HEAT TRANSFER AND FLOW CHARACTERISTICS OF AIR-WATER HEAT EXCHANGER INSERTING POROUS MATERIAL WITH HIGH POROSITY

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ABSTRACT

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. However it is necessary to consider the problem on account of processing heat transfer area. In this study, we have obtained heat transfer characteristics of an air-water heat exchanger inserting a metal wire as porous material. In addition to that the heat transfer characteristics of the heat exchanger compared with those of a fin type heat exchanger.

Experimental apparatus is composed of a heat exchanger, a blower, a heater and a cooling water system. The heat exchanger consists of a horizontal rectangular duct having narrow eight channels. Air was used as working fluid. Air was supplied to the heater from the blower and then supplied to the heat exchanger. In the experiment, water was supplied to the cooling water channel of the heat exchanger from an isothermal bath. The temperature of cooling water was constant at 70°C. A copper wire was inserted into the heat exchanger as a porous material. Experiment was conducted changing the porosity of the flow channel. Heating temperature of air set to the range from 200°C to 450°C with the porosity changing from 0.97 to 0.995. In order to investigate the heat transfer and fluid flow characteristics in the high temperature region, the heating temperature set to the range from 200°C to 800°C with the porosity changing from 0.99 to 0.995.

The heat and fluid flow characteristics of the heat exchanger were evaluated by an amount of removed heat and a pressure drop. As a result of the experiment, the amount of removed heat by the heat exchanger having copper wire was slightly decreased as compared with that by the fin type heat exchanger. However, the pressure drop of the heat exchanger was greatly reduced as compared with that of the fin type heat exchanger.

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. These methods increase the heat transfer coefficient or heat transfer area by processing to the heat transfer surface. These methods for heat enhancement are used as 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 surface. Moreover, there is the most suitable design with respect to the workability of the surface. Therefore, the application of these methods requires sufficient study.

On the other hand, there is the method for enhancement of heat transfer inserting a porous material into a channel. This method is not necessary to process the heat transfer surface. Moreover, it is possible to choose various design, because the porous material can decide regardless of the channel material. Therefore, this method is applied to the various heat utilization system.

In previous study, we reported the heat transfer and flow characteristics of horizontal circular channel inserting metallic wire as porous media [1-5].

The purpose 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. In addition to that, heat transfer performance of heat exchanger attaching fins on the channel surface was compared to that of inserting porous material into the channel under the high temperature condition.

EXTERNAL BOUNDARY CONDITIONS

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 narrow eight channels made of stainless steel. The dimension of the heat exchanger is 60mm in height, 63mm in width and 240mm in length. The dimension of the narrow channel is 60mm in height and 4.5mm in width. The length of a region inserting porous material is 200mm. Air was used as working fluid. Air was supplied to the heater from the blower and then supplied to the heat exchanger. In the experiment, water was supplied to the cooling water channel of the heat exchanger from an isothermal bath. The temperature of the cooling water kept at 70°C by installing a cooling device into an isothermal bath. The water temperature of inlet and outlet were measured using K-type sheathed thermocouples. In addition, the thermocouples and the static pressure tap were installed at the circular tube portion of inlet and outlet of the heat exchanger. The pressure drop was measured using manometer. The measurement error of the temperature was ± 1.5°C. The measurement accuracy of the manometer was ±0.15%F.S. The flow rate of air was obtained by measuring the pressure drop using the friction coefficient of the straight pipe. The cooling water flow rate was measured with a vortex ultrasonic flow meter.

For evaluation of the heat transfer characteristics, 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.

In the first experiment, the porosity was set from 0.970 to 0.995 and the temperature of the heater was set from 200 to 450°C. In order to research the case of higher porosity, the second experiment was conducted at a high temperature condition. The porosity was set from 0.990 to 0.995 and the temperature of the heater set from 200 to 800°C. The temperature of the cooling water was 70°C. The flow rate of air was determined by the power of the blower.

In these experiments, a 0.5 mm diameter copper wire was used as the porous material. The metallic wire was inserted in the form of a metallic scourer to the air side channel of the heat exchanger. The porosity ε of a channel can be obtained by the following formula.

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

Here, d_w is the diameter of the metal wire, l_w is the length of the metal wire, h is the height of the channel, t is the width of the channel, and l_0 is the length of the region inserting porous material. Table 1 shows the experimental condition regarding the porosity the metallic wire in the case of the heating temperature from 200 to 450°C. Experimental conditions of the metal wire when the heating temperature is from 200 to 800°C are shown in Table 2.

