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Enhancement of Flow Insulation System by Stainless Steel Fibrous Material

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Abstract

Due to the advantage of porous material having a large of surface for all heat transfer modes, it could absorb the energy by convection, transmit the energy by conduction, and emit energy in mode of radiation heat transfer. The porous material, which prevents the heat transfer from the fluid flowing through it, could be called the flow insulator. The present research article aims to propose the enhancement of flow insulation system by using the stainless steel fibrous material. The stainless steel fibrous plate (porous plate) having diameter 120 mm, thickness 10, 20, and 30 mm, and three porosities 0.9292, 0.9469, and 0.9646 were examined. In the experiment, volume flow rates 6-12 m^3/h and the inlet air temperatures 350-550 ºC were varied flowing through the porous media normally. The temperature change along the test tube, temperature drop across the porous plate, and the thermal conversion efficiency were proposed. Obviously, the temperature drop across the porous plate and the thermal efficiency of the porous plate increase with the inlet gas temperature due to the effect of radiation heat transfer mode. The increasing of porosity, which decrease the heat transfer area, leads to decrease both of temperature drop and thermal efficiency. It could conclude that the fibrous porous material could be a good flow insulator at low velocity, high inlet fluid temperature and low porosity.

Keywords: Porous media; Flow insulator; Thermal efficiency; Stainless steel fibrous.

1. Introduction

Heat transfer of the porous media has been studied over past two decades both experiment and theoretical. y. The heat transfer was done by means of increasing the heat transfer area to increase the heat transfer coefficient at the surface. The porous material was applied for high temperature application, for example, a gaseous core nuclear reactor, plasma, combustion burner [1-3] and high temperature heat exchanger [4]. This application can be done by using a multiphase medium consisting of fluid phase (gas) and particulate phase (solid) [5-8] of the porous media.

Flow insulator is the material that causes the temperature different between the upstream and the downstream side when the hot fluid flowing through it. In 1982s, Echigo [9] has proposed the novel concept of flow insulation system by placing high porosity porous material (open-cellular porous material) normal to the hot gas flow direction in an exhaust duct. It was found that the high temperature exhaust gas was greatly reduced owing to the energy was transferred to the porous material by convection heat transfer leading to decrease its temperature. Moreover, the porous emits the thermal radiation into both upstream and downstream side. In 2009s, Viskanta [10] was presented the advantage of high porosity porous materials that could emit, absorb, and radiate the thermal radiation due to it has a large of surface for heat transfer. Many researchers [11-18] were studied both numerically and experimentally the energy conversion using the porous materials which involve with the flow insulation concept. Khantikomol et al. [19-20] has been proposed the numerical and experimental study on the flow insulation system using open-cellular porous material. They indicated that the upstream radiation temperature strongly affected the quantity of the gas temperature drop across the porous plate.

From above mentioned, it seems that the high porosity porous material is significant to the flow insulation system. However, it has not found any information about the fibrous material as flow insulator. Therefore, the present study aims to enhance the flow insulation system using the stainless steel fibrous material as high porosity porous material to be the flow insulator.

2. Theory

In the present study, the wall of the experimental tube with thermal insulator is assumed as the adiabatic wall. Therefore, the gas temperature difference occurred across the porous plate is due to the exchange energy between the gas and solid phase (porous plate) and then the porous media convert the energy to radiation emitting into the upstream layer. The energy of the gas that transfers to the porous plate can be determined by using the sensible heat equation as follow:

$$\dot{Q} = \dot{m}C_p\Delta T \quad (1)$$

Where, $\dot{Q}$ is the rate of the heat transfer (W), m is the mass flow rate (kg/s), C_p is the specific heat $(W/(kg\cdot^{o}C))$ and ΔT is the temperature difference (^{o}C).

The thermal efficiency (η_T) of the flow insulator can be evaluated using the equation (2) as follow

$$\eta_T = \frac{\dot{Q}_{porous}}{\dot{Q}_{input}} \quad (2)$$

Where,

$$\dot{Q}_{input} = \dot{m}C_p\left(T_4 - T_\infty\right) \quad (3)$$

$$\dot{Q}_{porous} = \dot{m}C_p\left(T_3 - T_4\right) \quad (4)$$

From equations (2)-(4), $\dot{Q}_{porous}$ is the energy rate that transfers to the porous plate (W) and $\dot{Q}_{input}$ is the supplied energy (W).

3. Experimental Setup

In the present experimental study, the stainless steel fibrous material was examined to be the flow insulator. The fibrous material was prepared as flat plate with five thickness as 10, 20, and 30 mm. Each thickness having three porosities as 0.9292, 0.9469, and 0.9646 were tested.

