HEAT TRANSFER AND FLUID FLOW CHARACTERISTICS OF AIR-WATER HEAT EXCHANGER INSERTING METAL WIRE

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ABSTRACT

There are various methods for heat transfer enhancement. For example, one can attach various fins on the heat transfer surface, process the surface roughly, insert twisted tape, and so on. These methods increase the heat transfer coefficient or area by manufacturing changes to the heat transfer surface. In this study, heat transfer performance of air-water heat exchanger was evaluated under the condition inserting metallic wire. Moreover, heat transfer performance of heat exchanger attaching fins was compared with that inserting porous material. Experimental apparatus consists of a heat exchanger, a blower, a heater and a cooling water system. The heat exchanger has horizontal rectangular channel and it's inside region of heat exchanger is separated with eight small channels. Air is used as working fluid. The air is supplied to the heater using the blower as a forced convection. After being heated by heater, the air is supplied to heat exchanger. During experiments, the temperature of the water is kept constant. The water is supplied to the channel of cooling water of heat exchanger from the isothermal bath. The temperature of air was set to the range from 200°C to 450°C. The temperature of cooling water was kept 70°C constantly. The fine cooper wire diameter of 0.5 mm was used as porous material. The heat transfer performance of the heat exchanger was evaluated by the amount of heat removal and pressure drop. The results of experiments show that the amount of removed heat was increased slightly by increasing the amount of inserting metallic wire. However, the pressure drop by increasing them was significant. It shows that it is necessary to improve the heat removal increases due to radiation. It is assumed that amount of heat removal increases by increasing the porosity of metallic wire and increasing the temperature of the air.

INTRODUCTION

When cooling high temperature circular or rectangular channels by forced convection of gas, there are several methods for enhancement of heat transfer; for example, there are attaching radial or spiral fins on the heat transfer surface, processing the surface roughly, or inserting twisted tape in the channel, and so on. There are several methods for heat transfer enhancement. For example, one can attach various fins on the heat transfer surface, process the surface roughly, insert twisted tape, and so on. These methods increase the heat transfer coefficient or area by manufacturing changes to the heat transfer surface. These methods of heat transfer enhancement are used a wide variety of products such as heat sink and radiator. However, in these methods, it is necessary to consider the deterioration of the structure strength due to processing and manufacturability of the finned tube. Moreover, there is the most suitable design with respect to the workability of the surface or the securing of flow rate due to resistance increase. Therefore, the application of these methods requires sufficient study.

On the other hand, there is the heat transfer enhancement method inserting porous material into the channel. This method is possible to simplify the evaluation of structure strength, because there is not processing for heat transfer surface. Moreover, it is possible to expand the choice of design, because the heat transfer enhancement element which insert in channel can decide regardless of the channel material. Therefore, this method is simulated in the wide variety utilization such as requiring additional heat removal.

In previous study, heat transfer and flow characteristics of horizontal circular channel by under the condition inserting metallic wire as porous material were evaluated and the trend of heat transfer and flow characteristics were revealed [1-5].

The objective of this study is to clarify performances of a method for heat transfer enhancement using porous material with high porosity by an experiment. The experiment has been performed using an apparatus which simulated the passage structure of an air-water heat exchanger applied as vehicles to obtain characteristics of heat transfer and pressure drop [6]. Moreover, heat transfer performance of heat exchanger attaching fins was compared that inserting porous. Final goal of this study is to apply to vehicles this air-water heat exchanger.

NOMENCLATURE

d_w	[m]	Diameter of metallic wire
h	[m]	Height of channel
l_0	[m]	Length of a region inserting porous material
l_w	[m]	Length of metallic wire
t	[m]	Width of channel
ε	[-]	Porosity

