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Research Article

EXPERIMENTAL STUDY OF HEAT TRANSFER CHARACTERISTICS OF STAINLESS STEEL FIBROUS FLOW INSULATOR

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ABSTRACT:
Flow insulation is the reduction of heat transfer of flowing fluid moving through the objects. The materials chosen for flow insulation is the porous material, which the fluid can flow through it and recover the heat from the flowing fluid leading to reduce the temperature of the fluid. The present research article aims to propose the heat transfer characteristics of the stainless steel fibrous material as the flow insulator. The stainless steel fibrous plate (porous plate) having diameter 120 mm, thickness 10, 15, 20, 25, and 30 mm, and porosities 0.9292, 0.9469, and 0.9646 were examined. In the experiment, Reynolds number 1000-2500 and the inlet air temperatures 350-550 ^{o}C were varied flowing through the porous media normally. The temperature change along the test tube, temperature drop across the porous plate, and the heat recovery 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: *Flow insulator, Thermal efficiency, Fibrous material, Heat transfer, Reynolds number*

1. INTRODUCTION

Over pass two decades, heat transfer in the porous media has been studied both experiment and theory analysis. Due to the porous having high areas for heat transfer, therefore it have high heat transfer coefficient at the surface. Many high temperature facilities were done by the high porosity porous material, 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. Owing to the advantage of the porous media on high efficiency heat transfer, the energy of the flowing fluid flow through the porous element was recovered leading to the temperature different between the upstream and the downstream side. This so call novel concept was called flow insulation due to the porous could act the same behavior as thermal insulator.

In 1982s, Echigo [9] has presented placing high porosity porous material normal to the gas flow direction in an exhaust duct. It was found that the high temperature exhaust gas was greatly reduced owing to the energy was

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transferred to the porous material by convection heat transfer leading to decrease its temperature more than 100 ^{o}C for only 15 mm thickness. When the porous receive the thermal energy, the porous emits the thermal radiation into both upstream and downstream side. In 2009s, Viskanta [10] was proposed about the high porosity porous material and its application. He has been showed 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. Several researchers [11-18] were studied both numerically and experimentally, they illustrated the recovering thermal energy from flowing fluid 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.

According to the literature, 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. In the present work, the heat transfer characteristics of the flow insulation system using the stainless steel fibrous material as high porosity porous material is proposed. The stainless steel fibrous is prepared into the porous plate with 10, 15, 20, 25, and 30 mm thickness. Three porosities are examined. Heat transfer characteristics are presented in terms of heat recovery, temperature drop and the temperature profile.

2. 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, 15, 20, 25, 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 ^{o}C and volume flow rate 6-12 m^{3}/h. Type K-thermocouples were used to measure the temperatures of the flowing air at inlet of the heater (T_1), outlet of the heater (T_2), inlet of the porous plate (T_3) and out of the porous plate (T_4). Moreover, the ambient temperature was also measured during the experiment.

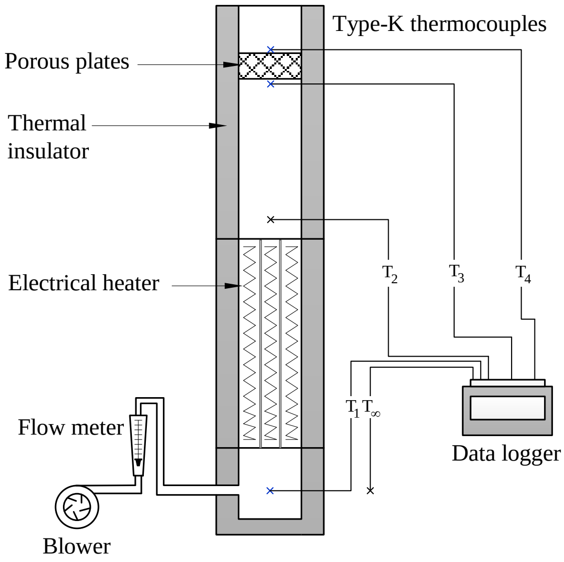


Fig. 1. The schematic diagram of the experimental apparatus.

