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Application of the heat pipe to enhance the performance of the vapor compression refrigeration system

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ABSTRACT

This paper presents an application of the heat pipe to enhance the performance of the air conditioner. The study is done in two steps. First, the effect of pertinent parameters on the heat transfer rate of the heat pipe set is investigated. Then the heat pipe set is installed in the split-type air conditioner and tested in the actual condition. The heat pipe set consists of a heat pipe, holder, and plate fins. The length of the heat pipe is 300 mm. The working fluid inside the heat pipe is deionized water. Two different geometries of holder which are A-geometry and B-geometry are used in the study. Both holders are made of copper. The numbers of heat pipe in each set are 2, 4 and 6. The experimental results show that the maximum heat transfer rate obtained from the heat pipe set is about 240 W at the air velocity of 5 m/s and the heater surface temperature of 70 °C. The heat pipe set with A-geometry consisting of 6 heat pipes is the best configuration. However, this configuration provides the highest air-side pressure drop because of the highest velocity. The best heat pipe set is installed at the outlet of the compressor in the air conditioner with a cooling capacity of 9,000 BTU/hr. The experimental results show that the energy efficiency ratios (EER) of the air conditioners with heat pipe set are slightly higher than those of the conventional air conditioner. The EER of air conditioners with copper holder of heat pipe increases about 3.11%. The results from the present study are important for enhancing the performance of the vapor compression refrigeration system.

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1. Introduction

Nowadays, the vapor compression refrigeration system is widely used in numerous applications such as air conditioner, refrigerator, cooling equipment, ice maker, etc. The air conditioner is one of the vapor compression refrigeration systems that are important for the quality of human life. The purpose of the air conditioner is to control the air condition and make it suitable for office and residential purposes. In addition, air conditioners are used in the industrial sector such as the electronic parts manufacturing industry, textile industry and publishing industry. At present, many air conditioners are in use worldwide and their use is increasing. That means the consumption of energy by air conditioners is on the rise. An air conditioner establishes the highest energy consumption when compared with other electronic household devices [1]. Therefore, the improvement of the air conditioner in terms of its performance is needed. From the existing research, the researchers have presented many enhancement techniques. One of them is the application of a heat pipe to enhance the performance of air conditioning systems. The heat pipe is a kind of heat exchanger with high ability for heat transfer, no electricity input and no moving parts. It can work by phase change of working fluid inside the pipe. With this feature, the heat pipe is applied to increase the performance and reduce the energy consumption of air conditioning systems in various forms. The research that relates to the application of heat pipe in an air conditioner can be classified into two groups: for dehumidifying and for heat recovery. The heat pipe for dehumidifying can be used in air handling unit [2–4]. In 1996, Wu et al. [5] reported on the heat pipe for dehumidifying the air. They found that the cooling capacity of the cooling coil increased 20–32.7%. In 2007, Wan et al. [6] studied the effect of heat pipe on energy consumption of the air conditioning system. They concluded that the relative humidity reduction by heat pipe could reduce the energy consumption of air conditioners. In 2007, Yau [7] investigated dry-bulb temperature, relative humidity and air velocity on sensible heat ratio (SHR). The heat pipe type in his study was the thermosyphon type. He also reported that heat pipe could enhance dehumidification in the air conditioning system. In 2008 Alklaibi [8] studied the effect of the heat pipe location in the air conditioning system on the system's performance. The best location of the heat pipe that provided the best COP was installed astride the cooling coil. In 2016, Guo et al. [9] investigated the pump-assisted separate heat pipe for dehumidification. The heat pipe set was installed at the cooling coil. They found that the heat pipe set can reduce the relative humidity by 30%. The application of heat pipe could reduce the moisture and energy consumption for replacing the electronic heater in the reheating air

Nomenclature

C_P	specific heat (kJ kg^{-1} K^{-1})
COP	coefficient of performance
D	outside diameter of heat pipe (mm)
EER	energy efficiency ratio (Btu/hr/W)
I	current (A)
L	length of heat pipe (mm)
$\dot{m}$	mass flow rate (kg s^{-1})
N	number of heat pipe
$\dot{Q}$	heat transfer rate (W)
T	temperature (°C)
V	voltage (V)
v	velocity (m s^{-1})
$\dot{W}$	power (W)
Greek symbols	
φ	cooling capacity (Btu/hr)
$\cos\theta$	power factor
υ	kinematic viscosity (m^2.s^{-1})
ΔP	pressure drop (Pa)
Subscripts	
a	air
avg	average
elect	electrical
i	inlet
in	input
max	maximum
o	outlet
out	output
ref	refrigerant
sur	heater surface

Table 1
Experimental conditions.

