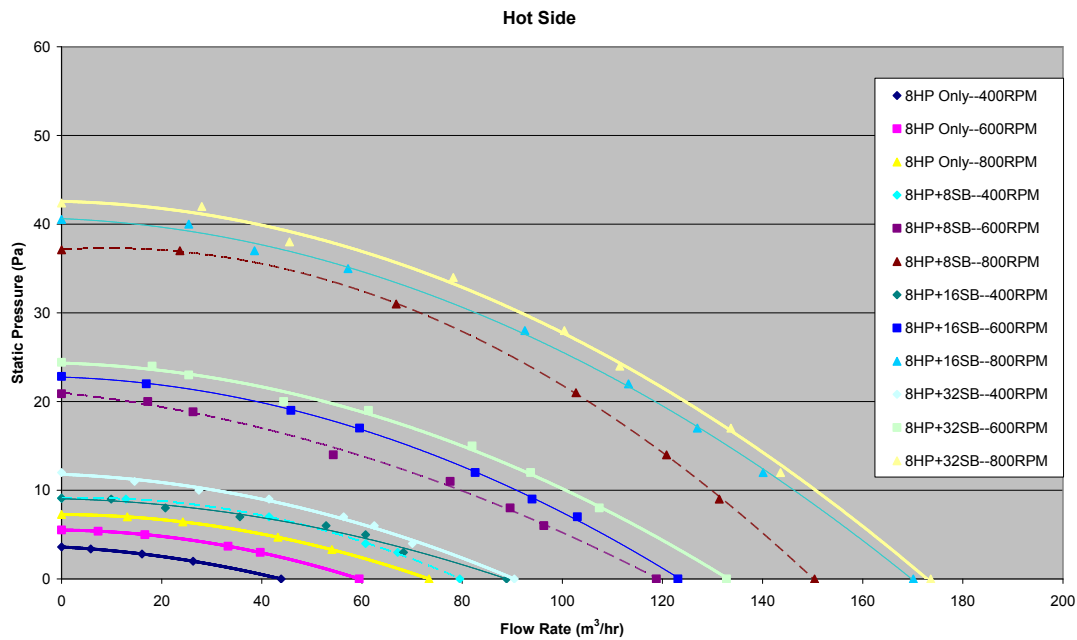


Fig. 4: Fan performance with different numbers of blades on hot side

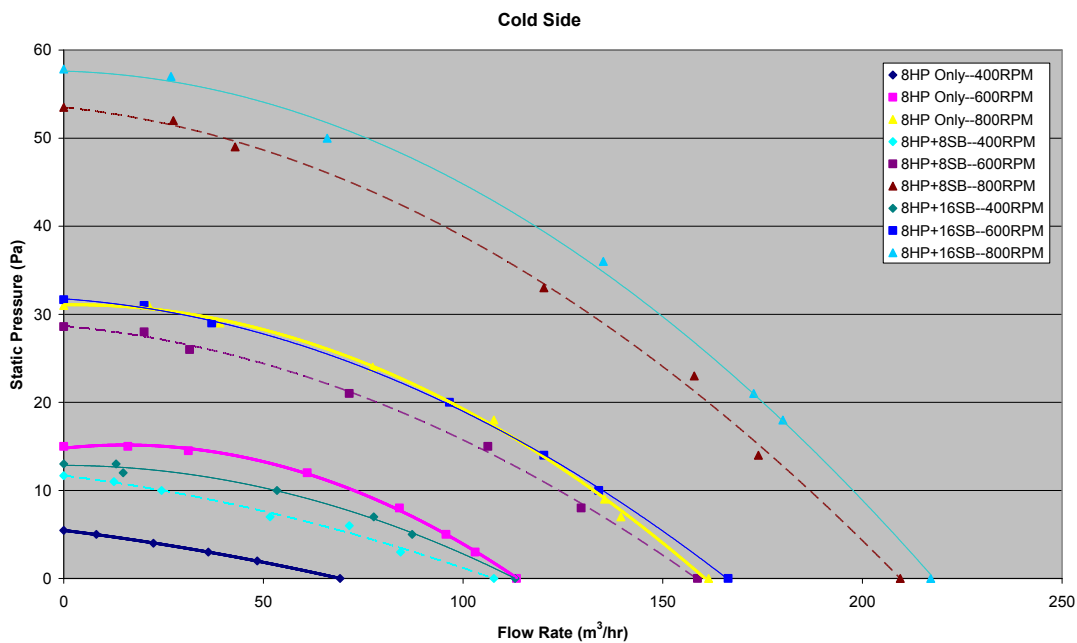


Fig.5: Fan performance with different numbers of blades on cold side

Compared between Fig.4 and Fig.5, it is suggested that the case of eight heat pipes with 8 blades on cold sides can match the case of eight heat pipes with sixteen blades on hot sides in

terms of fan performance. The arrangements of heat pipes and straight blades are illustrated in Fig.6 and Fig.7 (CAD pictures), and will be used for following thermal performance tests.

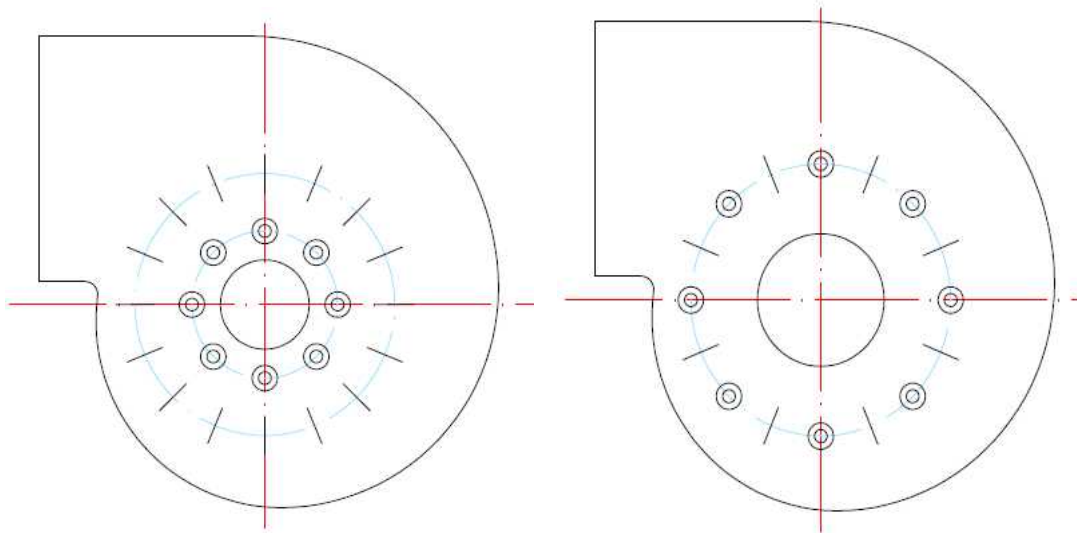


Fig. 6: Heat pipes and blades on hot side Fig.7: Heat pipes and blades on cold side

The thermal performance varies upon the rotating speeds, TEC power supply, inlet air conditions, and so on. It was tested under the rotating speed of 300-600 RPM. The power supply for TEC can be adjusted between 0-300 W (0-19 V for voltage). The comfort temperature is chosen to range between 20 °C and 21 °C for both heating and cooling [9]. For cooling mode, the temperature of simulated inlet airflow from hot outside is 28-32 °C; while for heating mode, the temperature of cold air from outside is 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 change from 0.15 to 0.60, while cooling loads change from 13.0 W to 67.5 W (Fig.8 and Fig.9). It can be seen that the more power input for TEC, the more cooling capacity it delivers, while the less COP it has. The maximum cooling capacity occurs when TEC power supply is 248.9 W, (i.e. 19 V x 13.1 A). It increases only by 6.6%-10.8% with increasing rotating speeds from 300 RPM to 600 RPM. So lower rotating speed is desirable if the requirement of fan performance is satisfied.

