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Investigation of Heat Transfer Enhancement for Natural Convection through Porous Carbon Foam

V. B. Vaidya

Asst. Professor, K. D. K. College of Engineering, Nagpur

***Abstract:-*Porous carbon foam is considered as a suitable material to enhancement of convective heat transfer results from the passage of fluid through the open, interconnected void structure, exposing the fluid to large surface area. This was proved experimentally by comparing a bare copper pipe and copper pipe wrapped with porous carbon foam. With the same heat input; porous carbon foam has shown a noticeable enhancement (30 to 55%) in convective heat transfer. The various properties of porous carbon foam, their different applications and its production processes are also discussed. The results are presented with the help of suitable graphs and the phenomenon of heat transfer enhancement is explained in detail.**

A brief discussion presents in this paper on the application of using porous media (e.g., Carbon foam) to enhancement of convective heat transfer results are found in good agreement with each other and experimental results are comparatively shown with the help of suitable graphs.

***Keywords:* Experimental, Heat Transfer Enhancement, Porous Media, Natural Convection**

I. INTRODUCTION

In most natural convection heat exchangers, the thermal resistance is highest at the fluid/solid interface; especially if the fluid is air. Porous mediums have been identified as a means to reduce the thermal resistance at the gas/solid interface and enhance heat transfer rates. A porous medium enhancement of convective heat transfer by the use of porous materials results from the passage of fluid through the open, interconnected void structure, thereby exposing the fluid to internal surface area. Due to high effective conductivities of the foam the conductive resistance of the foam was insignificant. The depth of foam required to obtain the best heat transfer enhancement based upon depth of penetration of air was deduced to be 3mm (Straatman and Gallego, 2006). Enhanced heat transfer could be achieved when the effective conductivity of the porous layer was higher than that of fluid; when a thin porous layer is attached to a flat plate in a forced convection environment (Vafai and kim, 1990). When a porous layer with porosities of 0.93 and 0.97 was attached to a flat plate, there is an increase in Nusselt number up-to four times relative to a bare plate (Angirasa, 2002). The volumetric heat transfer coefficient increases with decrease in pore size of ceramic foams. Also the heat transfer coefficient increases with decrease in foam porosity (Younis and Viskanta, 2000). Use of porous metal foam baffles can enhance heat transfer as 300% compared to heat transfer in straight rectangular channel with no porous baffles (Ko and Anand, 2003). H. Togashi and K. Yuki (2001) have developed a cooling technique with metal porous media, and have succeeded in removing inlet heat flux of over 50 MW/m2. In their study, high heat removal experiments are performed by using cylindrical homogeneous and functionally graded metal porous media to estimate their fundamental heat transfer performances. Carbon foam is recognized as having the great potential to replacement for metal fins in thermal management systems such as heat exchanger equipments (Duston et al 2004). Porous medium has shown to enhance the heat transfer; it has also been used in liquid and gaseous fuel combustion to improve the combustion process (Muhad Rozi and Bin Matnawi, 2008). It is verified that the cooling performance of porous media whose porosity and fiber-diameter are spatially uniform, becomes higher as the pore size is smaller. For the porous media with the finer pore, the pressure loss becomes higher, which prevents the increase of flow velocity of cooling water. For this reason, the heat transfer enhancement by forced-convection is quite low.

The aim of this research is to study experimentally the heat transfer by natural convection in porous carbon foam to enhance the heat transfer process. Porous carbon foam is considered as a suitable material to enhancement of convective heat transfer results from the passage of fluid through the open, interconnected void structure, exposing the fluid to large surface area. The various properties of porous carbon foam, their different applications and its production processes are discussed.

II. EXPERIMENTAL

Experimental set-up shown in fig. 1 consists of two copper pipes of thickness 3mm. One copper pipe is wrapped throughout its length by porous carbon foam (Fig. 2). Six thermocouples are soldered to the surface of each copper pipe to measure the surface temperature. One more thermocouple is placed outside the test section to measure the ambient temperature. A coil is mounted on another small copper pipe and this pipe is inserted inside the main copper pipe to provide heat input to the main pipe. A test section is fabricated out of plastic glass inside which the main copper pipe is mounted on a small clamp with bronze bushes. The copper pipe is filled with asbestos powder at both the ends to prevent heat loss. A voltmeter and ammeter is provided on the control panel to measure the heat input. The heat input is given through a variable current dimmer-stat power supply. All the temperatures can be recorded on a digital temperature indicator with a selector switch. The test section is open at the bottom end for supply of ambient air supply in the chamber with minimal disturbance to the natural convection currents.