EXPERIMENTAL APPARATUS AND PROCEDURE

Figure 1 shows schematic drawing of an experimental apparatus. Figures 2 and 3 show a schematic drawing of an air-water heat exchanger. Experimental apparatus consists of a heat exchanger, a blower, a heater and a water cooling system. The heat exchanger is the horizontal rectangular channel which is separated at eight small channels made of stainless steel. The dimension of the heat exchanger is 60 mm in height, 63 mm in width and 240 mm in depth. The dimension of the small channel is 60 mm in height and 4.5 mm in width. The length of a region inserting porous material is 200 mm. Working fluid used air. Air is supplied to the heater by the blower as forced convection. After being heated, air is supplied to the heat exchanger. In the experiment, water is supplied as constant temperature to the cooling water channel of the heat exchanger. Temperature of the cooling water keep constant by installing a cooling device into an isothermal bath. The water temperature at the inlet and outlet of the channel were measured using K-type sheathed thermocouples. In addition, K-type sheathed thermocouples are installed at front and rear of the heat exchanger for measuring of air temperature. Static pressure taps are attached with the circular tube for measuring of pressure drop. The measurement error of the temperature was within ± 1.5 K and the measurement accuracy of the manometer was ±0.15%F.S.

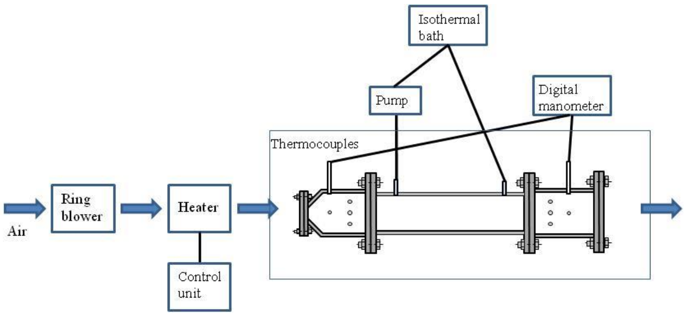

Figure 1 Schematic drawing of experimental apparatus

For the evaluation of the amount of heat transfer, the amount of removed heat by air was determined from the temperature difference of air between inlet and outlet and the flow rate of air. The amount of removed heat by cooling water was determined from the temperature difference of cooling water between inlet and outlet and the flow rate of cooling water.

Heating temperature of air was set to the range of 200°C to 450°C. The temperature of cooling water was 70°C. The flow rate of the air was determined by the power of blower pump. Experiments were conducted in two types of pump power conditions. At first, we carried out the experiment under the condition of mass flow rate of air about 14 g/s. Next, we carried out the experiment under the condition of mass flow rate of air about 18 g/s.

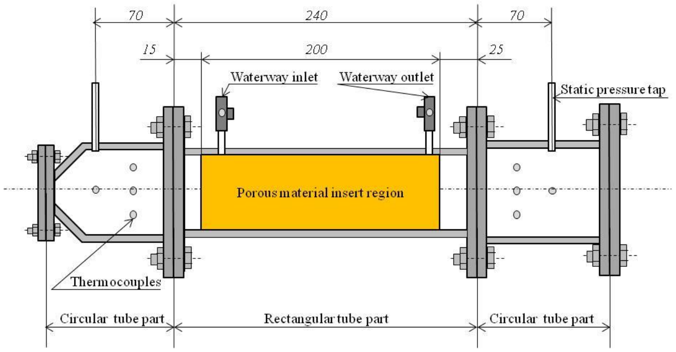

Figure 2 Schematic drawing of air-water heat exchanger

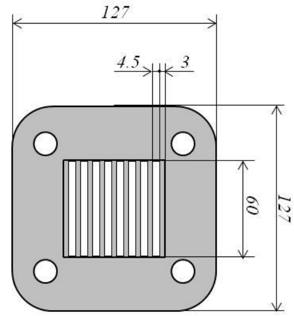

Figure 3 Cross section of rectangular tube

In these experiments, copper wires whose diameter is 0.5 mm were used as a porous material. The porosity of the rectangular channel was set to the range of 0.955 to 0.970. The metallic wire was inserted in the form of a metallic scourer to the channel of air of heat exchanger. The channel porosity, ε, can be obtained by the following equation.

$$\varepsilon = 1 - \frac{\frac{1}{4}\pi d_w^{\ 2} l_w}{8thl_0} \quad (1)$$

Here, d_w is the diameter of metallic wire, l_w is the length of metallic wire, h is the height of channel, t is the width of channel, and l_0 is the length of a region inserting porous material. Experimental condition of metallic wire in case of the mass flow rate about 14 g/s is shown in Table1. Moreover, experimental condition of metallic wire in case of the mass flow rate about 18 g/s is shown in Table2.