The experimental apparatus diagram was shown in fig.1. The experimental apparatus was made of the steel tube with 120 mm inner diameter. The tube was insulated by the ceramic fiber both inner and outer side. Therefore, the experimental tube had the inner diameter 100 mm. An air was used to be a working fluid blew by the blower through the electric heater controlled by the PID temperature controller. The single porous plate was placed normally to the hot air flow at the top of the experimental tube which was distance 300 mm from the electric heater. The air temperatures in front of the porous plate were varied from 350-550 °C and volume flow rate 6-12 m^3/h. Several type K-thermocouples were used to measure the temperatures.

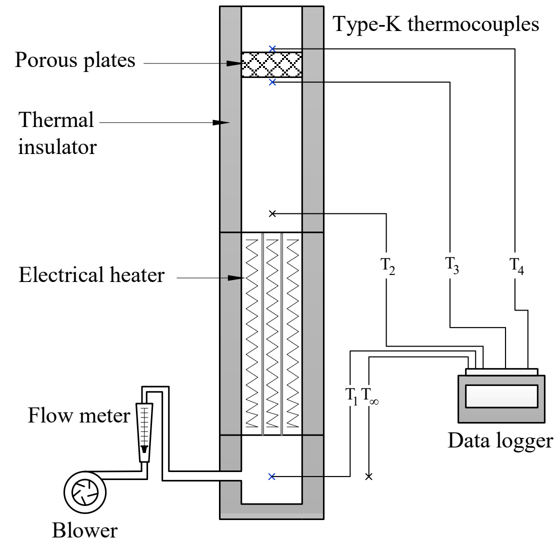

Fig. 1 The schematic diagram of the experimental apparatus.

4. Results and Discussions

To investigate the flow insulation property of the fibrous material. The flat plate with several thickness and porosities were examined. The temperature profile in the testing pipe, the temperature drop across the porous plate, and the thermal efficiency of the flow insulator were proposed experimentally.

4.1 Temperature profiles

The stainless steel fibrous material (porous material) used in the present work have the same dimension of width and thickness. Therefore, the area of heat transfer will depend on the amount (mass) of the material. In the same volume of the porous, the porosity decrease with increasing the mass of the fibrous. It could explain that the area of heat transfer increases with decreasing porosity.

Figures 2-4 show the temperature profiles along the test tube which consider the influence of the inlet hot air temperature, the thickness of porous plate, and the porosity. Consideration the effect of the inlet hot air temperature in front of the porous plate as flow insulator, all of temperature profiles along the test tube increase with the inlet hot air temperature as shown in fig.2. It reveals that the inlet air temperature affect to the temperature profiles at the upstream of the porous plate extremely owing to the radiation heat transfer acts as the importance role at high temperature.

Figure 3 indicates the influence of the porous plate thickness to the temperature profiles along the test tube. The temperature profiles along the test tube at the insulated section (upstream side) somewhat similar. But at the downstream side, the temperature rather high decrease with the porous thickness due to a large of heat transfer area.

In consideration of the influence of the porosity to the temperature profiles shown in fig.4, the temperature at the upstream side quite similar of the case of porous thickness. At the same thickness, however, the decreasing temperature along the porous plate was high according to the decreasing porosity due to the area of heat transfer increases with decreasing porosity.

It could conclude that increasing to the inlet hot air temperature, the porous thickness, and the porosity significantly influence to the temperature profile along the porous plate especially at the porous plate owing to the change of heat transfer area.

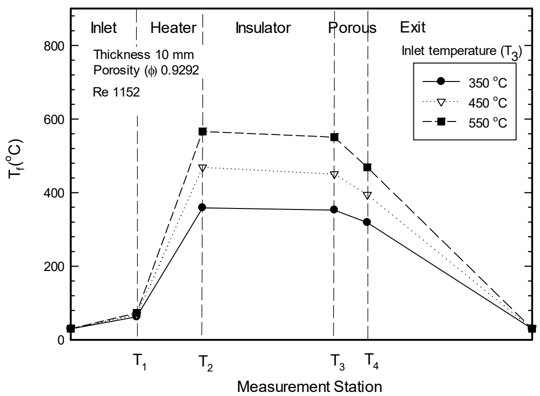

Fig.2 Influence of inlet temperature to the temperature profiles along the test tube.