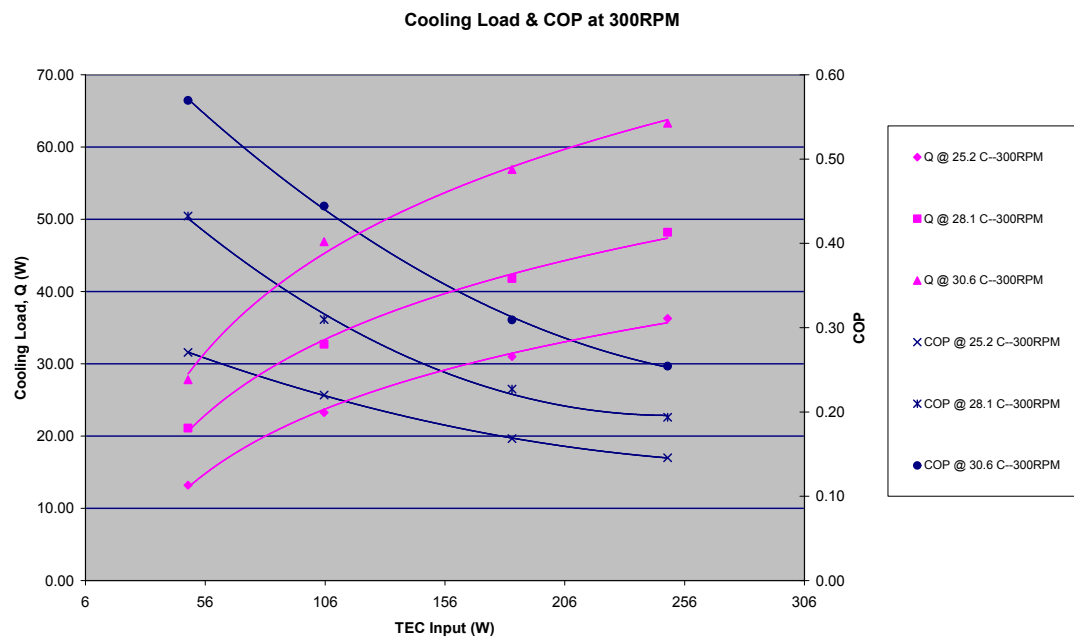


Fig.8 Cooling load and COP against TEC power input

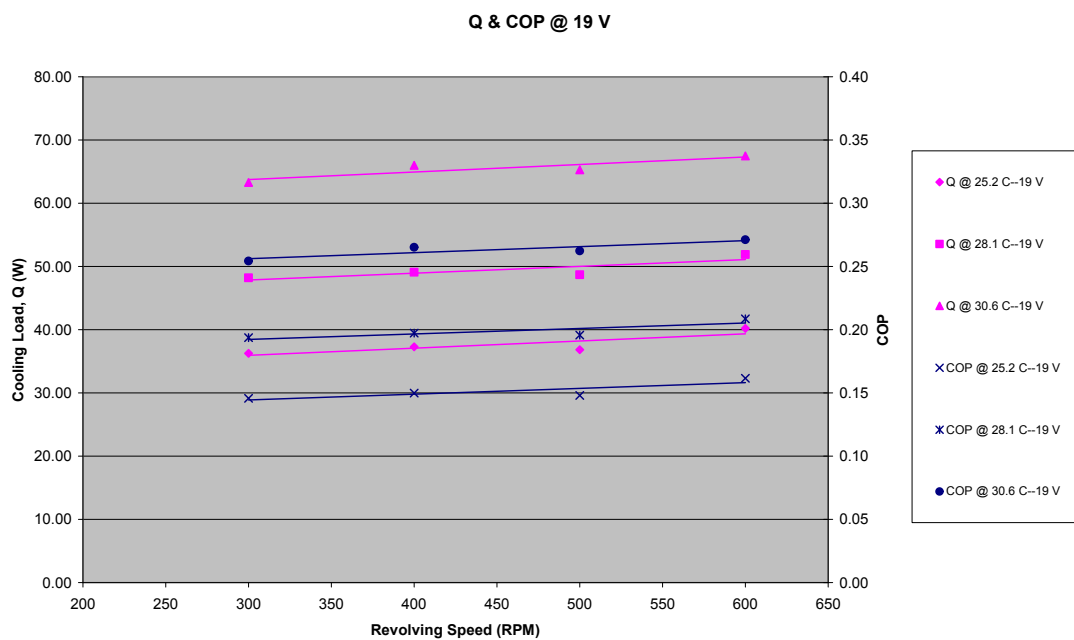


Fig.9 Cooling load and COP against revolving speed

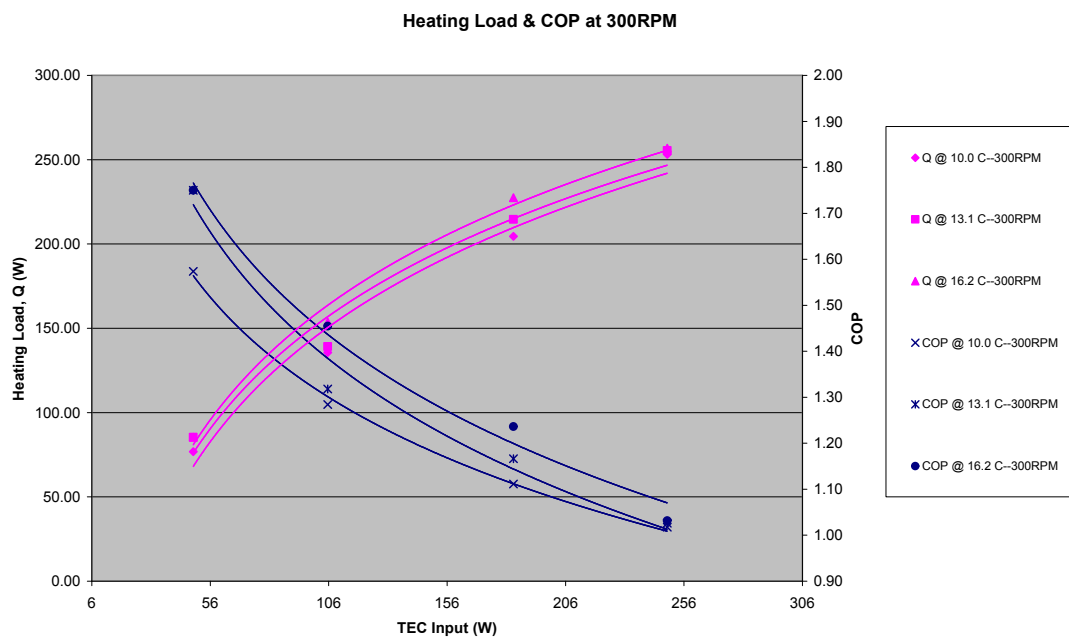


Fig.10 Heating load and COP against TEC power input

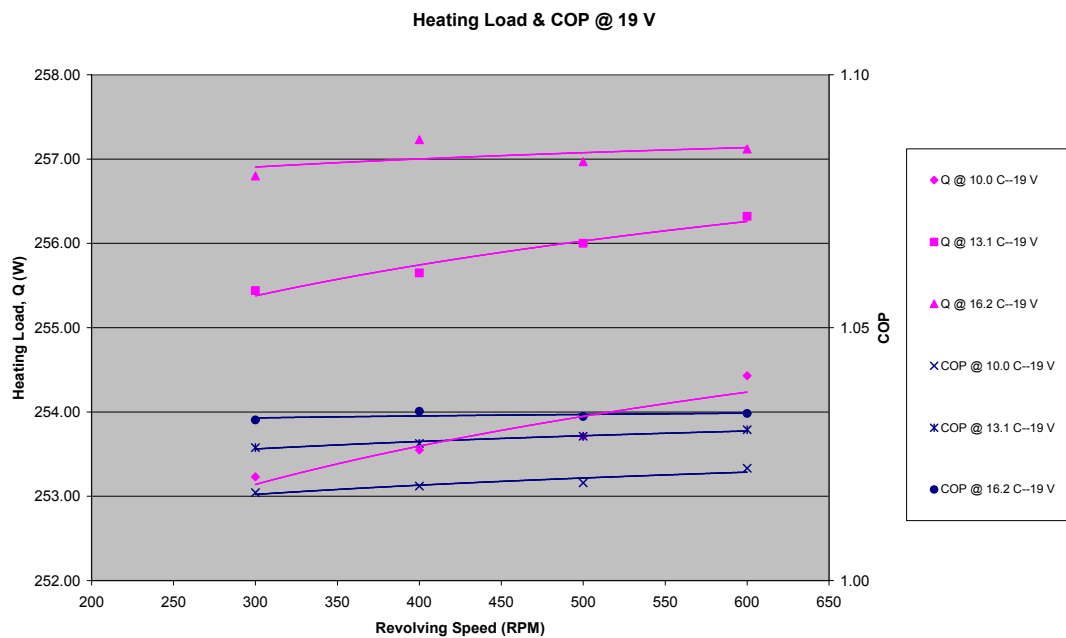


Fig.11 Heating load and COP against revolving speed

From Fig.10 and Fig.11, heating COPs vary from 1.0 to 1.96, and heating load is from 76.8 W to 257.1 W. Similarly, the maximum heating load occurs when TEC power supply is 248.9 W. its change is less than 1% when rotating speeds is from 300 RPM to 600RPM, therefore the effect of rotating speeds on the maximum heating load can be ignored.

Both cooling and heating modes don't deliver the good thermal performances in terms of COPs, especially when in the higher level of the TEC power input. It is because that not all of the heat pipes have a strict 90 