Cooling-Heating System Using Thermoelectric Module and Parallel Flow Type Pulsating Heat Pipe

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ABSTRACT: The purpose of this study was to develop a cooler/heater using a thermoelectric module combined with a parallel flow type pulsating heat pipe with R-142b as a working fluid. The experiment was performed for 16 thermoelectric modules (6 A/15 V, size: 40×40×4 mm), varying design parameters of the heat pipe (inclination angle, working fluid charging ratio, etc.). Experimental results indicate that the optimum charging ratio and the inclination angle of the parallel flow type pulsating heat pipe were 30% by volume and 30°, respectively. The maximum cooler/heater capacity were 479 W (COP: 0.47) and 630 W (COP: 0.9), respectively.

Nomenclature

COP : coefficient of performance
I : current [A]
k : thermal conductivity [W/mK]
P : power [W]
Q_C : cooling quantity of heat [W]
Q_h : heating quantity of heat [W]
R : electric resistance [Ω]
V : voltage [V]

Greek symbols

α : Seebeck coefficient [V/K]
ΔT : temperature difference [K]
θ : inclination angle [°]
ϕ : diameter [mm]

Subscripts

c : cold side of thermoelectric
cal : calculated
exp : experimental
h : high side of thermoelectric
j : Joule effect
k : conduct
p : Peltier effect
w : water

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1. Introduction

Since James Prescott Joule and William Thomson find adiabatic expansion effect (Joule-Thomson Effect) by an experiment in 1845, refrigeration industry accomplished brilliant development over one century. But, development of refrigerating system based on compressor at recent times has reached at a stable state. For that reason, there is no increase of refrigerating efficiency (COP) without the use of CFCs/

HCFCs that is worth watching eagerly for last several decades. Because of the GWP (Global Warming Potential) and ODP (Ozone Depletion Potential) effects, the uses and production of CFCs, HCFCs have been limited according to Vienna (1985), Montreal (1987), Kyoto (1997) agreements. Therefore, it is required to develop environment-friendly refrigerant in several fields of present refrigerating industry, but highly satisfactory refrigerant usable in real conditions has not develop yet. So, refrigerating system of various methods like electric refrigeration, magnetic refrigeration, supersonic refrigeration etc. is developed. Among these, research about electronic refrigeration system is conducting in and out of Korea and application field is wide comparatively. Electronic refrigeration is more expensive than refrigerating system based on compressor and has constraints about making in larger size and efficiency, but precision temperature control is available and application to various field is promoted by reliability, low noise, miniaturization, conveyance etc.[1-2]

Seebeck in 1821 announced experimental result that showed potential difference that occurred on both end when applied heat on joint of two different conductor. When Jean Peltier passed current to different material in 1833, found that a different temperature occurs in the vicinity of connection. Since then, essence searching examination of Peltier effect by Lenz and correlation of Seebeck and Peltier coefficient by Thomson were proved, theory about heat pump and development took a triangular position by Altenkirchon in 1911.[3-4] Lately, research by Solomon[5] revealed measures involving improving of performance of refrigerating machine through change of material, shape of a thermoelement, structure. Miner and Majumdar[6] reported improved performance of thermoelement using transient current thermoelectric effect. And Huang et al.[7] announced that thermoelement can display maximum performance in case of enough thermolysis consists in high temperature side of thermoelement. Hong and Wendy[8] published investigation about thermoelement to remove heating value of Processor of notebook. Yoo et al.[9] examined closely maximum coefficient of performance and relation of temperature characteristic through theory analysis and an experiment about thermoelement and thermocouple cooling system.

Heat transfer by air side to become Heat Pumping in thermoelement is greatly influenced by convective heat transfer device; it needs extension of heating surface area to improve air convective heat transfer. Research that use thermoelement and radiating fin, water-cooling Jacket or heat pipe of wick style majority announced[10-12] but, research that apply Parallel Flow Type Pulsating Heat Pipe (PHP) to thermoelement is lacking real condition. Pulsating heat pipe shows that manufacture is easy and superior heat transfer performance more than general heat pipes that use wick.[13] If make use of aluminum micro channel heat exchanger that is used by condenser of air conditioner or automobile radiator by Pulsating Heat Pipes device that can improve heat transfer performance of air because congestion of heat exchanger heating surface area increases greatly.

Therefore, in this study, we designed an experimental apparatus by applying PHP (Pulsating heat pipe) to replace a traditional heat exchanger and conducted a test of performance of PHP. We also develop a thermoelement room cooler/heater applying thermoelement analysis and available experimental results.

