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Development of Solar Concentrator Cooling System

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태양광 시스템의 냉각장치 개발

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Abstract To increase the efficiency of a solar module, the development of solar concentrator using a lens or reflection plate is being proceeded actively and the concentrator pursues the a concentration using a lens or an optical device of a concentration rate and designing as a solar tracking system. On the other hand, as the energy density being dissipated as a heat according to the concentration rate increases, the cares should be taken to cool the solar concentrator to prevent the lowering of efficiency of solar cell by the increasing temperature of the solar cell.
This study, researched and developed an economical concentrator module system using a low priced reflection optical device. A concentrator was used as a general module to increase the generation efficiency of the solar module and heat generated was emitted by the concentration through the cooling system.
To increase the efficiency of the solar concentrator, the cooling system was designed and manufactured. The features of the micro cooling system (MCS) are a natural circulation method by the capillary force, which does not require external power. By using the potential heat in the case of changing the fluid, it is available to realize high performance cooling. The 117W solar modules installed on the reflective plate and the cooling device in the cooling module and the module unit was not compared. The cooling device was installed in the module resulted in a 28% increase in power output.

요 약 태양광 모듈 효율의 증가를 위해 렌즈나 반사판 등을 이용한 집광 시스템 개발이 활발하게 진행되고 있으며, 집광장치는 일반적으로 렌즈를 사용하거나 고집속비의 광학장치를 이용하여 태양광 추적형으로 설계하여 고집속화를 추구하고 있다. 그러나 집속비에 비례하여 열로 소산되는 에너지 밀도가 증가하므로, 고집속에 따른 태양전지 온도상승에 의한 태양전지 효율 저하를 방지하기 위해 집광장치의 냉각에 유의해야 한다.
본 논문에서는 이러한 여러 가지 제약 조건을 피하여, 저가격의 반사형 광학장치를 이용한 경제적인 저집광형 태양광 모듈 시스템을 연구 개발하였다. 일반모듈에 저집광장치를 사용하여 태양광 모듈의 발전효율을 증대 시키면서 집광으로 인해 발생하는 열을 냉각장치를 통해 방출하였다.
제안된 저집광형 냉각장치(MCS, Micro Cooling System)의 특징은 모세관력에 의한 자연 순환 방식으로서 외부 동력원이 불필요하며, 유체 상변환시의 잠열을 이용함으로써 고성능 냉각 구현이 가능하다. 117W 태양광 모듈에 반사판을 설치하고 냉각장치가 있는 모듈과 냉각장치가 없는 모듈을 비교 하였다. 냉각장치를 설치한 모듈에서의 발전량이 28% 증가하였다.

Key Words : Concentrator, Micro channel, Cooling system, PV Tracking

1. INTRODUCTION

Regarding to solar module technology, the development of concentrator system using a lens or reflection plate to increase the efficiency of module is being proceeded actively and the concentrator pursues

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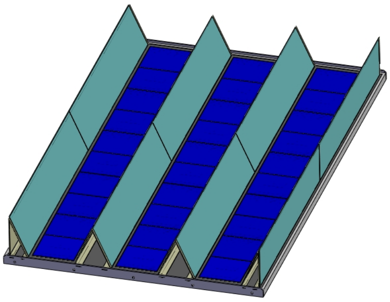
the high concentration by using a lens generator or optical device of high concentration rate and designing as a solar tracking system[1,2]. However, as the energy density being dissipated as a heat according to the concentration rate increases, the cares should be taken to the cooling of solar efficiency of solar cell by the temperature rising concentrator to prevent the lowering of solar cell.

In addition, the Si solar cell of crystal system covering more than 90% of the whole market is limited for the concentration due to the increase of series resistance. For single crystal solar cell, the dissipation of output due to the series resistance is proportional to the square ratio of concentration ratio. As the existing solar cell reduces the generation efficiency sharply when the ambient temperature rises, the device to reduce the temperature of solar cell is needed. To cool the temperature-rising solar panel, the air cooling method and water cooling method are used to reduce the temperature of cell. However, for concentration cell, as there are several problems occurred to lower the temperature as above, the cooling plate (copper plate) of cell is used for cooling but the effect is slight. The refrigerant embedded cooling system developed through this research maximized the cooling efficiency and we developed the cooling system that can be used semi-permanently by absorbing the heat of cell through the refrigerant having the fast heat absorption and then emitting the evaporated heat due to the heat absorption through micro structure and making it return to the refrigerant[3-6].