Experimental parameter	Specification
Temperature of heater surface (°C)	60, 65, 70
Air inlet temperature (°C)	35
Frontal air velocity (m s^{-1})	2, 3, 4, 5
Number of heat pipe	2, 4, 6
Type of material	Copper
Type of the holder geometries	A-geometry, B-geometry

Table 2
Accuracy of measured quantities.

Parameter	Accuracy
Temperature of heater surface (°C)	± 0.1
Frontal air velocity (%)	± 3.3
Pressure drop (%)	±0.5

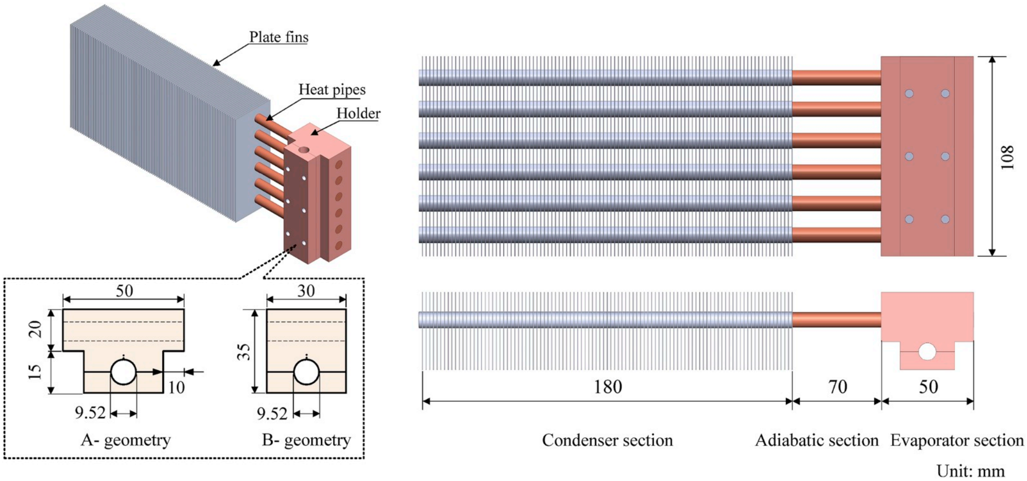

Fig. 1. Schematic diagram of the test section.

process. In 2019, Barrak et al. [10] used the oscillating heat pipe to enhance the dehumidification capability of the cooling coil. The result showed that the dehumidification capacity was higher with enhancement ratio of 17–25%. In addition, the heat pipe was also used in the energy recovery application [11–22]. In the case of the heat recovery of the exhaust air to fresh air, the heat pipe was also used to exchange heat between hot and cold air. In 2013, Ahmadzadehtalatapeh [23] used software to investigate energy saving by using heat pipe for heat recovery in the air-handling units responsible for pre-cooling and reheating of air between cooling coils. In 2019, Yang et al. [24] applied the pulsating heat pipe for energy recovery from exhausted air. The results showed that the overall effectiveness of the heat exchanger was in the range of about 30% and 50%, depending on the fresh air temperature, installation angle, and the speed of air. Moreover, the heat pipe could also be used in the split-type air conditioner. In 2011, Supirattanakul et al. [25] investigated the closed loop oscillating heat pipe with check valves for a cooling coil unit. The results showed that the energy consumption of an air conditioning system with a closed-loop heat pipe with check valves was less than a conventional air conditioning system. In 2019, Guanghui et al. [26] investigated the heat pipe heat sink for cooling the controller in the condenser. There were two types of heat pipe heat sink (L-type and U-type). The result shows that the L-type heat pipe was better than the U-type. It could reduce the average temperatures of small-power chips and large-power chips by 10.0 °C and 5.9 °C, respectively.

According to these works, most researchers applied heat pipes to increase the dehumidification capacity and heat recovery of the air conditioning system. However, the investigations of the heat pipe for the condensing unit in the vapor compression refrigeration system are less. In this research, an experimental study of heat pipe application for enhancing the performance of the vapor compression refrigeration system is carried out. This research is divided into two steps. Firstly, the effect of related parameters on the heat transfer rate of a heat pipe set is investigated. After that, the heat pipe set is installed in the condensing unit of the split-type air conditioner and tested under the condition of the test room ISO 5151: 2010.