2. Experimental methods and apparatus

2.1 The basic heat transfer characteristic and correlation

If ignore heat transfer for Thomson effect and side direction of thermoelement that is basic principle of thermoelement, the amount of

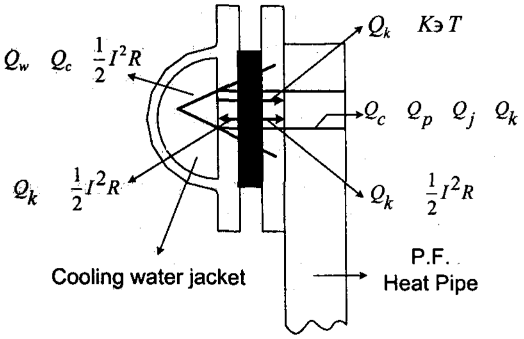


Fig. 1 Heat balance between thermoelectric module and PHP.

heat through thermoelement can appear with Eq. (1).

$$Q_c = \alpha T_c - \frac{I^2R}{2} - k\Delta T \qquad (1)$$

First clause is cooling caloric value Q_p by Peltier effect from right side areas, and second clause is heat transfer rate Q_j that invades to cold part by appropriate value in addiction half that happen in thermoelement. Third clause is conduction heat transfer rate Q_k by hot part T_h of thermoelement and temperature difference of cold part T_c. It can express removed caloric value with Eq. (2) because of in electrical special quality of thermoelement if set heat balance with Fig. 1 cooling ability Q_c and exothermic department Q_w of thermoelement.

$$Q_c = Q_w - \frac{I^2R}{2} \qquad (2)$$

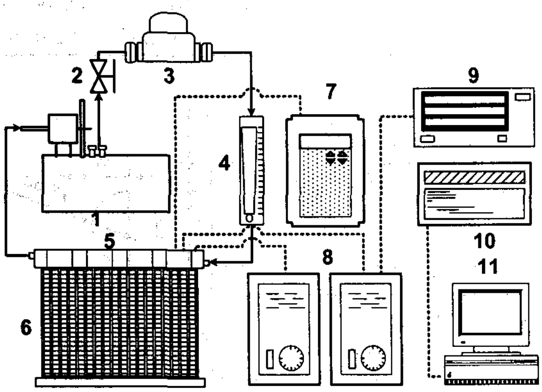
A heating application experiment can apply Eq. (3).

$$Q_h = Q_w + \frac{I^2R}{2} \qquad (3)$$

2.2 Experimental apparatus

The schematic diagram of experimental apparatus used in this study is shown in Fig. 2. Experimental apparatus is consisted of chilled/hot water circulating device and DC power supply device. The experiment are consisted of chilled/hot water circulating device and DC power supply device. The experiment are consisted of heat reservoir part, measurement part, controller part and test section part respectively, Heat reservoir part is thermostatic bath (Heto, HMT300) that is kept at a temperature of cooling water 283~313 K.

Data measurement part is consisted of a PC for Hybrid Record (Yokogawa, DR-230) and interface that measures multipoint temperature. Electric power is supplied by thermoelement and kept at a constant rate of by 5 A and 12 V using Digital Power Meter. Controlling part composed of needle valve and circulating pump to control flux of chilled/hot water that is sup-



1. Water circulation bath
2. Needle valve
3. Water pump
4. Flow meter
5. Thermoelectric module
6. Parallel flow pulsating heat pipe
7. Inverter
8. AC/DC convertor
9. Power meter
10. Data Logger
11. Personal computer

Fig. 2 Schematic diagram of experimental apparatus.

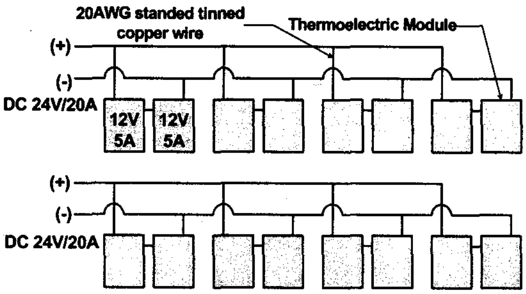


Fig. 3 The lead wires arrangement.

plied by 50~200 kg/h followed by fan and invert (LG, IS3) to control air flow capacity that pass test section part.

Maximum cooling and heating ability are 610 W and 1,100 W in PHP's case that is used by this research,[14] 53 W using thermoelement 16 test department compose.