Table 1 Experimental condition of metallic wire (The mass flow rate is 14 g/s)

No.	Material	Wire diameter [mm]	Porosity ε	Wire length [m]
1			1.000	0.00
2	Cu	0.5	0.970	67.87
3			0.960	90.49
4			0.955	101.80

Table 2 Experimental condition of metallic wire (The mass flow rate is 18g/s)

No.	Material	Wire diameter [mm]	Porosity ε	Wire length [m]
1	Cu	0.5	0.970	67.87
2			0.960	90.49
3			0.955	101.80

EXPERIMANTAL RESULTS AND DISCUSSIONS

Experimental results (Flow rate of air: 14g/s)

Figures 4 and 5 show the amount of removed heat by air flow in terms of various temperature of the heater. Flow rate of air is 14 g/s. When the metallic wire was inserted into the air-water heat exchanger, the amount of removed heat by air flow slightly increased with decreasing porosity of the channel. Moreover, the amount of removed heat by air flow in the case of inserting metallic wire was greater than that in the case without metallic wire. In particular, the amount of removed heat by air flow in the case of ε = 0.955 was nearly 1.4 times greater than that in the case without metallic wire. However, as compared with attaching fins, the amount of removed heat by air flow in the case of inserting metallic wire was decreased in all cases. As a reason for this result, it seems that the amount of heat transport by thermal radiation in the case of inserting metallic wire was small compared with the amount of heat transport by thermal conduction of fins.

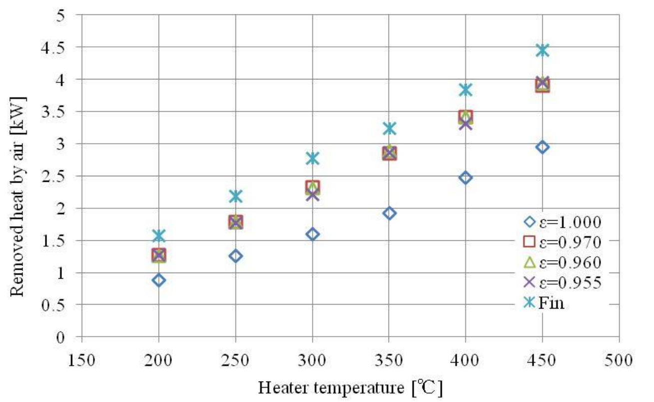

Figure 4 Amount of removed heat by air flow

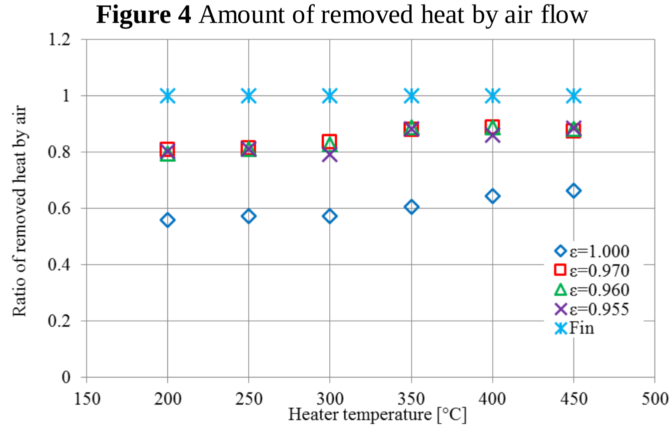

Figure 5 Ratio of amount of removed heat by air flow

The ratio of the amount of removed heat by air flow in the case of inserting metallic wire to that in the case of attaching fins increased with increasing heater temperature. As a reason for this result, it seems that heat transport by thermal radiation slightly increased in the case inserting metallic wire.

Figures 6 and 7 show the amount of removed heat by cooling water in terms of various temperature of the heater. The amount of removed heat by cooling water indicated a similar tendency of the amount of heat removed by air flow. However, the amount of removed heat by cooling water was greater than that by air flow. As a reason for this result, it seems that the temperature difference of the air at the inlet and outlet of the heat exchanger was estimated small due to the temperature distribution of the air at the inlet and outlet section.

