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A Study on the Condensation Heat Transfer Characteristics of a Loop Heat Pipe Heat Exchanger for High Speed Rotary Shaft Cooling

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고속 회전축 냉각용 루우프 히트파이프 열교환기의 응축열전달 특성에 관한 연구

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ABSTRACT

In the present study, we used a loop thermosyphon heat exchanger consisting of condensers with internal fins and external plate fins which are 480 mm wide, 68 mm long, and 1,000 mm high. The heat transfer pipes in the heat exchanger were 15 mm in diameter and 1,000 mm in length, and 98 heat transfer pipes were installed in the heat exchanger. According to the experimental results, as the spaces between the internal discontinuous pins decreased, the frequency of pressure drops increased and changes in temperature at the outlet of the condenser were shown to be a little smaller. Therefore, we can see that as the spaces between internal discontinuous pins decreased, the heat transfer performance increased. For the loop heat pipe heat exchanger consisting of a condenser with internal and plate fins, as the temperature of the air flowing into the condenser increased, the condensation heat transfer rate also increased, and as the condenser refrigerant inflow temperature increased, the condensation heat transfer rate increased as well.

Key Words : Loop Heatpipe Heat Exchanger(루우프 히트파이프 열교환기), Condenser Section(응축부), Internal Fins(인터널 핀), Plate Fins(플레이트핀), Performance of Heat Transfer(열전달성능)

1. Introduction

Cooling systems using technology of loop heatpipe heat exchanger for high speed rotary shaft cooling consisting of a condenser with internal fins and external plate fins can improve cooling performance[1-6].

Knaani[7] constructed an electronic component cooling time is to cut at high spindle speed in most machining fields.

In the present study, experimental studies were conducted on the heat transfer performance of the loop heatpipe heat exchanger for high speed rotary shaft cooling consisting of a condenser with internal

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fins and external plate fins that can discharge the large amounts of heat generated by the high speed rotation of the high speed rotation shafts of high voltage motors, generators, and large lathes, simulations were conducted to evaluate the heat transfer performance, and the results were verified through comparison with experimental results.

2. Experimental facility and method

Fig. 1 shows the loop heatpipe heat exchanger for high speed rotary shaft cooling consisting of a condenser with internal fins and external plate fins for high speed rotating shaft heat release[8~11]. The loop thermosyphon consisting of a condenser with internal fins and external plate fins is installed with an evaporator which is a heating section and a condenser which is a cooling section that are separated from each other[12]. The evaporator with the heat exchanger of ring type and the condensers are assemblies of pipes composed of many pipes and they are constructed so that they are connected to each other through pipes gathered on the top and bottom. In heat exchangers of loop heatpipe heat exchanger consisting of a condenser with internal fins and external plate fins because of the characteristics of loop thermosyphon consisting of a condenser, the condenser should be installed at a higher location than the evaporator without fail to obtain the pressure difference for circulation of the working fluid.

Fig. 2 shows schematic diagram of the experimental facility. The exhaust valves were attached to the condenser so that the working fluid can be filled and non-condensable gases can be exhausted. As shown in Fig. 2, for performance experiments of the 10 kW grade heat exchanger of loop heatpipe heat exchanger consisting of a condenser, the height difference between the evaporator and the condenser was set to 2 m. The

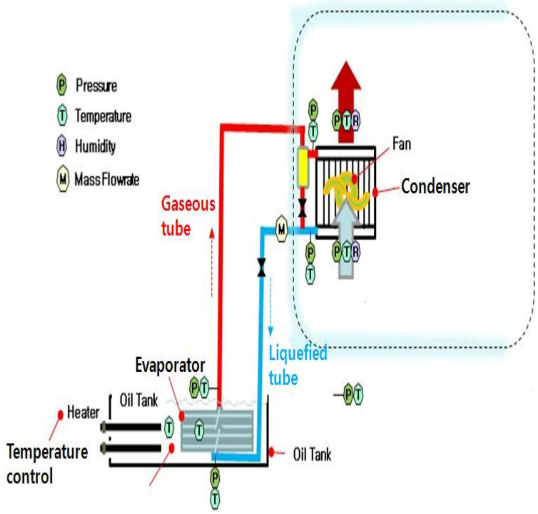


Fig. 1 Loop heatpipe heat exchanger consisting of a condenser for high speed rotating shaft heat release