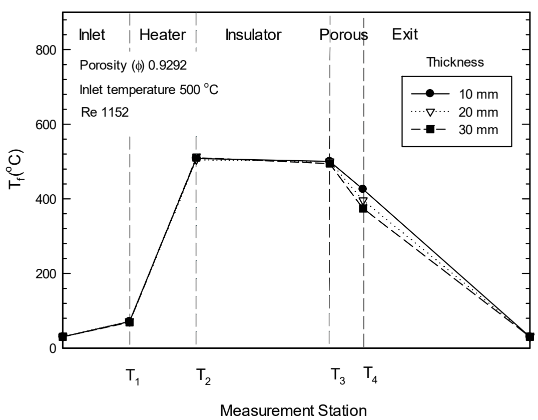

Fig.3 Influence of thickness to the temperature profiles along the test tube.

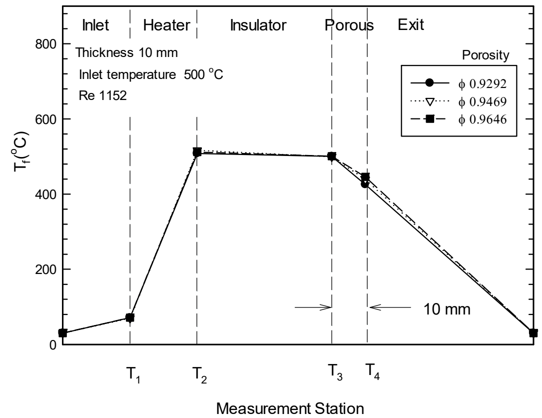

Fig.4 Influence of porosity to the temperature profiles along the test tube.

4.2 Temperature drop

The temperature drop across the porous plate is the main parameter of thermal insulator property. It means that the material keep higher temperature drop is better thermal insulator. Figs.5-7 show the influence of the inlet hot air temperature, the porous thickness, and the porosity to the hot air temperature drop across the porous plate. The experimental results revealed that the temperature drop across the porous plate (flow insulator) increase with the inlet hot air temperature and decrease with the Reynold number ($Re = \rho_\infty V D_{tube} / \mu_\infty$) through the porous plate owing to the porous plate could act as the good radiation absorbing and emitting thermal radiation at high temperature. The convection heat transfer would act as the important role at high velocity (V). Although the convection heat transfer mode could be good at high velocity but the amount of energy transfer by mass is also high too leading to decreasing of the ratio of energy transfer from the fluid to the porous and the energy transfer by mass. These reasons verify the results that the temperature drop across the porous plate could be high at low fluid velocity and high inlet hot air temperature.

Figure 6 indicate the influence of thickness of the porous plate to the temperature drop. The experimental results revealed that the temperature drop (ΔT) increase with the porous' thickness due to the reason of heat transfer area. Although the large thickness effect to the pressure drop of the fluid flow across the porous plate but it is not significant for the high porosity porous material. Therefore, the amount of energy transfer from the high temperature air to the solid phase of porous element by convection heat transfer could increase with the thickness (increasing heat transfer area) while the porous could convert the energy to heat radiation and emits to the upstream region leading to larger temperature drop.

In the case of porosity affect to the temperature drop, the results was shown in fig.7. Obviously, the temperature drop increases with decreasing porous' porosity owing to increasing of the heat transfer area.

From the experimental results for the temperature drop across the porous plate, it could explain that the stainless steel fibrous material could act as a good flow insulator the same as another high porosity porous material for example the open-cellular porous material.