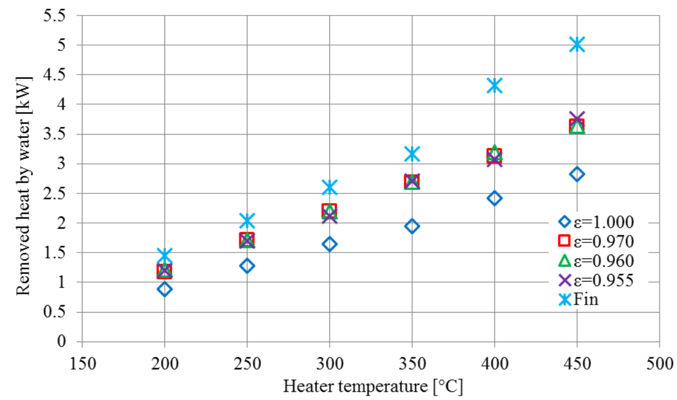

Figure 6 Amount of removed heat by cooling water

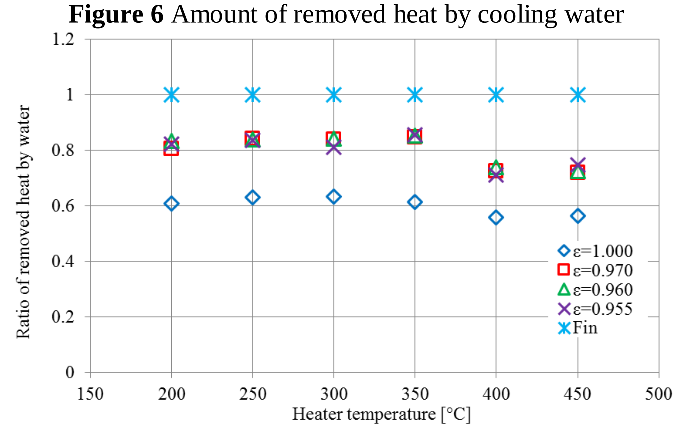

Figure 7 Ratio of removed heat by cooling water

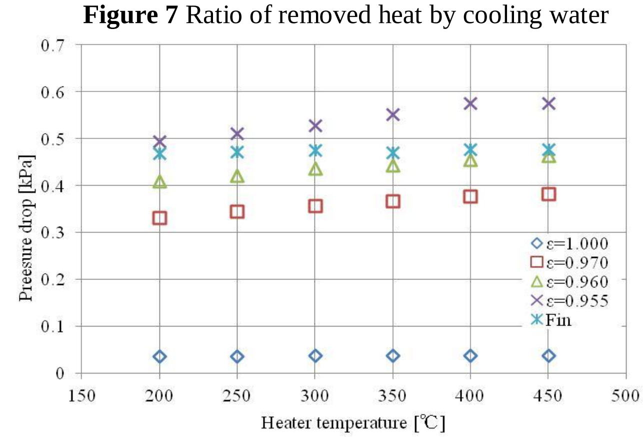

Figure 8 Pressure drop

Figure 8 shows the pressure drop between the inlet and outlet of the heat exchanger in terms of the various temperature of the heater. When the metallic wire was inserted, the pressure drop slightly increased with increasing temperature. However, in the case of attaching fins and of a smooth surface, the pressure drop was approximately constant. It seems that the difference of tendency of the pressure drop depends on the difference of a shape resistance and a friction resistance. Moreover, the pressure drop of inserting metallic wire excluding the case of ε = 0.955 was lower than that of fins. In particular, the pressure drop decreased drastically in the case of ε = 0.970. In the case of high porosity, the amount of removed heat decreases slightly. On the other hand, the pressure drop decreases significantly. Therefore, it is possible that the amount of removed heat can be maintained by inserting metallic wire with high porosity. It is also possible that the pressure drop can be reduced significantly compared with attaching fins.

Experimental results (Flow rate of air: 18g/s)

Figures 9 and 10 show the amount of removed heat by air flow in terms of various temperature of the heater. Flow rate of air is 18 g/s. The amount of removed heat by air flow was increased slightly with decreasing porosity of the channel same as the previous experimental results.