As each thermoelement appears to Fig. 3, 2 thermoelement is serial connection to article 1, and article 4 parallel after elect 8 thermoelement by series and parallel to be connected DC of 24 V/20 A capacities all in mourning connect. Thermoelement is AceTec Co. Of used HMN6040 and details item of thermoelement appeared to Table 1. PHP produced itself making use of aluminum micro channel heat exchanger that consist of 39 aluminum mini channel Tube and 2 division header by instrument, shape and detail appeared Fig. 4 and Table 2 each. PHP's working fluid used refrigerant R-141b that have triple point and critical point do each 223 K and properties of matter of 398 K under atmospheric pressure.

Table 1 Specification of thermoelectric module (AceTec Co., HMN6040)

Thermoelectric module	
Maximum current, A	6.0
Maximum voltage, V	15.0
Maximum capacity, W	53
ΔT_{max}, K	69
Internal resistance, Ohm	2.1 ± 10%
Height, mm	4 ± 0.2
Unflatness and nonparallel	0.020

2.3 Experimental method

This experiment is divided by cooling and a heating experiment. To yield cooling caloric value of thermoelement T type thermocouples of 0.25 mm in cooling water entrance-exit's archetype department for cylinder direction 4 points attach. And attached 6 points for vertical direction and 5 points for horizontal direction on PHP's the surface for PHP's efficiency test. It

Table 2 Specification of PHP

Parallel flow type oscillating heat pipe	
Size (L × W × T)	450 × 325 × 20
Fin	Louvered plat fin
Fin pitch	750
Area of heat transfer (m^2)	2.8224
Working fluids	R-142b
Charging ratio (volumetric)	20, 30, 40%
Inside figuration of each tube	ϕ2 mm × 6

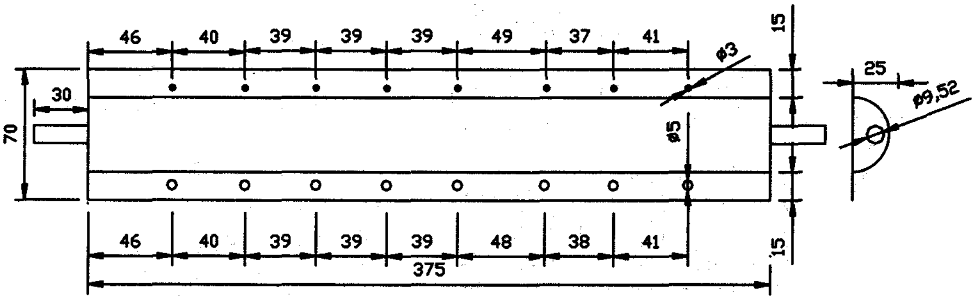


Fig. 4 Specification of water jacket.

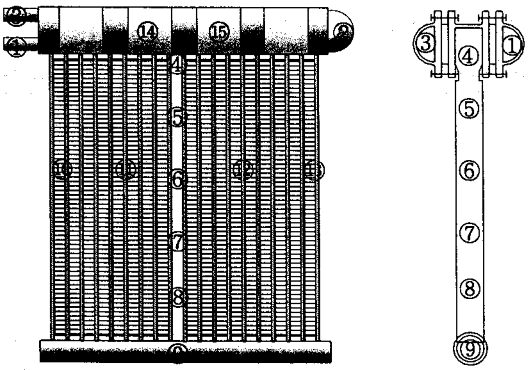


Fig. 5 Thermocouple locations.

attached thermocouples by each 1 point cold part and hot part of 4 places among 16 thermoelement to yield hot part of thermoelement and average temperature of cold part. Flux rate of cooling water that is flowed in test department regulated through number of rotations of circulating pump and Needle valve. Shape of water-cooled jacket that is installed in both exothermic department of thermoelement is same with Fig. 5.

3. Experimental results and discussion

3.1 Cooling capacity

In a cooling experiment used thermoelement and PHP, temperature and flux rate of cooling water is supplied at heat generation department from constant-temperature water tank changelessly by 283 K and 200 kg/h, to search cooling capacity of thermoelement by PHP's charge ratio of working fluid, temperature of cooling water entrance and frontal air velocity. This time, dry-bulb temperature 298±1 K and relative humidity 70±2%'s air being flowed in PHP's entrance experimentalize. Figure 6 displayed cooling ability of thermoelement by charging ratio. PHP's charge ratio 20% and 30% displayed similar cooling capacity but cooling ability is low about 10% in charge ratio 40%. Charge ratio means volume ratio here.