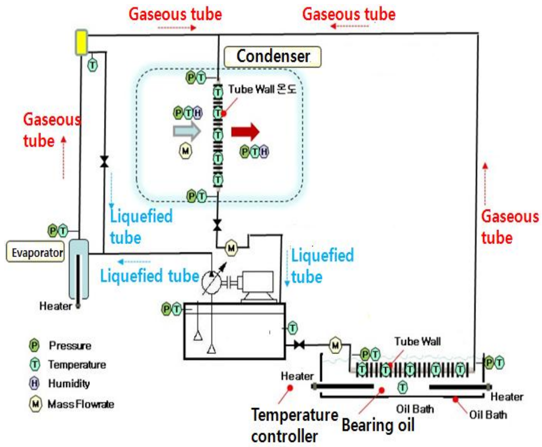


Fig. 2 Schematic diagram of the experimental facility for loop heatpipe heat exchanger

outside diameter of the conveying pipe that connects the evaporator and the condensers with internal fins and external plate fins is 50 mm. The experimental data were measured and recorded using a Hybrid Recorder. A refrigerant flowmeter was installed at the condensers with internal fins and external plate fins outlet tube to measure the condensate refrigerant flow rate. In loop heatpipe

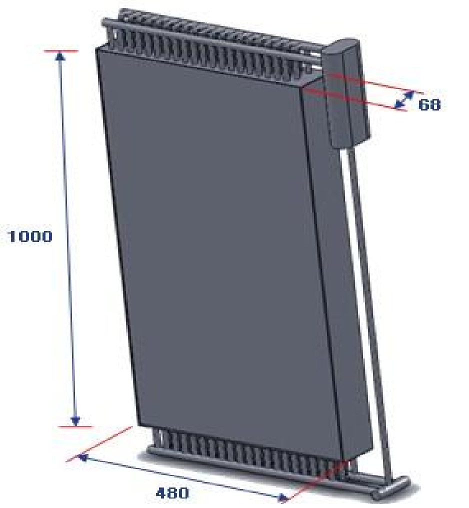


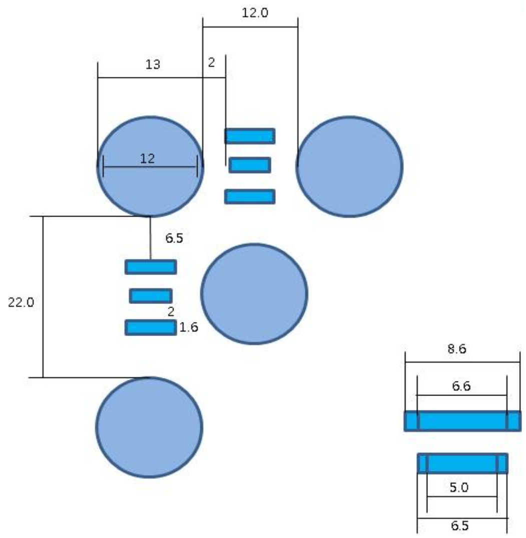
Fig. 3 Condenser section with internal fins and external plate fins

heat exchanger for high speed rotary shaft cooling consisting of a condenser with internal fins and external plate fins performance experiments, initial temperatures are very important.

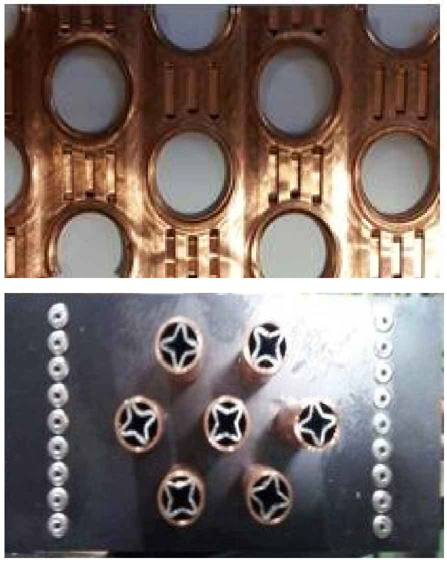
Fig. 3 shows the condenser heat exchanger. The condenser is 480 mm wide, 1000 mm long and 68 mm high.

Eighty 12 mm diameter, 1,000 mm long copper pipes were installed on the condensers with internal fins and external plate fins. In addition, exhaust valves were attached to the condenser so that the working fluid can be filled and non-condensable gases can be exhausted.