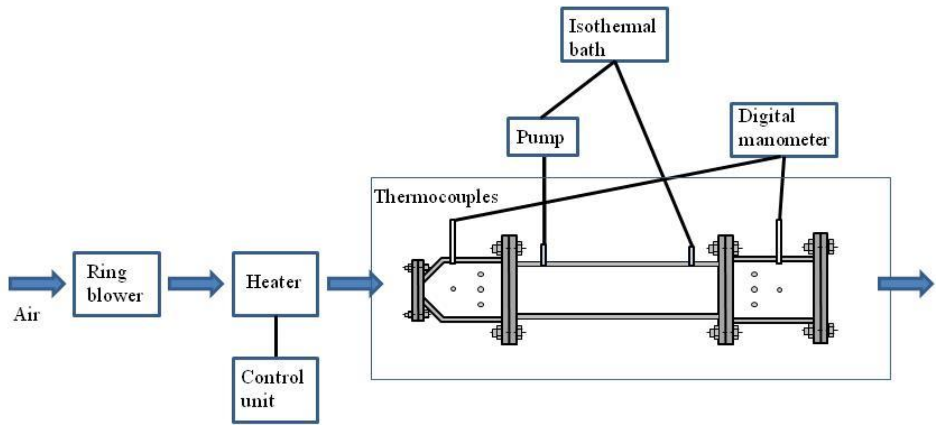

Fig.1 Schematic drawing of experimental apparatus

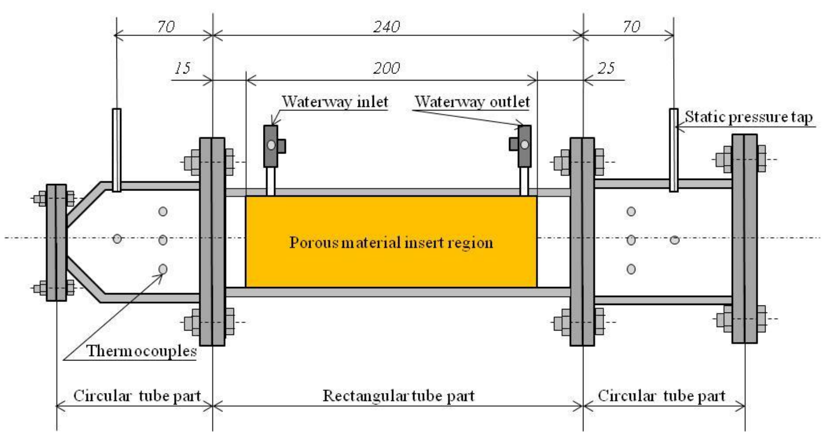

Fig.2 Schematic drawing of air-water heat exchanger

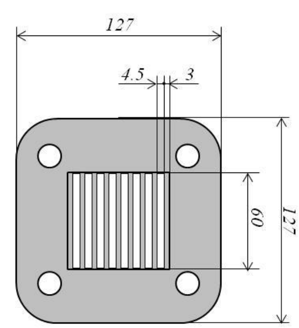

Fig.3 Cross section

Table.1 Experimental condition of metallic wire
(Heating temperature 200°C~ 450°C)

No.	Material	Wire diameter [mm]	Porosity ε	Wire length [m]
1			1.000	
2	Cu	0.5	0.995	11.02
3			0.990	22.03
4			0.985	33.05
5			0.980	44.07
6			0.975	55.09
7			0.970	66.10

Table2 Experimental condition of metallic wire
(Heating temperature 200°C ~ 800°C)

No.	Material	Wire diameter [mm]	Porosity ε	Wire length [m]
1			1.000	
2	Cu	0.5	0.995	11.02
3			0.990	22.03

EXPERIMENTAL RESULTS AND DISSCUSSIONS

From the viewpoint of practical use, we have conducted experiment under the constant pump power. Therefore, we discussed the amount of heat removed and the pressure drop of the heat exchanger, separately.

Results of the first experiment (Heating temperature from 200°C to 450°C)

Figure 4 shows the amount of removed heat by cooling water in terms of various temperature of the heater. When the metallic wire was inserted into the air-water heat exchanger, the amount of removed heat by cooling water increased slightly with decreasing of the porosity of the channel. The amount of removed heat by cooling water in the case of inserting metallic wire was greater than that in the case without metallic wire. However, the amount of removed heat by cooling water in the case of inserting metallic wire was decreased as compared with that in the case of attaching fins. Although heat is transferred mainly by heat conduction in the case of attaching fins, heat will be not transferred from the metallic wire to the channel surface in the case of inserting metallic wire. 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 the fin. However, it will be possible to increase the amount of transported heat by thermal radiation as the temperature rises.

It was found that the amount of heat removed by inserting porous material increased as compared with the heat removed by the smooth channel. The amount of removed heat by cooling water in the case of the porosity from 0.970 to 0.990 was nearly 1.4 times greater than that in the case without metallic wire. It is possible to enhance heat transfer by inserting metallic wire into the narrow channel.