2. Configuration of Solar Concentrator PV System

In order to maximize the generation efficiency of solar cell, the sunlight should be concentrated and generally the reflection plate is used to increase the concentration rate of sunlight. In this study, we used the reflection plate to design the device with optimal concentration efficiency and as a result of verification through simulation, we selected the optimal product and manufactured the system.

Fig. 1 is the processing drawing of reflection plate module. The 70° reflection plate was installed and the general PV cell was used for PV cell. The used solar module is general 117W PV module. The reflection plate used Alanod MIR-SUN PV (Weather-proof 90) for manufacturing.



[Fig. 1] Processing Drawing of Reflection Plate Module

Fig. 2 is 2-axis solar tracking system which enables to move up/down and left/right and run by using 2 actuators. The method applied to the tracking system is an image recognition system and the non-matched tracking error is ±0.1° to raise the accuracy of tracking [7].

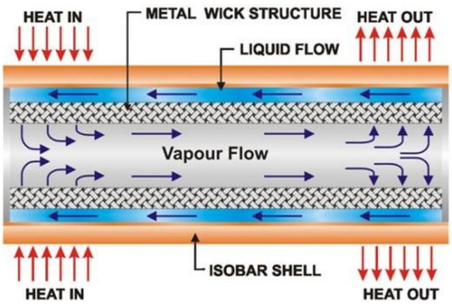
[Fig. 2] 2-Axis Solar Tracker

3. Development of Cooling System

Generally, the cooling system being used at home and overseas is divided into air cooling and water cooling system. When cooling system is not used, people spray water to the module directly to lower the temperature and raise up the efficiency of solar module. For the cooling system used generally, the circulation device and injection device are connected to the cooling device for use but the demand in the market is low due to the motion using the electricity and motor, the use of electricity, high unit price, and thus the application degree is very low.

To increase the generation efficiency of concentration cell, the heat generated from the cell should be discharged but the cooling system used in this study, intends to increase the generation efficiency of cell by discharging the heat at maximum through the cooling system with the structure that enables to discharge the inflowed heat energy by using the circulating refrigerant. Fig. 3 is the cooling system using the micro channel and has a cooling characteristics as well as plays the role of heat sink as a plain plate unlike a heat pipe, and has a self fan function by manufacturing a fin by the fine processing technology[3]-[6].

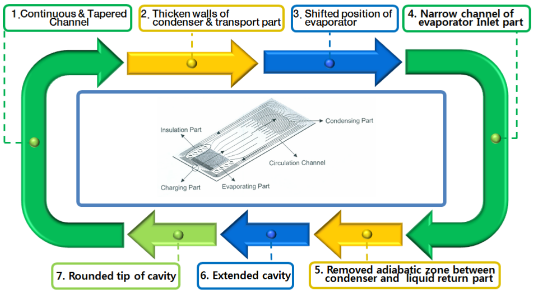
The operation principle of designed cooling system is automatic circulation type, the method that the heating area is attached with module and the heat delivered from the module becomes to heat the heating area of cooling system and the refrigerant inside becomes evaporated and liquefied again as it becomes far from the heating area.



[Fig. 3] Conceptual Diagram of Heat Pipe

The cooling system of solar concentrator module was developed to solve the problem of generation capacity reduction due to high temperature, which is the weak point of solar module by lowering the temperature generated from the module generation.

Fig. 4 is the structure of cooling system designed as plane plate and the conceptual diagram.



[Fig. 4] The Structure of Cooling System and the Process Chart

The operation principle of cooling system is the automatic circulating method, the method that the heating area is attached to the module and the heat delivered from the module heats the heating area of cooling system and the refrigerant inside becomes evaporated and then liquefied again as it becomes away from the heating area. The specification of each configuration is as follows.