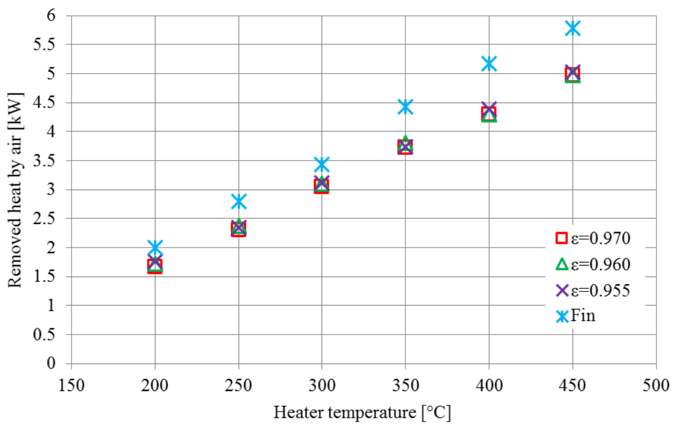

Figure 9 Amount of removed heat by air flow

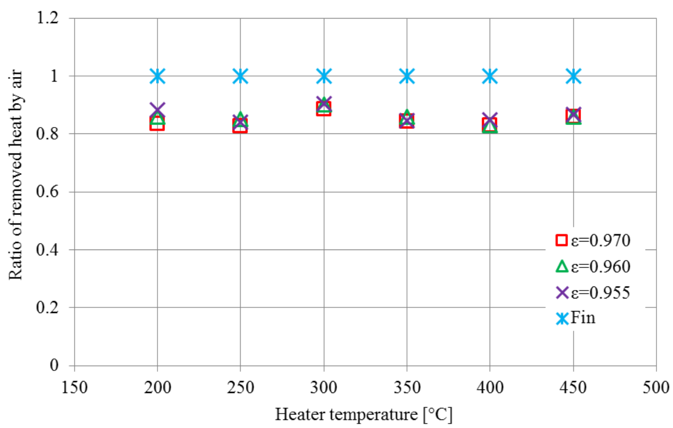

Figure 10 Ratio of amount of removed heat by air flow

Figures 11 and 12 show the amount of removed heat by cooling water in terms of various temperature of the heater. The amount of removed heat by cooling water indicated a similar tendency of the result which is 14 g/s in flow rate. However, the amount of removed heat by cooling water with inserting metallic wire is almost equal to that with attaching fins in case of 450°C in heater temperature.