When is charge ratio 30% and tilt angle 30° in Fig. 7 display COP by cooling capacity. Coefficient of performance (COP) is defined with Eq. (4).

$$\mathrm{COP} = \frac{\text{Cooling Capacity}}{\text{Input Power}} = \frac{Q_c}{P} \tag{4}$$

While COP value increases, frontal air velocity 3.12 m/s decrease quantity. This can know in Eq. (1), because quantity of heat value Q_j that invade to cold part about increase portion of input electric power is proportional and increases in square of current value. Therefore, even if there is increase of some cooling capacity, it may have to consider again in effi-

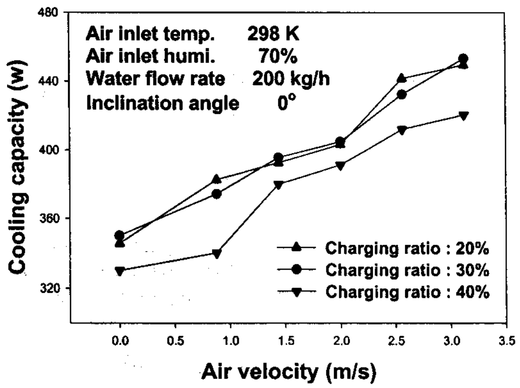


Fig. 6 Effect of charging ratio and air velocity on the cooling capacity.

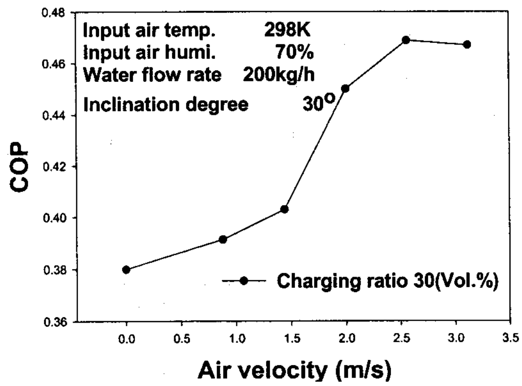


Fig. 7 Variation of COP with facial air velocity.

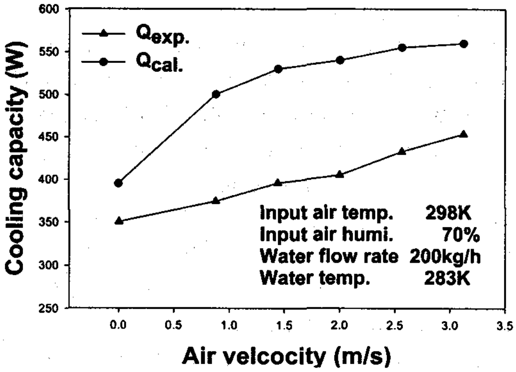


Fig. 8 Comparison of cooling capacity between theoretical and experimental values.

ciency side because COP decreases by high current value.

It compared theory value ($Q_{cal.}$) and experiment value ($Q_{exp.}$) in Fig. 8. Theory value is higher about 25% than experiment value. As this appears in Eq. (1), it thinks that permeate to moving cold part of heat value that Joule effect breeds first time. But, it was judged more than half that heat value permeates to cold part by temperature difference of quantity section and electrical resistance special quality of thermoelement actually. Figure 9 displayed heat transfer performance by temperature change of cooling water that is flowed in hot part of thermoelement. It showed tendency of decrease when temperature of cooling water that is flowed in an experiment department increases by 283 K to 303 K. But, cooling capacity decreased rapidly in 313 K. It must remove quantity of heat that thermoelement happens from hot part to operate effective certainly.

3.2 Heating capacity

Changing PHP's working fluid charge ratio and frontal air velocity, Achieved an experiment about heating capacity of thermoelement. When entrance air state condition is dry-bulb 293±1 K and relative humidity 60±2%, searched quantity of heat special quality of thermoelement and PHP. Figure 10 displayed heating capacity of thermoelement by PHP's working fluid (R-142b) charge ratio, and Optimum charge ratio showed according to experiment result that is 30%. Excess charge was problem in a cooling experiment. But, scarcity phenomenon of working fluid appeared in charge ratio 20% in a heating experiment.