Figure 5 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 of the heater temperature. However, in the case of attaching fins and of a smooth surface, the pressure drop was approximately constant. The difference of tendency of the pressure drop will depend on the difference of a shape resistance and a friction resistance. When the porous material was inserted into the channel, the pressure drop was much lower than that of the fin type heat exchanger.

In the case of high porosity, the amount of removed heat decreases slightly. However the pressure drop greatly decreases. Therefore, it is possible that the amount of removed heat is not decreased by inserting metallic wire with high porosity, while reducing the pressure drop.

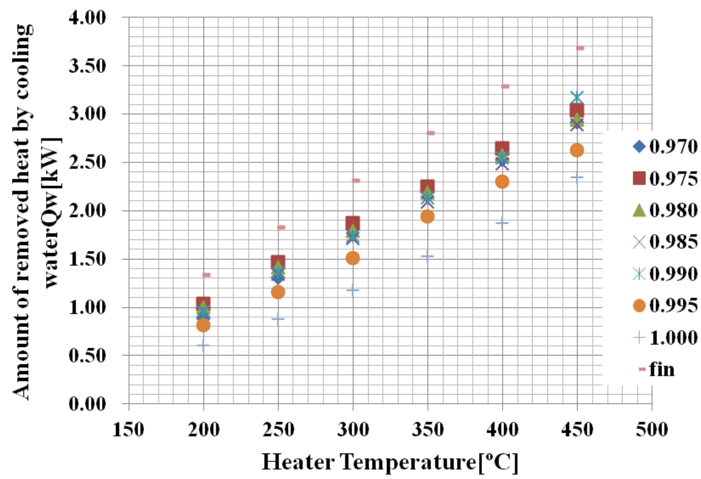

Fig.4 Amount of removed heat by cooling water

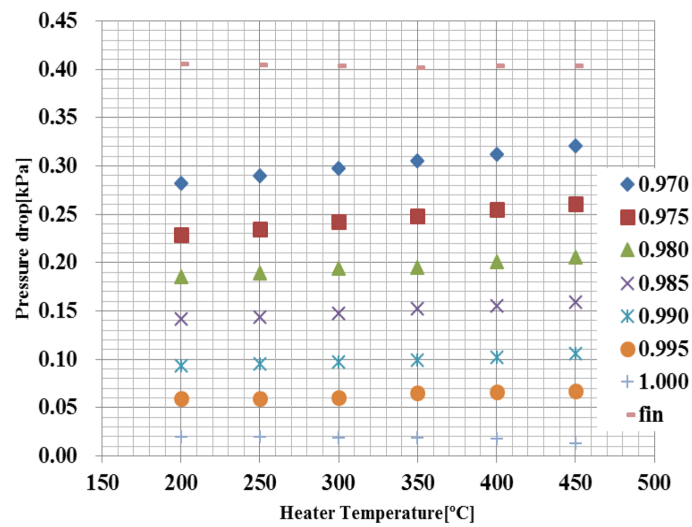

Fig.5 Pressure drop

Results of the second experiment (Heating temperature from 200°C to 800°C)

Figure 6 shows the amount of removed heat by cooling water in terms of various temperature of the heater. Table 3 shows the ratio of the amount of heat removed by inserting metallic wire and the amount of heat removed by attaching fin. The amount of removed heat by water in the case of inserting metallic wire was greater than that in the case without metallic wire in all cases. In addition to that, the amount of removed heat by cooling water in the case of inserting metallic wire was decreased as compared with that of attaching fins. Compared with the amount of heat removed from the fin type heat exchanger, the amount of heat removed by inserting metallic wire slightly increases in the high temperature range. When the temperature was 200°C, the amount of heat removed by inserting copper wire with ε=0.99 became 73 % of the amount of heat removed by the fin type heat exchanger. On the other hand, when the temperature was 800°C, the amount of heat removed by inserting metallic wire became 78 % of the amount of heat removed by the fin type heat exchanger. In the same way, when the temperature was 200°C, the amount of heat removed by inserting copper wire with ε=0.995 became 65 % of the amount of heat removed by the fin type heat exchanger. When the temperature was 800°C, the amount of heat removed by inserting copper wire became 70 % of the amount of heat removed by the fin type heat exchanger. Thus, the ratio of the amount of heat removed by inserting copper wire and the amount of heat removed by attaching fins increases with increasing of heater temperature. This is the influence of radiation. It is difficult to estimate the amount of radiative heat transfer from the experimental results because the gas temperature in the flow channel, the temperature of the wall surface, and the temperature of the copper wire were not measured. We plan to clarify the amount of heat transport by thermal radiation using the three dimensional CFD code.