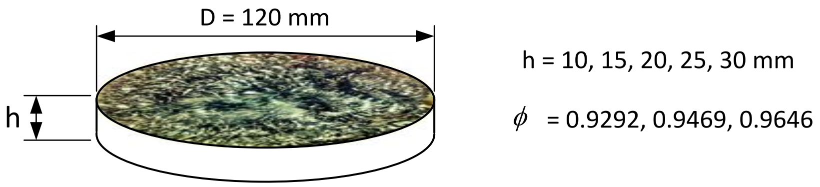


Fig. 2. The examined porous plate made of stainless steel fibrous material.

3. DATA PROCESSING

In the present study, the heat transfer characteristics was done under the exchange of heat between the fluid and the solid element of the porous material (fibrous). The temperature distribution along the test section, the temperature drop across the porous plates (ΔT), the heat rate recovery of the porous from the hot gas ($\dot{Q}_{porous}$), and the thermal efficiency of the flow insulator (η_T) were conducted. The flow condition (Reynolds number, Re), the inlet temperature of hot gas (T_{in}), the porosity (ϕ), porous thickness were considered as the independent parameters. In this section, the relative equations would be described.

The Re based on the tube diameter is given by

$$\mathrm{Re} = \rho_\infty VD / \mu_\infty . \quad (1)$$

Where, ρ_∞ is the ambient air density (1.225 kg/m^3), μ_∞ is the atmospheric absolute viscosity (1.789×10^{-5} Pa$\cdot$s), V is the average hot air velocity (m/s), and D is the duct diameter (m).

In the present experiment, the wall of the 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). The air flowing through the test tube was assumed to be a uniform flow. The present work was done under the laminar flow condition due to the fluid flow was rather low. The data was done under the steady state. The recovery energy of the porous plate was equal to the heat loss of the air by convection to the solid element of porous material, which can be expressed as follow:

$$\dot{Q}_{\mathrm{recovery}} = \dot{m}C_p\left(T_{in} - T_{out}\right). \quad (2)$$

The recovery efficiency (η_r) of the flow insulator can be evaluated by the ratio of recovery heat $(\dot{Q}_{porous})$ and the input energy $(\dot{Q}_{input})$, which was expressed in equation (3).

$$\eta_r = \frac{\dot{Q}_{porous}}{\dot{Q}_{input}} = \frac{T_3 - T_4}{T_4 - T_\infty} \quad (3)$$

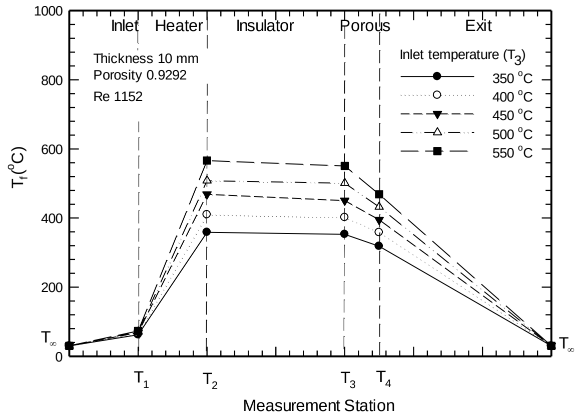
Where, T_∞ is ambient temperature (30 ^{o}C).

4. RESULTS AND DISCUSSION

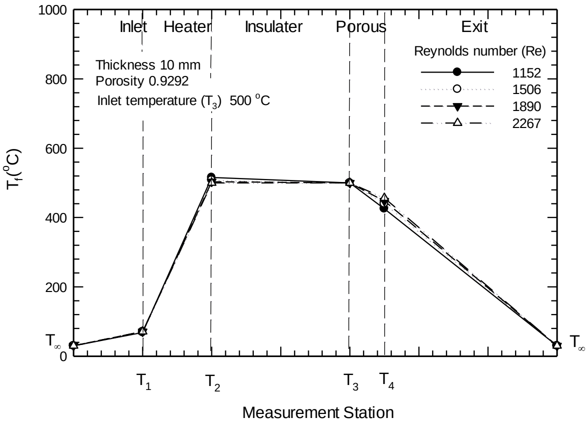
4.1 Temperature distribution in test section

The stainless steel fibrous material (porous material) used in the present work have the same element dimensions of width and thickness. Therefore, the area of heat transfer 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.