Fig. 4 shows a heat exchanger part with plate of condenser section and cooling fan of condenser section.



(a) Dimensions



(b) Shape of condenser

Fig. 4 Internal fins inserted in condenser section

3. Results and discussion

3.1 Condenser thermal flow analysis

Fig. 5 shows the mesh generation of the heat-transfer pipes of the condenser of the loop heat pip heat exchanger and boundary conditions. ANSYS FLUENT v13.0 was used as a condenser model. Only 1/4 of the circular tube of the condenser was constructed and symmetry conditions were given to the wall to implement heat and flow simulations.

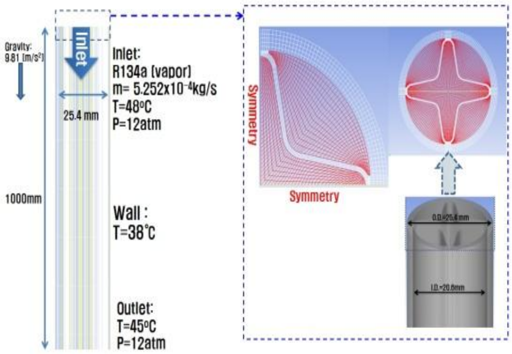


Fig. 5 Condenser shape and mesh generation

Table 1 Simulation cases of condenser section

Case	δ (mm)	Θ (degree)	L_f (mm)
1	0.5	144	50
2	0.5	144	75
3	0.5	144	100

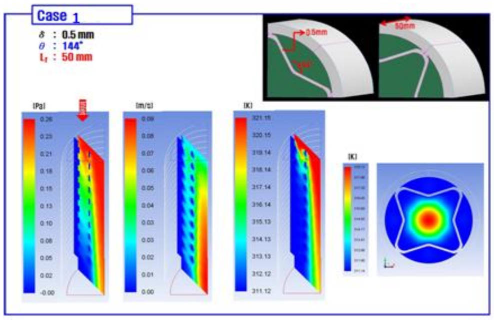
The heat transfer rate is expressed as

$$\dot{Q}_c = \int_5^1 U_c A_c (T - T_a) dz$$

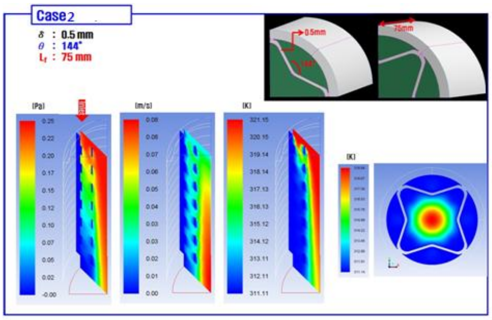
$$= U_{c2} A_{cw} LMTD_2 + U_{c1} A_{c1} LMTD_1 \qquad (1)$$

$$\dot{Q}_{c1} = U_{c1} A_{c1} LMTD_1 = \dot{m}(h_f - h_l) \qquad (2)$$

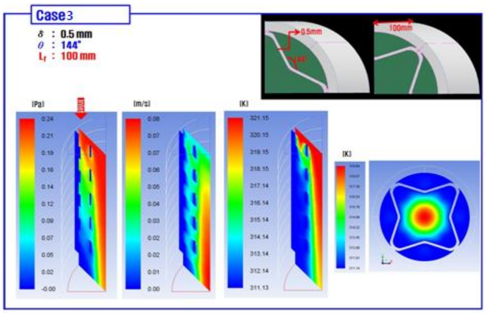
Table 1 shows condenser simulation cases. The simulations were implemented with 0.5 mm thick internal pins at angles of 110° under three length conditions; 50 mm, 75 mm, and 100 mm. The condenser tube area is 0.08m^2, the entire heat transfer area of the condenser including 625 plate pins is 2.895 m^2. The condenser is installed with 625 plate pins on its surface. The heat transfer area of one pin is 4.503E-3 m^2 and that of 625 pins is 2.815 m^2. Fig. 6 shows the results of simulations in cases 1~3 shown in Table 1. As shown in Fig. 4, cases 1~3 show the results of simulations with 0.5 mm thick internal pins fixed at an angle of 144° with different spaces between internal discontinuous pins.