degree bent. This distortion caused the consequent problem in assembly. However, it can be improved mechanically, and thermal resistance can be reduced with application of thermal grease.

Revolving speed contributes little toward the improvement of the thermal performance when the speed is over 300 RPM. Heat transfer limits of heat pipes and thermal resistance between the heat sink and heat pipes are more important factors which affect the whole thermal performance. Revolving speed is mainly required by the demand of fan performance.

4.0 Conclusion

This paper investigates the performance of revolving heat pumping system by using TEC and bent heat pipes. Laboratory experiments were involved including fan performance testing and thermal performance measurements. It can be drawn that:

Fan performance of revolving heat pipe system can be improved by inserted some fan blades. Straight blades were used during the experiments under the consideration of space limits and easy assembly. Eight pieces of straight blades with eight heat pipes on the cold side can deliver the similar fan performance with sixteen straight blades and eight heat pipes on the hot side. The air handling capacity can reach up to 168.7 m³/hr and static pressure can be up to 37 Pa when the rotating speed is under 600 RPM.

Experiments showed that this testing rig with eight pieces of TECs (UT8-12-40-RTV) can deliver the cooling capacity of up to 67.5 W, while heating capacity up to 257.1 W. Cooling COP varies from 0.15 to 0.60, while heating COP changes up to 1.96.

Application of bent heat pipes can increase the interface between the heat sink and heat pipes. However, mechanical faults or tolerance could cause the poor thermal performance. It can be improved by setting up a higher standard for the products.

Acknowledgement

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