Continuous & Tapered Channel (condenser inlet ~ evaporation inlet): We made the number of channel existing between condenser and evaporation inlet regularly and have the gradient of 0.3 ~ 0.5° and different curve size of meniscus before/after droplet staying inside channel. This made good direction of liquid and in case of non-operation, the liquid type refrigerant stay in the liquid returning area and evaporation area and causes the smooth flow of liquid when it operates.

Thicken walk of condenser & transport part: To inhibit the damage of sample due to the internal vacuum pressure generated from the overload, the thickness of silicon wall in the vapor shifted area and condensing area was increased from 50um to 200um which increased the adhesion between silicon and glass.

Shifted position of evaporator: the cooling performance was improved by shifting away 2.8mm from the condenser and increasing the condenser area

Narrow channel of evaporator inlet part: To inhibit the discontinuance of droplet at the evaporator inlet part in case of non-operation, we reduced maximum width of evaporator inlet channel from 1mm to 500um.

Removed adiabatic zone between condenser and liquid return part : To increase the area of condenser and the effect of tapered channel, we made the insulator formed to the condenser exist between shifted area and over cooling section.

Tapered charging port: we made the solid attachment by making the epoxy penetrated well when attaching the SUS tube and silicon.

Extended cavity: We extended the cavity of glass which exists only on the top of evaporator to the condenser in order to smooth the vapor movement by increasing the inflow area to reduce the friction of tube, and inhibit the phenomena that the refrigerant is absorbed to the vapor shifted area in case of non-operation.

Rounded tip of cavity : We made the tip of cavity of glass of vapor shifted area round for smooth movement by making the change of inflow area between vapor shifted area and condenser smoothly.

Before the development of cooling system, the design of cooling system is important but the refrigerant is also important. Thus, it is recommended to select the refrigerant good for heat conduction and the refrigerant which responds to the generation temperature (20-90℃) of solar module. The characteristics of representative refrigerant are shown in Table 1.

As shown in the above table, the one having the best cooling effect is water but the freezing point of water is 0℃ which is not suitable for our domestic environment as we have 4 distinctive seasons. Thus we selected methanol which is suitable for boiling point and freezing point as well as solar module and domestic environment.

[Table 1] Characteristics of Refrigerant

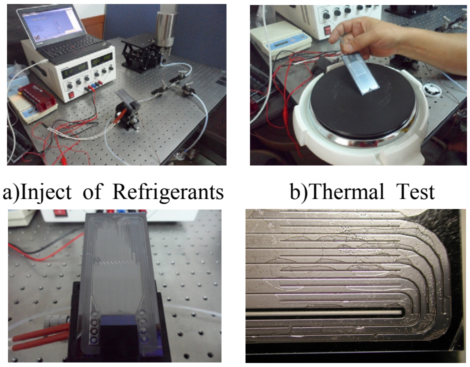
Medium	Melting point(℃)	Boiling point at 1 atm(℃)
Ammonia	-78	-33
Freon 11	-111	24
Freon 113	-35	48
Acetone	-95	57
Methanol	-98	64
Flutecpp[2]	-50	76
Ethanol	-112	78
Water	0	100
Flutec pp9	-70	160
Thermex	12	257

4. Manufacturing and Measurement of Refrigerant Device

The refrigerant device was manufactured as shown in Fig. 5. The dimension of manufactured refrigerant device is 8.6 x 3.8cm2 with waper and reinforced glass as well as micro channel structure with 250㎛ width.

[Fig. 5] Manufactured Micro Cooling System (MCS) of Solar Concentration

As a result of simulation by injecting the refrigerant to the manufactured cooling system, check if automatic circulation is available according to the temperature. As shown in Fig. 6, we verified that the injected refrigerant after heating the heating area of cooling system is evaporated and then liquefied again for automatic circulation.