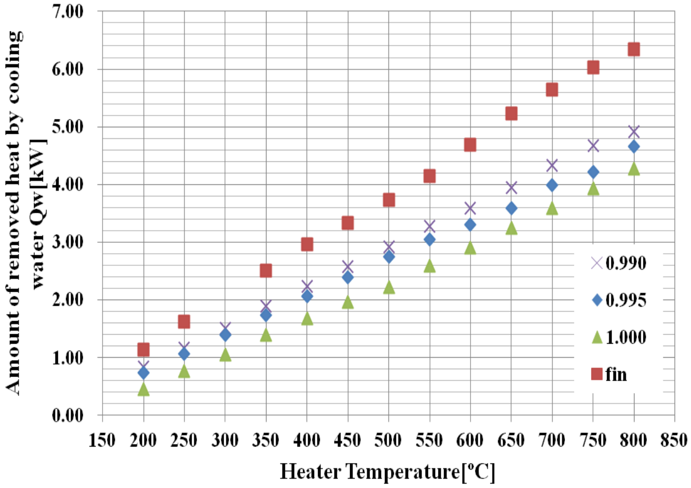

Fig.6 Amount of removed heat by cooling water

Figure 7 shows the pressure drop between the inlet and outlet of the heat exchanger in terms of the various temperature of the heater. In all temperature range, the pressure drop of the metallic wire inserted into the channel was much lower than the pressure drop of the channel attaching fin. As shown in fig.5, the pressure drop slightly increased with increasing of the heater temperature in the case of ε>0.99. However, in the case ε<099, the pressure drop was almost constant even in high temperature region. Therefore, in the case of ε<099, the amount of removed heat by inserting copper wire decreased 22% in the case of 750°C of the heater temperature. On the other hand, the pressure drop of the channel inserting copper wire decreased about 70% in comparison with the pressure drop of the channel having fin. In order to decrease the pressure drop of the channel as compared with the fin type heat exchanger, this method will be possible to apply to the heat exchanger.

Table3 Ratio of the amount of heat removed by the porous material and the amount of heat removed by the fin

Heater temperature	0.990	0.995	1.000
200	0.73	0.65	0.39
250	0.72	0.66	0.47
300			
350	0.75	0.69	0.56
400	0.75	0.70	0.57
450	0.77	0.72	0.59
500	0.78	0.74	0.60
550	0.79	0.74	0.63
600	0.76	0.70	0.62
650	0.75	0.69	0.62
700	0.77	0.71	0.64
750	0.78	0.70	0.65

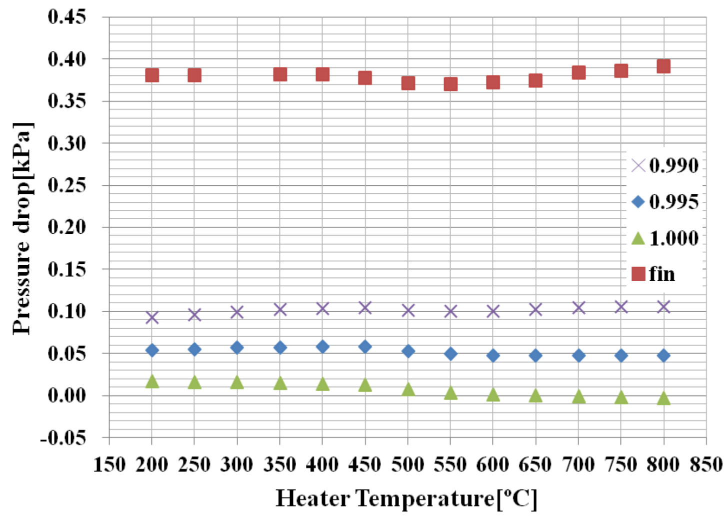

Fig.7 Pressure drop

CONCLUSION

We have investigated the heat transfer performance of air-water heat exchanger which has metallic wire inserted into the channel experimentally. Conclusions are as follows.

(1) From the results of the first experiment, 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 the fin. However, it will be possible to increase the amount of transported heat by thermal radiation as the temperature rises. When the porous material was inserted into the channel, the pressure drop was much lower than that of the fin type heat exchanger. It is possible that the amount of removed heat is not decreased by inserting metallic wire with high porosity, while reducing the pressure drop.

(2) From the results of the second experiment, the pressure drop of the channel inserting copper wire decreased about 70% in comparison with the pressure drop of the channel having fin. In order to decrease the pressure drop of the channel as compared with the fin type heat exchanger, this method will be possible to apply to the heat exchanger.

(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) We have been performing numerical analysis of the air-water heat exchanger by using three-dimensional computational fluid dynamic (3D CFD) code.

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