Table 3
Details of the heat pipe.

Item	Specification
Outside diameter of heat pipe (mm)	8
Length of heat pipe (mm)	300
Inside tube	
Inner surface	Groove
Diameter of wire in the wick (mm)	0.08
Number of wire in the wick	210
Working Fluid in heat pipe, DI Water (cc)	1.21–1.31

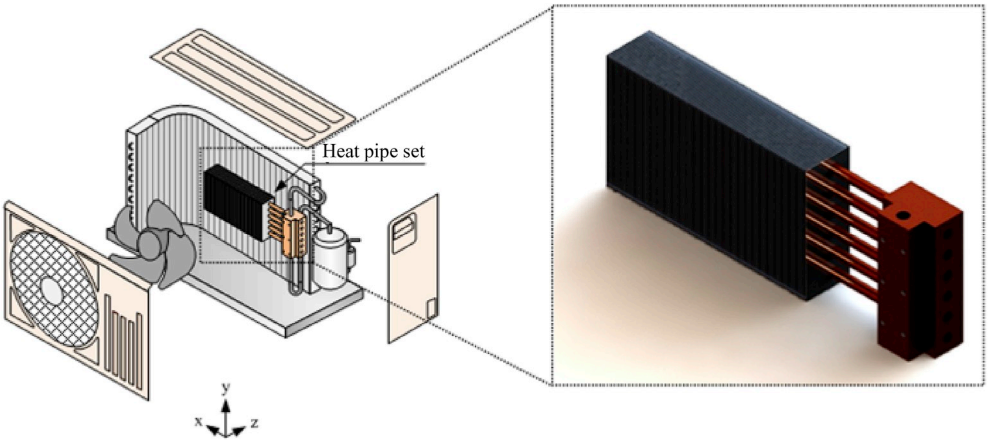

Fig. 2. The position of heat pipes in the air conditioner.

2. Experimental apparatus

2.1. Description of the experimental test loop

The experimental apparatus described in Srisomba et al. [27] is used in the present study. The apparatus consists of three main parts: test section, wind tunnel and data acquisition system. The air flow inside the wind tunnel is driven by an axial flow fan. The velocity of air is controlled by variable speed fan with an inverter. After that, the air flows through the heater, which is used to control the inlet air temperature. The orifice meter based on the ISO 5167-1 international standard (1991) is used to measure pressure drop, with the volume flow rate of air calculated from the measured pressure drop. The pressure drop across the orifice meter and test section is measured by a digital manometer. The thermocouples are installed to measure the average air temperature at the inlet and outlet of the test section. All data are recorded at a steady state. The details of the experimental conditions and accuracy of measured quantities are shown in Tables 1 and 2, respectively.

2.2. Description of the test section

In this study, the test section consists of three parts: holder, heat pipes and plate fins as shown in Fig. 1. The holder is made of copper, which is studied on two different geometries as shown in Fig. 1. It is used for holding the heat pipe with a heater. The rod heater is used as a heat source, which is controlled by the AC power supply controller (TDGC2-3 kVA capacity: 3000 VA, Max 12 A). For the heat pipe, it is made of copper with an outside diameter of 8 mm and a length of 300 mm. The details of the heat pipe are presented in Table 3. For the inside of the heat pipe, the working fluid is deionized water (DI Water). The type of wick is a composite wick which is the combination of grooved tube and copper wire. The heat pipe can be divided into three sections: evaporator, adiabatic and condenser sections. In the evaporator section, the heat pipes are inserted into the holder for an exchange of heat between the holder and heat pipes. The heat is transfered from the rod heater to the holder and heat pipe and is then rejected through plate fins. The plate fins that enhance the heat transfer between the air and heat pipe are made of stainless steel. The heat transfer area of the plate fin is fixed. T-type thermocouples with a diameter of 0.5 mm are installed in the holder between the heater and heat pipe to measure the temperature gradient used to calculate the temperature of heater surface.

Table 4
Indoor and outdoor air conditions.