Figure 11 expressed heating efficiency by frontal air velocity. COP was more than 0.85 more than frontal air velocity 2.0 m/s, and frontal air velocity 3.12 m/s expressed maximum value. Reason of heating efficiency of thermoelement is lower than that efficiency of general heater because Peltier effect occurs additionally except Joule effect. Figure 12 display-

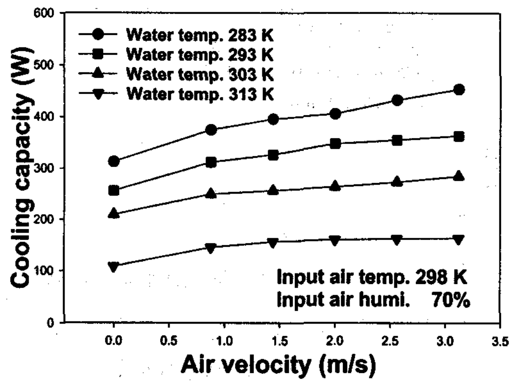


Fig. 9 Effect of cooling water temperature and air velocity on the cooling capacity.

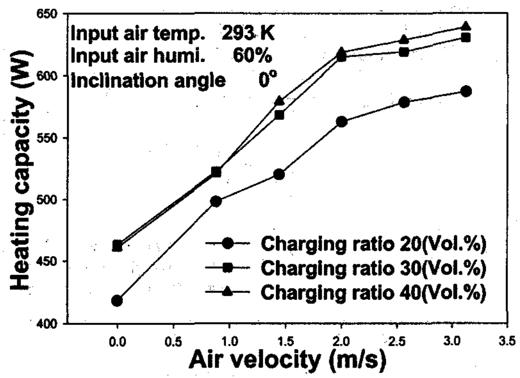


Fig. 10 Effect of charging ratio and air velocity on the heating capacity.

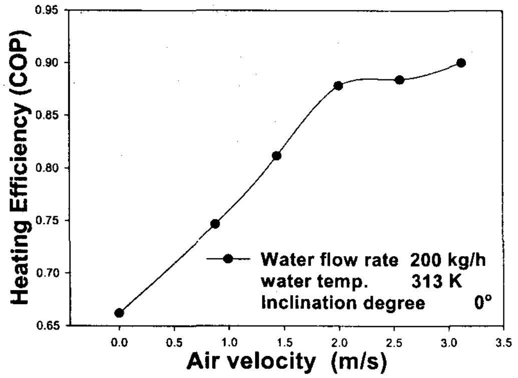


Fig. 11 Variation of COP with facial air velocity.

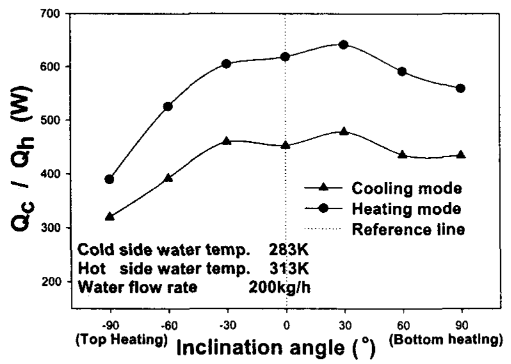


Fig. 12 Variation of cooling and heating capacity with inclination angle.

ed cooling and heating capacity by PHP's operation angle. Tilt angle does heating part by shaft If rotate for counter-clock wise, have the positive angle and If rotate for clockwise, have the negative angle (Upper portion of Fig. 5 is heating department). It could know that two ways are satiable tilt angle 0° (Horizontal mode), Followed 30°>0°>−30°>60°>90°>−60°>−90°'s tendency both cooling and heating.

4. Conclusions

In this paper, We got conclusion such as that achieve an experiment about cooling and heating using PHP that use thermoelement and working fluid R-142b.

(1) The parallel flow type pulsating heat pipe which was charged as 30 (Vol.%) showed better performance than 20 (Vol.%) and 40 (Vol.%) on cooling and heating mode.

(2) The maximum cooling capacity was 479 W (29.94 W/unit) and COP was measured 0.47.

(3) Heat Pumping action occurs though remove enough heat that produce temperature of cooling water in thermoelement in experiment by fluent. That is to say, radiant heat is important fluent in cooling ability of thermoelement from hot part.

(4) Heat transfer capacity of thermoelectric module was influenced by cooling water temperature and water flow rate but there was irrespective of thermal response.

(5) The highest efficiency of PHP was obtained while the satiable tilt angle was 30; however, horizontal mode was satisfied with cooling and heating simultaneously. The performance of the cooling and heating can be order according to the inclination angles 30°> 0°>−30°>60°>90°>−60°>−90°.

(6) The maximum heating capacity was 630 W (39.37 W/unit) and COP was 0.9.

Acknowledgement

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