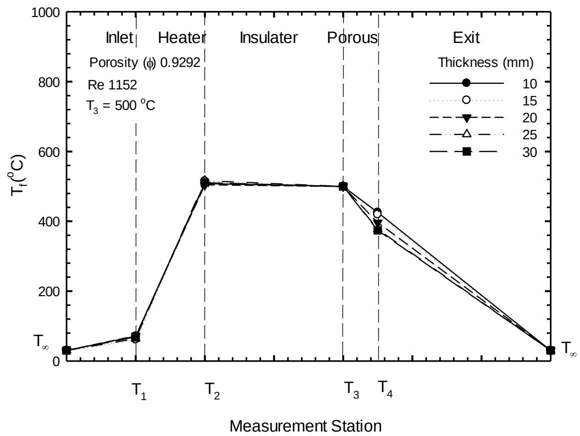
Figures 3 shows the effect of the inlet hot air temperature (T_3), Reynolds number (Re), the thickness of porous plate, and the porosity to the temperatures distribution along the test tube. The results indicated that the temperature decrease with increasing the inlet hot air temperature as shown in fig.3 (a). 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. Obviously, the Reynolds number is more effect to the temperature profile than those of thickness and the porosity (fig.3 (b)). In consideration of the effect 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 as illustrated in fig 3 (c). In consideration of the influence of the porosity to the temperature profiles shown in fig. 3 (d), 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.



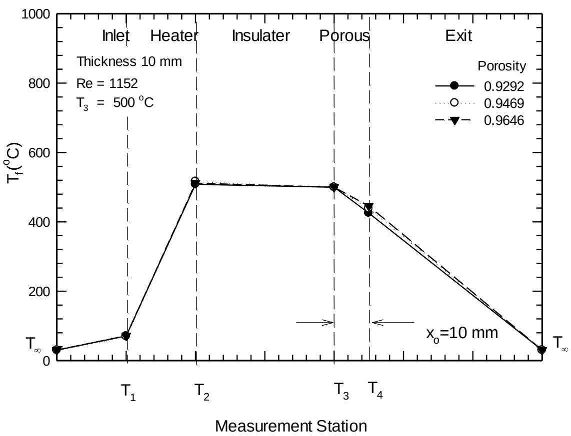
(a) Effect of inlet temperature



(b) Effect of Reynolds number



(c) Effect of porous plate thickness



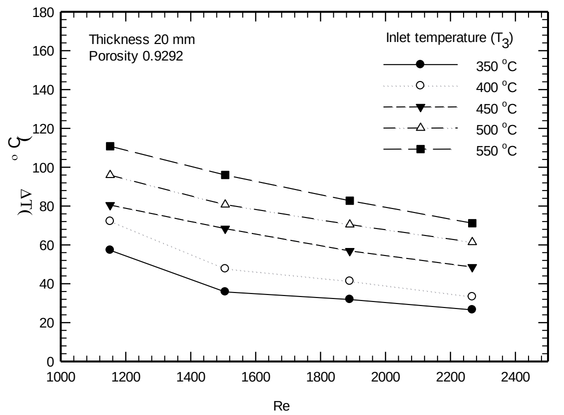
(d) Effect of porosity

Fig. 3. Temperature distribution in the test section.

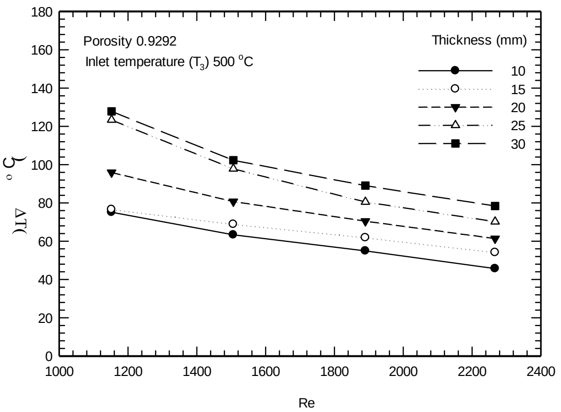
4.2 Temperature drop

The temperature drop across the porous plate (ΔT) is the main parameter of thermal insulator property. It means that the material keep higher temperature drop is better thermal insulator. Fig. 4 indicates the temperature drop across the porous plate. The experimental results reveal the effect of several parameters, which were the inlet hot air temperature, Reynolds number, the porous plate thickness and the porosities, to the temperature drop due to the heat recovery by the porous media. Higher temperature drop of the hot air flowing through the porous plate depicted the high heat exchange between the hot air and the solid element of the porous. The experimental results revealed that the temperature drop across the porous plate (flow insulator) increase with the inlet hot air temperature owing to the porous plate could act as the good radiation absorbing and emitting thermal radiation at high temperature (fig.4 (a)). While the temperature drop decrease with Reynolds number ($Re = \rho_\infty V D_{tube} / \mu_\infty$) due to the heat carry by the air element is higher than the heat transfer from the hot air to the porous element by convection. 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.