Item	Dry bulb temperature (°C)	Wet bulb temperature (°C)
Indoor	27 ± 0.5	19 ± 0.3
Outdoor	35 ± 0.5	24 ± 0.3

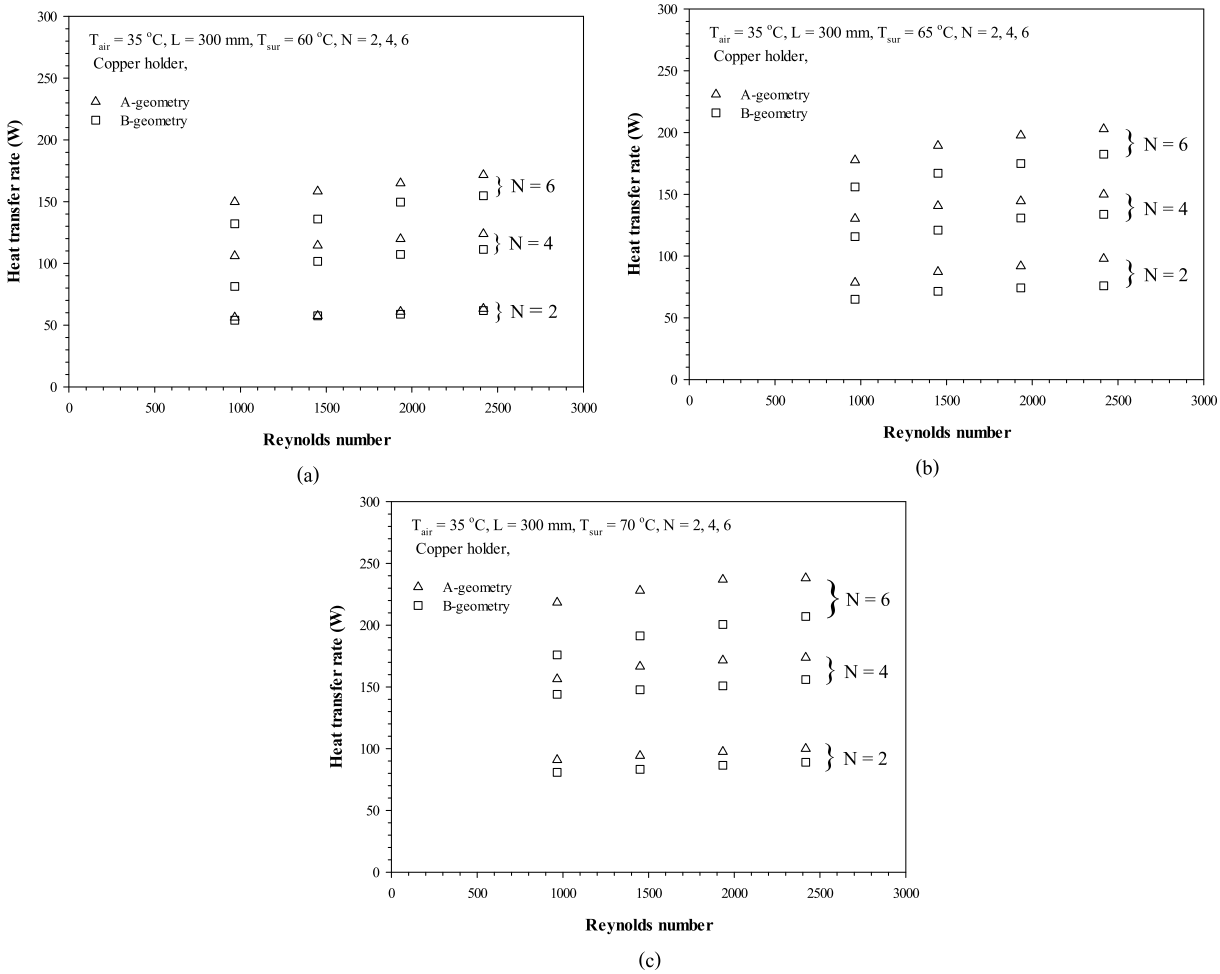

Fig. 3. Effect of holder geometries and number of heat pipes on the heat transfer rate.

2.3. *Heat pipe set with commercial air conditioner*

The best heat pipe set is installed at the outlet of the compressor in the air conditioner with a cooling capacity of 9,000 BTU/hr. The installation of the heat pipe set is shown in Fig. 2. The performance of the conventional air conditioner and the air conditioner with a heat pipe set is compared under the condition of ISO 5151: 2010. The conditions of air temperature in this test are shown in Table 4. The temperature of the refrigerant at the outlet of the compressor, heat pipe set, and condensing unit are measured by T-type thermocouples. The pressures of the refrigerant at high and low pressure sides are measured by pressure gauges. The total cooling capacity and total power input are used to calculate the energy efficiency ratio by Eq. (5).