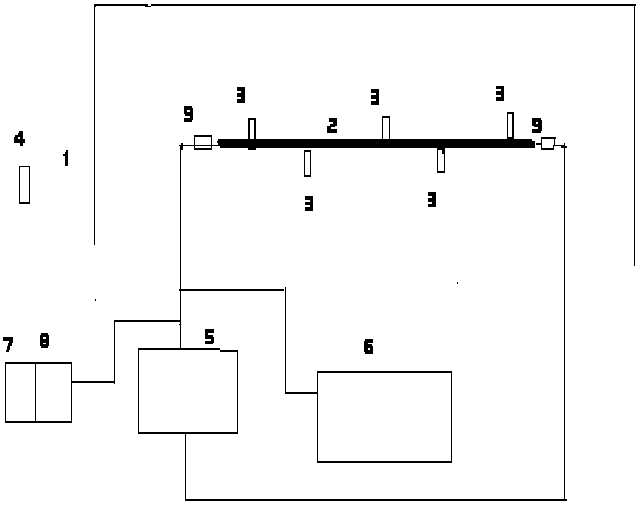

Fig. 1: Experimental set up.

1 – Test section walls
2 – Copper pipe
3 – Thermocouples for surface temperature measurement
4 – Thermocouple for ambient temperature measurement
5 – Dimmer-stat power supply
6 – Digital temperature indication system
7 – Voltmeter
8 – Ammeter
9 – Bronze bushes

Fig. no. 2: Bare copper pipe & copper pipe wrapped with porous carbon foam.

III. RESULT AND DISCUSSION

When a bare copper pipe and copper pipe wrapped with porous carbon foam are compared by giving same heat input through a variable current power supply dimmer-stat; the convective steady state heat transfer enhancement was shown to be 30 to 55%. The critical thickness of porous carbon foam was taken as 3 mm. The heat transfer coefficient does not vary linearly with the length of the pipe. The heat transfer coefficient is having a high value at the beginning as expected because of the just starting of the building of the boundary layer and is deceased as expected in the upward direction due to the thickening of layer which is laminar one. This trend is maintained up-to half of the length (approximately) and beyond that there is little variation and turbulent boundary layer. The last point shown somewhat increase in the value of heat transfer coefficient which is attributed to end loss causing the temperature drop.

The length averaged surface temperature and mean Nusselt number verses Rayleigh number are presented. It is observed that as the surface temperature increases, the ratio of buoyancy forces to viscous forces increases. It follows that air flow rate and consequently Nusselt number increase with increasing surface temperature and Rayleigh number. Part of the Nusselt number increase observed can be explained by surface area coefficients. This observation suggests that a heat transfer enhancement is observed due to an increased surface area. This phenomenon can be explained as there is high resistance to flow and air velocity is low may be fast enough to have a noticeable effect on overall natural convection Nusselt number. Because of tremendous surface area within the porous layer, even small flow rates can be responsible for noticeable heat transfer under natural convection conditions. Also, the high thermal conductivity foam offers a continuous surface for the development of flow in horizontal direction. Being a good conductor the surface temperature of foam remains relatively high and the air density gradient is allowed to develop along the continuous horizontal surface, thus producing continuous air flow and good natural convection. Finally radiation heat transfer plays a very significant role in overall heat transfer.

Graphical representation shown in figures given below for Bare copper pipe (Case 1) and Copper pipe wrapped with porous carbon foam (Case 2) for experimental study of Heat transfer coefficient Vs length of pipe, Surface temperature Vs Rayleigh number and Nusselt number Vs Rayleigh number as shown in respective figures .