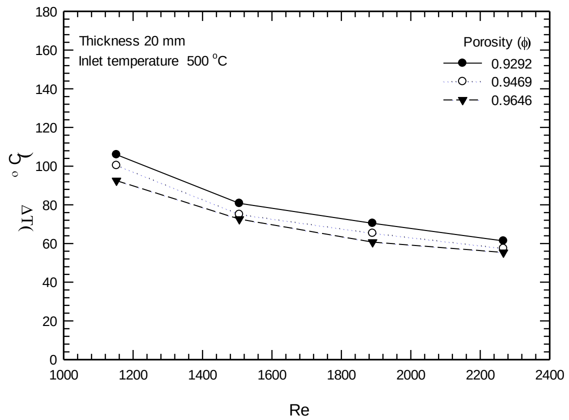
In consideration of the effect of the porous thickness (fig.4 (b)) and the porosities (fig.4 (c)), it indicated that the temperature drop (ΔT) increase with the porous' thickness but decrease with the porosity due to the reason of heat transfer area. Although the large thickness effect to the pressure 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.



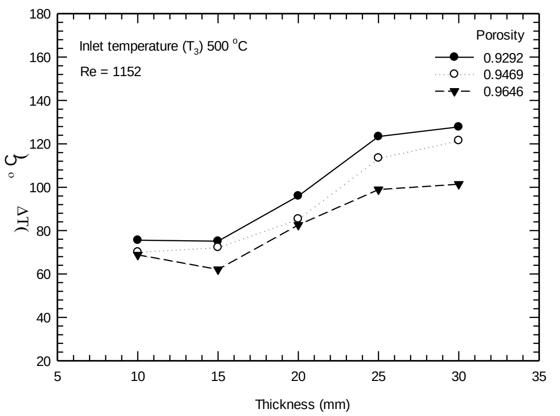
(a) Effect of Reynolds number and inlet temperature



(b) Effect of Reynolds number and thickness



(c) Effect of Reynolds number and porosity

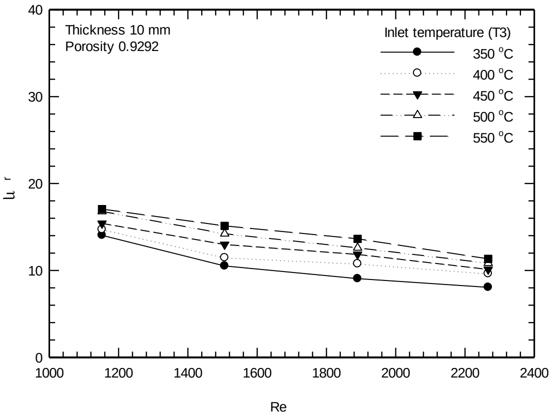


(d) Effect of thickness and porosity

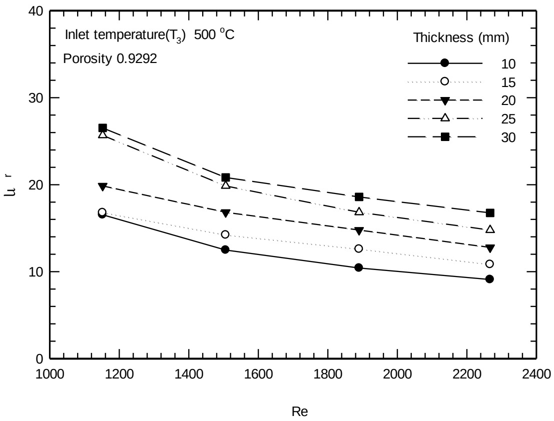
Fig. 4. Temperature drop across the porous plate.