(a) Case 1



(b) Case 2



(c) Case 3

Fig. 6 Simulation results of case 1~3

It can be seen that differences in spaces between internal discount inuous pins have considerable effects on refrigerant flows. As the spaces between internal discontinuous pins decreased, pressure drops increased. Changes in the temperatures at the outlet of the condenser were shown to be a little smaller. Therefore, it can be seen that as the spaces between internal discontinuous pins decreased, the heat transfer performance increased.

3.2 Results of condenser experiments

Fig. 7 and Fig. 8 show the results of condenser temperatures following changes in the temperature of the cooing are flowing in the condenser. The refrigerant used in the experiment is 134a. The experiment was conducted with the quantity of the refrigerant filled in the condensers with internal fins and external plate fins in a range of 6~9 kg. The air flowing in the condenser was in a range of 0.58~1.36 kg/s when the experiment was conducted.

The rate of heat transfer of oil expressed as

$$Q_o = m_o C_p (T_2 - T_1) \quad (3)$$

The rate of heat transfer of refrigerant expressed as

$$Q_c = \dot{m}_c h_{fg} \quad (4)$$

As the condenser air temperature increased, the condenser refrigerant circulation rate also increased. Therefore, it can be seen that as the temperature of the air flowing in the condenser increases, the condensation heat transfer rate of the loop heatpipe heat exchanger consisting of a condenser with internal fins and external plate fins increases.

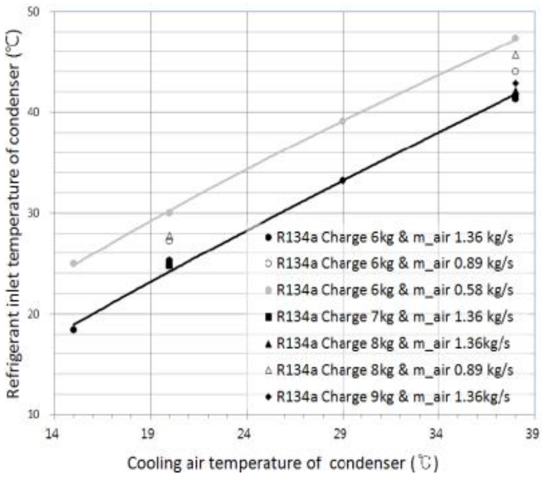


Fig. 7 Comparison of refrigerant inlet temperature of condenser with cooling air temperature of condenser with internal fins and external plate fins

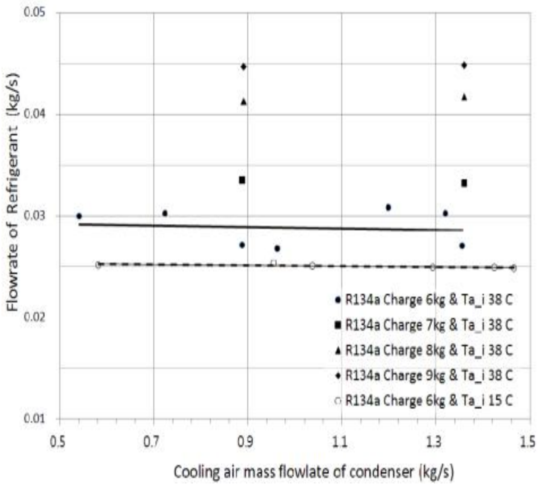


Fig. 8 Comparison of flowrate of refrigerant with cooling air temperature of condenser with internal fins and external plate fins

5. Conclusion

Experiments of the condensers with internal fins and external plate fins of the loop heatpipe heat exchanger consisting of a condenser with internal fins and external plate fins for high speed rotating shaft heat release were conducted using R-134a as a working fluid. The results of experimental studies conducted on changes in working fluid refrigerant circulation rates, condenser air flow rates, and evaporator oil temperatures following changes in spaces between internal discontinuous pins analyzed in comparison with simulation results are summarized as follows.

1. As the spaces between internal discontinuous pins decreased, the condensers with internal fins and external plate fins pressure drops increased.
2. Changes in the temperatures at the outlet of the condensers with internal fins and external plate fins were shown to be a little smaller. Therefore, it can be seen that as the spaces between

internal discontinuous pins decreased, the heat transfer performance increased.

3. As the temperature of the air flowing in the condensers with internal fins and external plate fins increased, the condensation heat transfer rate of the heat exchanger of loop heatpipe heat exchanger consisting of a condenser with internal fins and external plate fins increased.

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