3. Data reduction

3.1. *Heat transfer rate*

The heat transfer rate obtained from AC power supply can be calculated as follows:

$$\dot{Q}_{elect} = VI\cos\theta \quad (1)$$

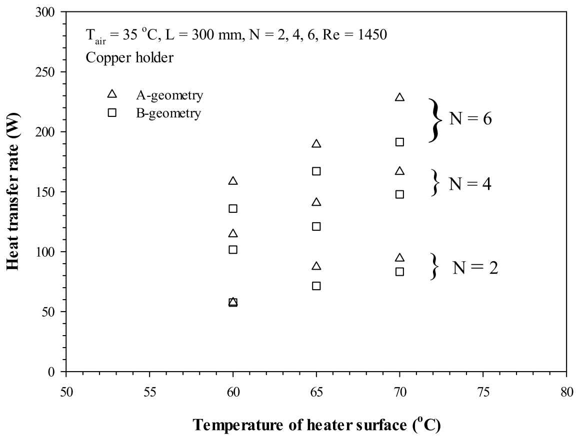

Fig. 4. Effect of temperature of heater surface on the heat transfer rate.

The heat transfer rate received by the air can be calculated from:

$$\dot{Q}_a = \dot{m}_a C_{p,a}(T_{a,o} - T_{a,i}) \quad (2)$$

The average heat transfer rate is determined from

$$\dot{Q}_{avg} = \frac{\dot{Q}_{elect} + \dot{Q}_a}{2} \quad (3)$$

The Reynolds number (Re) of air can be calculated as follows:

$$Re = \frac{v_{a,max} D}{\upsilon_a} \quad (4)$$

3.2. Performance of air conditioner

The performance of the air conditioner can be expressed in terms of the energy efficiency ratio (EER) and coefficient of performance (COP) which are the ratio of total cooling capacity and total power input.

$$EER = \frac{\varphi}{\dot{W}_{in}} \quad (5)$$

$$COP = \frac{EER}{3.412} \quad (6)$$

4. Results and discussion

To validate the experimental apparatus and accuracy of results, it was referred to the energy balance, which shows the comparison of heat transfer rates between the electrical heat supplied and the air-side heat absorbed which were calculated by Eqs. (1) and (2), respectively. The comparison results show that most of the data points are within ±10%. The experimental uncertainty of heat transfer rate, air-side pressure drop and EER are ±8.5, ±4.7 and ± 7.0%, respectively.

The heat pipe set for thermal performance improvement is investigated with two different holders and three different numbers of the heat pipe.

4.1. Effect of holder geometries and number of heat pipes on the heat transfer rate

The effects of holder geometries and number of heat pipes on heat transfer rate are presented in Fig. 3. The data show the relationship between the Reynolds number and the heat transfer rate at two different geometries of the holder. The experiment is conducted under the conditions of inlet air temperature of 35 °C and the heat pipe lengths of 300 mm, and the numbers of heat pipes in each test section are 2, 4 and 6. The experimental results show that the heat transfer rate increases by increasing Reynolds number. The heat transfer rate of the A-geometry holder is higher than that of the B-geometry holder because the heat transfer area of the A-Holder is larger than that of the B-Holder. However, the mass of A-Holder (2.1 kg) is larger than that of the B-Holder (1.7 kg). Fig. 3 also shows the heat transfer rate with a different number of heat pipes. Six pieces of heat pipe demonstrate the best heat transfer rate because more heat pipes can absorb more heat. Four pieces is the second place and 2 pieces is the last place in terms of the heat transfer rate. At the heater surface temperature = 60 °C (Fig. 3a), the heat transfer rates of 2 pieces of both holders are the same. Then, the different heat

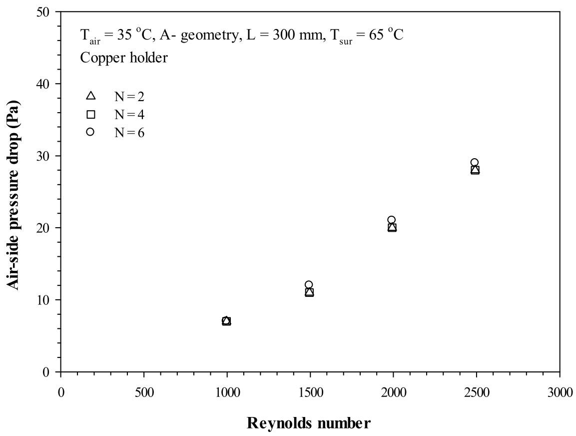

Fig. 5. Effect of number of heat pipes on the air-side pressure drop.