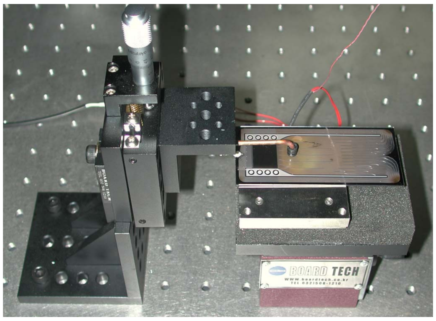


a)Inject of Refrigerants　b)Thermal Test

c)Cooling Test　d) Vaporization → liquid

[Fig. 6] Verification of Vaporization à Liquefaction Through Test

As shown in Fig. 7, we put the cooling system on the test equipment to test max. heat removal capacity. When the applied heat is T_J=100℃, the heat removal capacity was 30W(1.67W/cm^2) and when T_J=140℃, max. heat removal capacity was 52W(2.89W/cm^2).



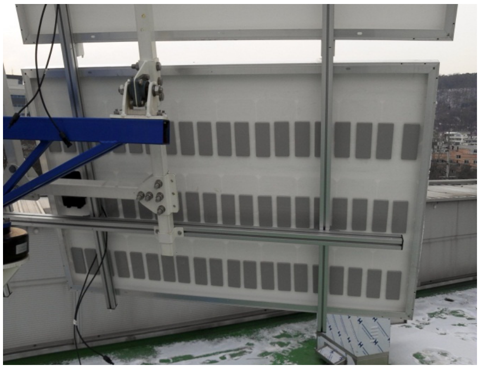
[Fig. 7] Cooling System Test

5. Verification Test of Cooling System

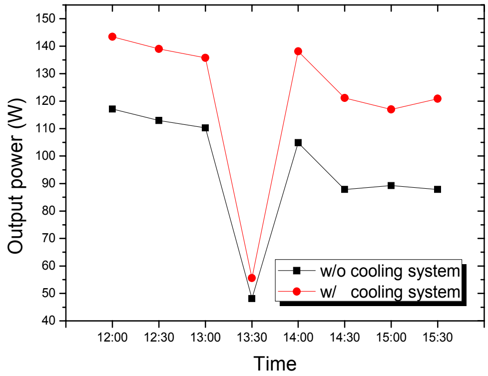
For the test of cooling system, we carried out the comparison test with 117W solar concentration module and the module that installed the cooling system to 117W solar concentration module. Fig. 8 as below shows the solar module with cooling system.

To verify the performance of solar concentrator module combining the cooling system, we recorded the temperature and generation capacity of 117W solar concentration module without cooling system and 117W solar concentration module with cooling system.

Fig. 9 is the graph that compared the generation capacity according to the time of solar concentration module without cooling system and the solar concentration module with cooling system. The circle symbol in Fig. 9 is a solar concentration module with cooling system and square symbol is a solar concentration module without cooling system.



[Fig. 8] Cooling System Combined to 117W Solar Concentration Module



[Fig. 9] Comparison of Generation Capacity According to the Time

As verified in the above graph, the difference of generation capacity of general module and the module combining the cooling system and solar concentrator was average 28% in winter. As the test environment was in winter and the altitude of the sun was low and the outside temperature was also very low, the response of the used methanol was slow but the developed cooling system increased the generation capacity of solar cell.

6. CONCLUSION

In order to increase the efficiency of solar concentrator, we designed and manufactured the cooling system. The features of micro cooling system (MCS) are a natural circulation method by capillary force which does not need the external power. By using the potential heat in case of changing the fluid, it is available to realize the high performance cooling and by using the characteristics of high efficient heat delivery in Micro Channel, it is available to maintain the little temperature difference (Less than 1°C). In addition, due to small internal volume, it is not affected by the gravity and the contact heat resistance can be reduced remarkably by complete attachment with cooling body.

To verify the performance of solar concentrator module combining the cooling system, we recorded the temperature and generation capacity of 117W solar concentration module without cooling system and 117W solar concentration module with cooling system. The cooling device is installed in the module's power output is increased by 28%. Increasing the cooling efficiency of the photovoltaic device will be proceeded in future study.

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