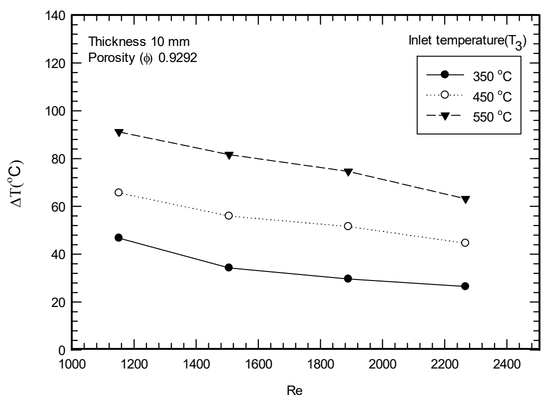

Fig.5 Influence of the inlet temperature to the temperature drop

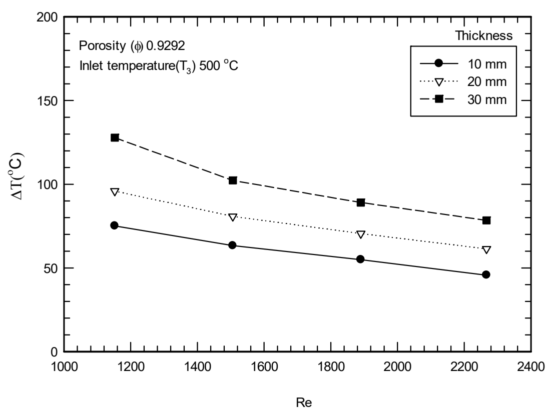

Fig.6 Influence of thickness to the temperature drop

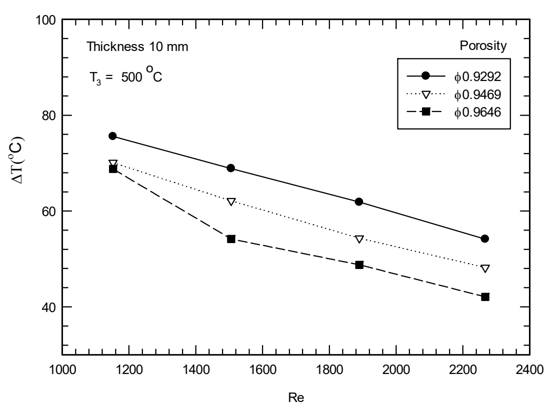

Fig.7 Influence of porosity to the temperature drop

4.3 Thermal efficiency

The thermal efficiency (η_T) of the flow insulator defined as the ratio of energy loss of the fluid to the input energy by using the equation (2). The experimental results have been indicated in figs. 8-10. Notice, the tendency of the thermal efficiency as same as the temperature drop across the porous plate.

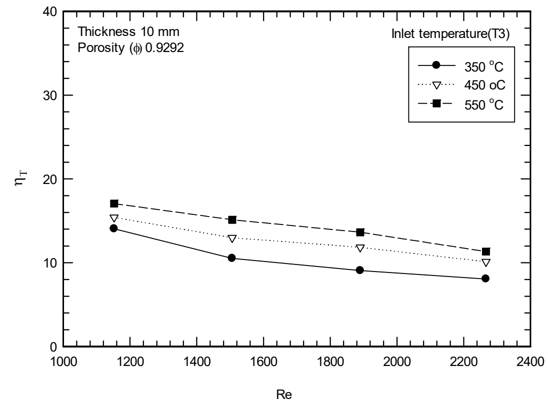

Fig.8 Influence of the inlet temperature to the thermal efficiency

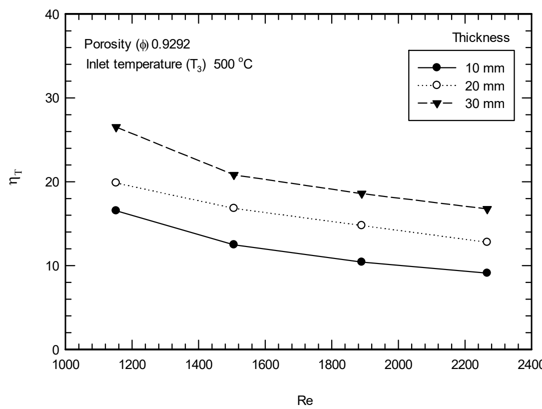

Fig.9 Influence of thickness to the thermal efficiency

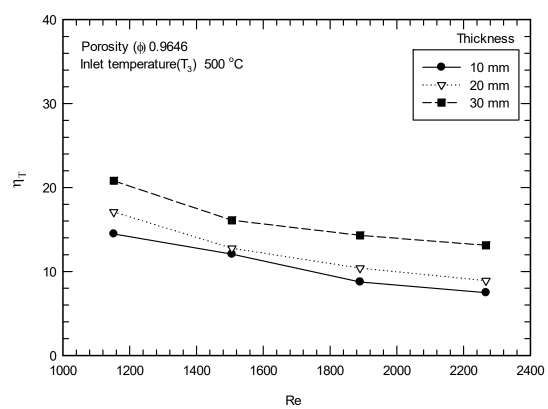

Fig.10 Influence of porosity to the thermal efficiency of porosity 0.9646

5. Conclusion

In experimental investigation of the fibrous material to enhancement of the flow insulator, the stainless steel fibrous material was prepared as porous plate to be the flow insulator. It could conclude the stainless steel fibrous material could act as a good flow insulator due to it has high porosity. The main point of study could conclude as follow:

1. The temperature profile (temperature change) along the test tube increase with the inlet air temperature. However, the porous' thickness and porosity are not significant to the upstream region temperature change. But the porous' thickness and porosity are significant to the change of temperature in the porous plate owing to the effect of heat transfer area and the high thermal radiation at high temperature.

2. The temperature drop and the thermal efficiency of flow insulator increase with the inlet air temperature due to the radiation heat transfer mode plays the important role at high temperature. Moreover, the area of heat transfer is also significant to energy conversion between the hot air and the solid element of the porous by convection heat transfer. Therefore, the temperature drop increases with the porous' thickness and decreasing porosity. Owing to the heat transfer area increases with decreasing porosity.

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