1: Heat transfer coefficient Vs length of pipe

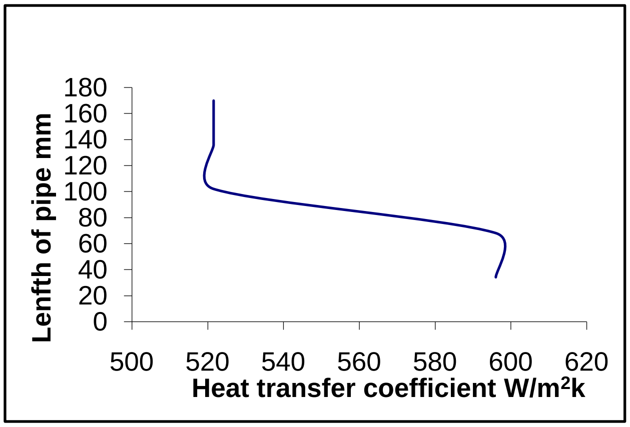

Fig. 5: Bare copper pipe: Case 1 – Set 3

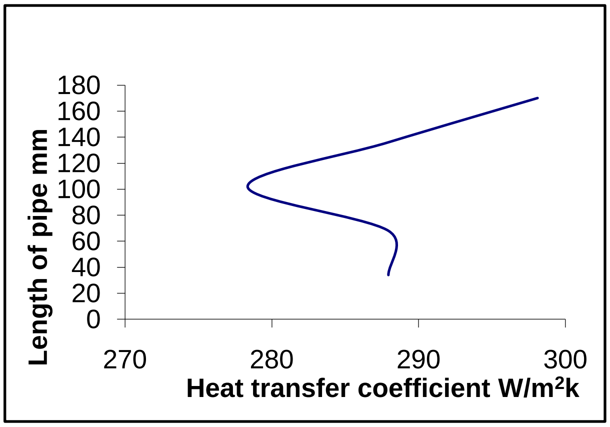

Fig. 6: porous carbon foam pipe: Case 2 – Set 1

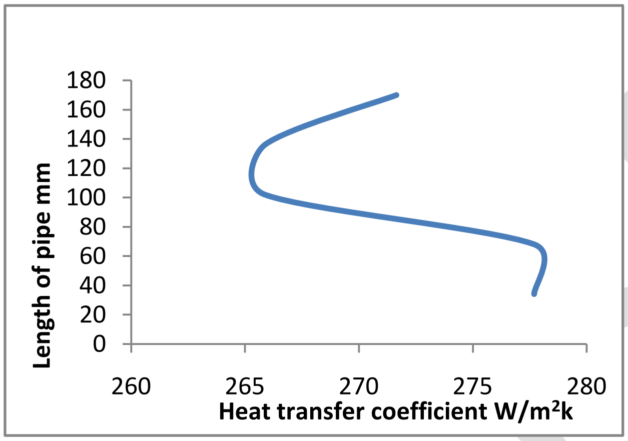

Fig. 7: porous carbon foam pipe: Case 2 – Set 2

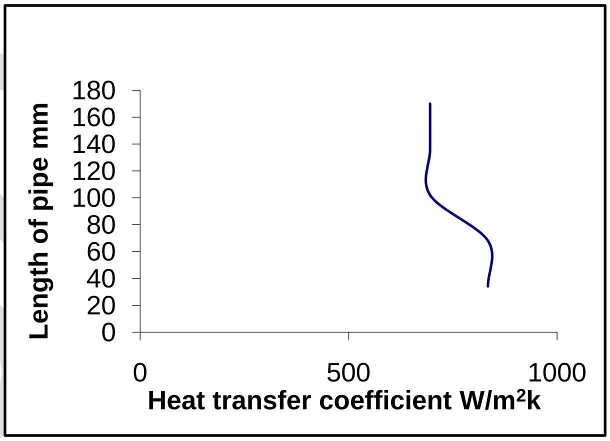

Fig. 8: porous carbon foam pipe: Case 2 – Set3

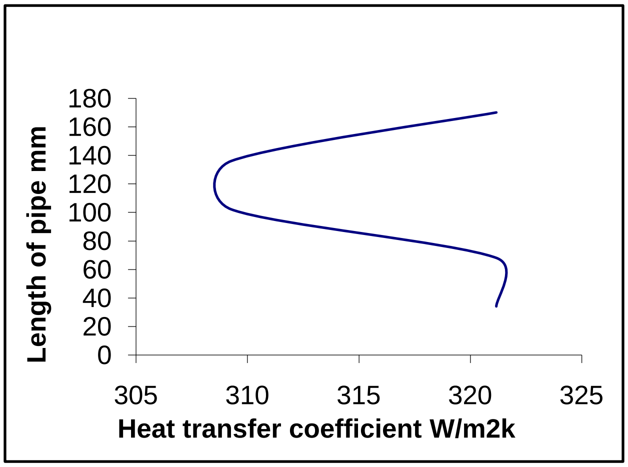

Fig. 7: porous carbon foam pipe: Case 2 – Set 2

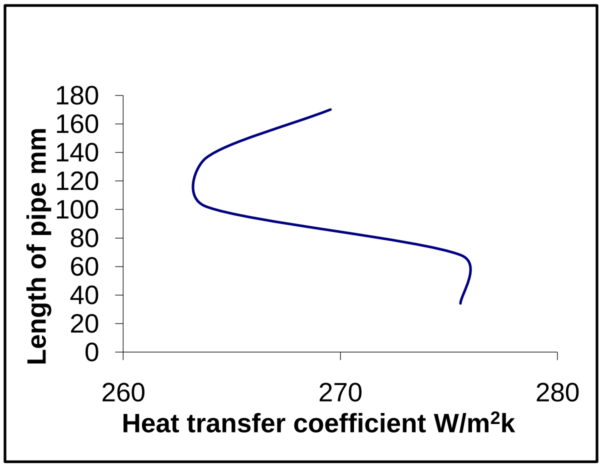

Fig. 8: porous carbon foam pipe: Case 2 – Set3

2: Surface temperature Vs Rayleigh number

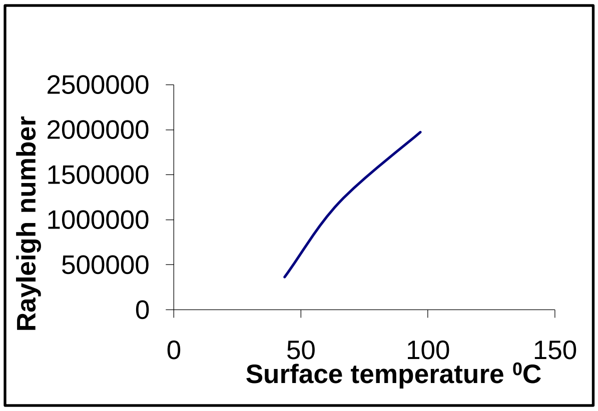

Fig. 8: Bare copper pipe: Case 1

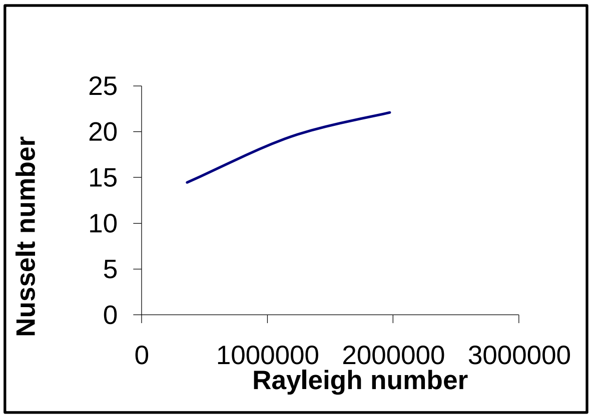

Fig. 9: porous carbon foam pipe: Case 2

3: Nusselt number Vs Rayleigh number

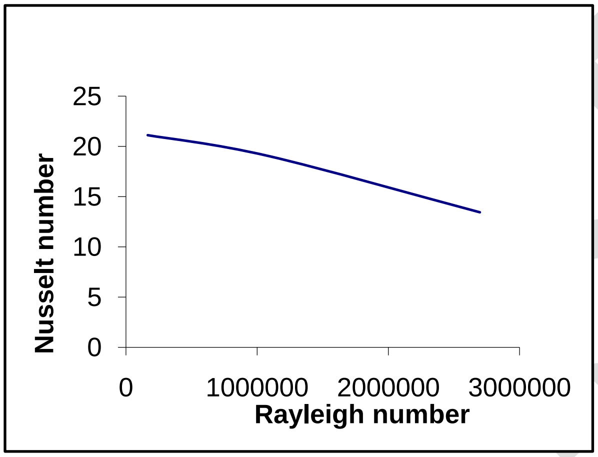

Fig. 10: Bare copper pipe: Case 1

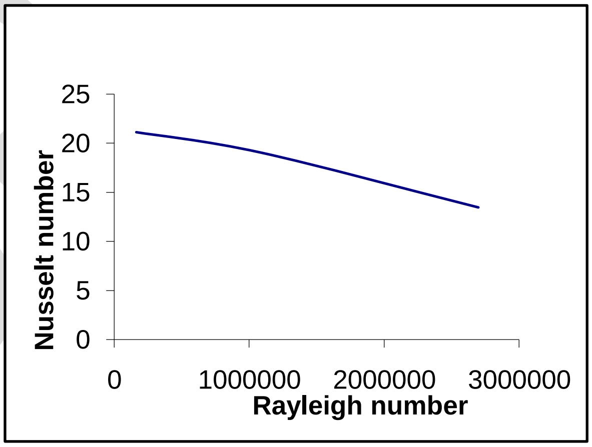

Fig. 11: porous carbon foam pipe: Case 2

IV. CONCLUSION

Wide used of heat exchanger are very important for successful implementation of new energy sources using energy conversion, energy conservation with heat recovery. Enhancement of heat transfer in heat exchanger using porous structures (e.g. carbon foam) due to their large surface area per unit of volume, and this was proved experimentally by comparing a bare copper pipe and copper pipe wrapped with porous carbon foam. With the same heat input; porous carbon foam has shown a noticeable enhancement (30 to 55%) in convective heat transfer. The various properties of porous carbon foam, their different applications and its production processes are also discussed.

A brief discussion presents in this paper on the application of using porous media (e.g. Carbon foam) to enhancement of convective heat transfer results are found in good agreement with each other and experimental results are comparatively shown with the help of suitable graphs.

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