Table 5
Comparison between air conditioning systems with heat pipe set and conventional system.

Parameter	Conventional air conditioner	Air conditioner with heat pipe	
		1 set	2 set
Power input (W)	768	767	758
Total of cooling capacity (Btu/hr)	8854.2	8988	9010.6
EER (Btu/hr/W)	11.53	11.72	11.89
COP	3.37	3.43	3.48
Increasing of EER (%)	0	1.65	3.12

transfer rate between both holders of each number of heat pipes can be clearly seen. However, when the heater surface temperature is increased, the heat transfer rate differences between both holders always appear. Apparently, the holder geometries and number of the heat pipe are the key for heat transfer enhancement.

4.2. Effect of temperature of heater surface on the heat transfer rate

Fig. 4 presents the relationship between the temperature of the heater surface and the heat transfer rate at two different geometries of the holder. The experiment is conducted under the following conditions: the number of test section in each set are 2, 4 and 6, inlet air temperature of 35 °C, Reynolds number is 1450 and the heat pipes length is 300 mm. The results show that the heat transfer rate increases when the temperature of heater surface increases. The increase in the temperature difference between the air and the surface results in the enhancement of the heat transfer rate. It was also found that the A-geometry of the holder and 6 pieces of heat pipe also give the maximum heat transfer rate.

4.3. Effect of number of heat pipes on the air-side pressure drop

The air-side pressure drop is a parameter used for design of cooling fan in the condensing unit. Fig. 5 shows the relationship between the Reynolds number and air-side pressure drop at 2, 4, and 6 of the heat pipe numbers. The experiment is conducted at the heater surface temperature of 65 °C, A-geometry, heat pipe lengths of 300 mm and an inlet air temperature of 35 °C. The experimental results show that the air-side pressure drop increases by an increment of the Reynolds number. It is found that the air-side pressure drop is not significantly different because the frontal areas of the heat pipe sets are not different.

4.4. The comparison between a conventional air conditioner and an air conditioner with the heat pipe

This topic presents the heat pipe set for improving the performance of the air conditioner. The best heat pipe set is installed at the outlet of the compressor in the air conditioner with the cooling capacity of 9,000 BTU/hr. The heat pipe set with A-geometry consisting of 6 heat pipes is the best configuration. This investigation is to compare the performance of the conventional air conditioner and an air conditioner with a heat pipe set. The results are shown in Table 5. The experimental results show that the cooling capacities of the air conditioners with a heat pipe set are slightly higher than those of the conventional air conditioner. The air conditioner with a heat pipe of 1 set and 2 sets can have an increased cooling capacity of 1.15% and 1.77%, respectively. The reason is that the heat pipe cools the refrigerant before entering the condenser. This results in the increase of subcooling degree of refrigerant exiting the condenser which also affects the cooling capacity of the evaporator.

The improvement of the cooling capacity affects the EER. Therefore, the EER of the air conditioner with a heat pipe of 1 set and 2 sets can increase by 1.65% and 3.12%, respectively.

5. Conclusion

This investigation focuses on the application of a heat pipe to enhance the performance of the vapor compression refrigeration system. The important experimental results are concluded as follows.

5.1. The heat transfer rate of heat pipe set

1. The Reynolds numbers, number of heat pipes, and temperature of the heater surface affect the increase in heat transfer rate.
2. The air velocity affects the increase of air-side pressure drop.
3. The maximum heat transfer rate of the heat pipe set is 240 W at an air velocity of 5 m/s and a temperature of heater surface of 70 °C.
4. The best configuration of the heat pipe set is 6 pieces of heat pipes with A-geometry made from copper.

5.2. The application of heat pipe for air conditioner

The energy efficiency ratio (EER) of the air conditioner with heat pipe sets can be increased. The heat pipe set can be applied for an improvement of the performance of the vapor compression refrigeration system.

Conflicts of interest

We would like to say that we and our institution don't have any conflict of interest and don't have any financial or other relationship with other people or organizations that may inappropriately influence the author's work.

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