4.3 Heat recovery efficiency

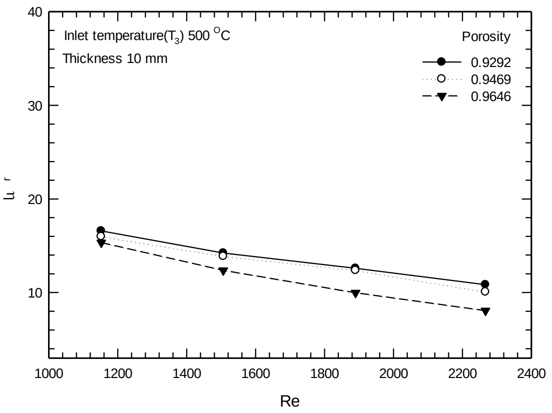
The heat recovery efficiency (η_r) of the flow insulator defined as the ratio of energy recovery from the flowing fluid of the porous media according to the equation (2). The experimental results have been indicated in fig. 5. The results depicted that the heat recovery efficiency decrease with increasing Reynolds number (Re) and porosities (ϕ), and increase with the inlet temperature (T3) and the porous thickness. Notice, the tendency of the heat recovery efficiency is same as the temperature drop across the porous plate. Consideration the effect of the porous thickness to the heat recovery efficiency, the optimum of the thickness for the present flow insulator was 25 mm, which recover the highest energy of all conditions.



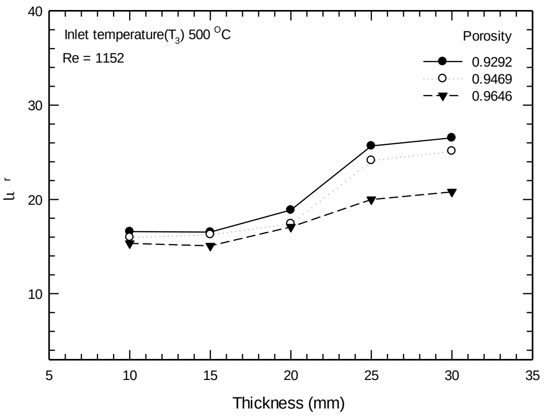
(a) Effect of Reynolds number and the inlet temperature



(b) Effect of Reynolds number and thickness



(c) Effect of Reynolds number and porosity



(d) Effect of thickness and porosity

Fig. 5. Heat recovery efficiency.

5. Conclusions

The present study conducted about the heat transfer of flowing fluid moving through the porous plate, the examined as the flow insulator. The experiment was done under the conditions according to the heat transfer characteristics of the porous media. The heat exchange between the hot air and the solid element of the porous was proposed in term of heat recovery. Many independent parameters were investigated which could conclude as follow.

1. The inlet hot air temperature in front of the porous plate rather affect to increase the temperature profile along the test duct, the temperature drop across the porous plate, and the recovery efficiency due to the effect of radiation heat transfer that plays an important role in high temperature.

2. In consideration of the effect of the flow velocity of the fluid (Reynolds number), the experimental results indicated that the temperature profile along the test duct, the temperature drop across the porous plate, and the recovery efficiency decrease with increasing the Reynolds number due to decreasing the ratio of the amount of heat transfer by mass of the fluid and the heat transfer by convection to the porous element.

3. The temperature drop and the heat recovery efficiency increase with the porous thickness until about 25 mm. Therefore, the optimum thickness condition for the stainless steel fibrous material plate was 25 mm thickness.

4. Although the area of heat transfer of the porous plate at low porosity increase but the fluid does not easy flow across the porous plate due to the porosity of the stainless steel fibrous material decrease with increasing the amount of mass. Therefore, the temperature drop and heat recovery increase with decrease the porosity.

6. Acknowledgement

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Nomenclature

Cp	specific heat at constant pressure, J/kg.K
D	tube diameter, m
$\dot{m}$	mass flow rate, kg/s
$\dot{Q}$	heat rate, W
Re	Reynolds number
T	temperature, ^{o}C
V	velocity, m/s
ρ	fluid density, kg/m^3
μ	absolute viscosity, Pa.s
Subscripts	
1	in front of the heater
2	out of the heater
3	in front of the porous plate
4	out of the porous plate
f	fluid (air)
r	recovery
porous	porous plate
∞	ambient

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