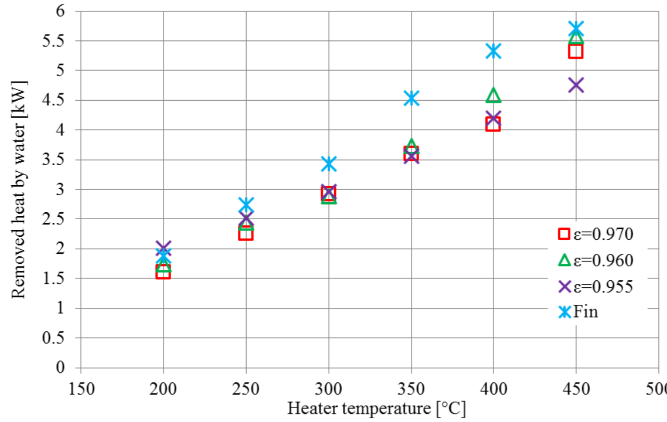

Figure 11 Amount of removed heat by water

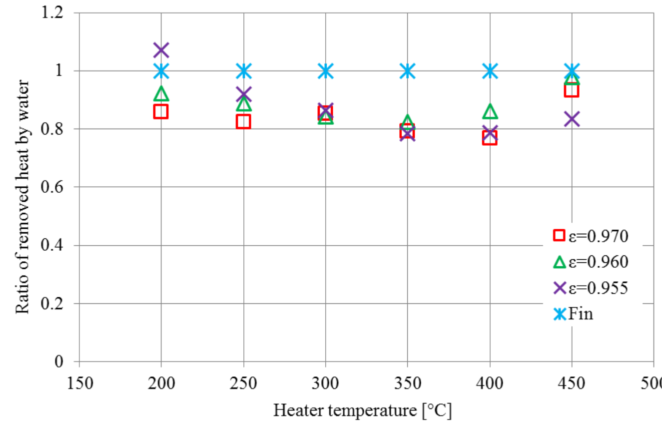

Figure 12 Ratio of amount of removed heat by water

Figure 13 shows the pressure drop between the inlet and outlet of the heat exchanger in terms of the various temperature of the heater. When the metallic wire was inserted, the pressure drop slightly increased with increasing temperature as same as the result which is 14 g/s in flow rate. The pressure drop of inserting metallic wire excluding the case of ε = 0.955 was lower than that of fins. Therefore, the amount of removed heat can be maintained by inserting metallic wire with high porosity. The pressure drop can be reduced significantly compared with attaching fins.

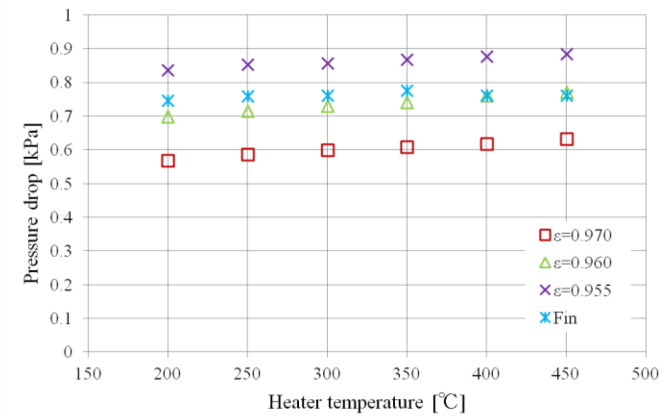

Figure 13 Pressure drop

CONCLUSION

The heat transfer and fluid flow performance of the air-water heat exchanger with inserting metallic wire were successfully evaluated. Conclusions are as follows.

(1) It was found that the amount of removed heat slightly increased with decreasing porosity of the channel. However, the pressure drop much increased with decreasing the porosity. Therefore, the amount of removed heat can be maintained by inserting metallic wire with high porosity. The pressure drop can be reduced significantly compared with attaching fins.

(2) The amount of removed heat in the case of inserting metal wire approaches that in the case of attaching fins under the higher temperature condition. Therefore, it was found that the amount of removed heat increases due to thermal radiation in the case of inserting porous material.

(3) It is possible to develop an air-water heat exchanger with inserting metallic wire which is replaced by the conventional fin type heat exchanger for existing vehicles.

(4) For future work, we have been performing numerical analysis of this air-water heat exchanger by using three-dimensional computational fluid dynamic (3D CFD) code.

REFERENCES

[1] Takeda, T. and Ichimiya, K., Experimental study on method for heat transfer enhancement using porous material with high porosity, *Proceedings of the International Conference on Power Engineering, (ICOPE-09)*, Kobe, Japan, G042, Nov. 16-20, 2009.

[2] Takeda, T. and Ichimiya, K., Experimental study on application of heat transfer enhancement method using porous material with high porosity, *Proceedings of the 17th International Conference on Nuclear Engineering (ICONE-17)*, Brussels, Belgium, Paper No. ICONE17-75060, 2009.

[3] Ichimiya, K. et al., Thermal performance of a circular tube filled with a high porous material, *Transactions of the Japan Society of Mechanical Engineers*, Series B, Vol.72, No.723, 2006, pp.2747-2752, in Japanese.

[4] Takeda, T. et al., Experimental study on application of heat transfer enhancement method using porous material with high porosity, *Transactions of the Japan Society of Mechanical Engineers*, Series B, Vol.74, No.748, 2008, pp.2607-2614, in Japanese.

[5] Takeda, T., Experimental study on method for heat transfer enhancement using porous material with high porosity, *Proceedings of the 8th World Conference on Experimental Heat Transfer, Fluid Mechanics, and Thermodynamics, ExHFT8*, Lisbon, Portugal, 4b.3, June 16-20, 2013.

[6] Okubo, T. Takeda, T., and Funatani, S., Heat transfer performance of air-water heat exchanger inserting porous material, *Proceedings of the 26th International Conference on Transport Phenomena*, Leoben, Austria, Sept. 27 – Oct. 1, 2015.