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Natural Convection Heat Transfer In Heated Vertical Tube Without Internal Rings

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ABSTRACT
An experimental investigation of natural convection heat transfer in heated vertical pipes dissipating heat from the internal surface is presented. The pipes are open-ended and circular in cross section. The test section is electrically heated imposing the circumferentially and axially constant wall heat flux. The purpose of this work is to study experimentally the natural convection pipe flows at different heating levels. The test section is a vertical, open-ended cylindrical pipe dissipating heat from the internal surface. The test section is electrically heated imposing the circumferentially and axially constant wall heat flux. Heat transfer experiment is carried out for four different channels of 45mm internal diameter and 3.8mm thickness with length 450 mm. Ratios of length to diameter of the channel is taken as L/D = 10. Wall heat fluxes are maintained at $q^{//}$ = 250 to 3341 W/m^2. A systematic experimental database for the local steady state natural convection heat transfer behaviour is obtained. A correlation is developed for average Nusselt number and modified Rayleigh number and another correlation is also developed for modified Rayleigh number and modified Reynolds number.
Keywords- Heat flux, heat transfer, natural convection, ring spacing, ring thickness

I. Introduction

Natural convection heat transfer has been a reliable, cost-effective cooling method for the fast growing electronic industry where hundreds of thermal connection modules are accommodated on a small base. As the density of these heat producing modules increases day by day, for more compactness, the heat released should be transferred from the surface not only to protect them but also for longer life. There is often the need to cool the internal surfaces of vertical open-ended ducts by natural convection, despite the low rates of heat transfer that this convection process affords. Thus information on the behaviour of natural convection flow through confined spaces has been found useful especially in the thermal fluid systems encountered in the diverse fields of nuclear and solar energy. Due to its importance, the natural convection problem has received increasing attention in the literature in recent years. At present, flow of gaseous heat carriers in vertical channels with natural convection is widely encountered in science and engineering. For example, in domestic convectors, cooling systems of radio electronic and electrical equipment, nuclear reactors with passive cooling systems, dry cooling towers, ground thermo siphons, etc. The purpose of this work is to study experimentally the natural convection pipe flows at different heating levels. The test section is a vertical, open-ended cylindrical pipe dissipating heat from the internal surface. The test section is electrically heated imposing the circumferentially and axially constant wall heat flux. As a result of the heat transfer to air from the internal surface of the pipe, the temperature of the air increases. The resulting density non-uniformity causes the air in the pipe to rise. Heat transfer experiment is carried out for channel of 45mm internal diameter and 3.8mm thickness with length 450 mm. Ratios of length to diameter of the channel is taken as L/D = 10, Wall heat fluxes are maintained at $q^{//}$ = 250 to 3341 W/m^2. Although extensive work has been done on the study of natural convection hydrodynamics and heat exchange in vertical open-ended channels without intensifiers, but the works on internal

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heat transfer with presence of intensifiers are not adequate in literature. Investigations are still going on to determine the effects of various parameters on hydrodynamics and heat transfer coefficients. Mallik and Sastri [1] studied experimentally the natural convection heat transfer over an array of staggered discrete vertical plates and found that the use of discrete vertical plates in lieu of continuous plates gives rise to enhancement of natural convection heat transfer. The highest local heat transfer values are encountered at the leading edge and least at the trailing edge of each plate for a particular temperature level and spacing. The highest value corresponds to the thinnest thermal boundary layer and as the thermal boundary layer starts growing from the leading edge of each plate, the heat transfer values starts decreasing and reach a minimum at the trailing edge. Had the plates been continuous, there would have been decrease in the heat transfer values continuously along the height of the vertical plate for same input conditions. They also found that the heat transfer quantities at the leading edge of the top plate are more than that at the trailing edge but less than that at the leading edge of the bottom plate. Degree of enhancement increases with increase in spacing. Sparrow and Prakash [2], and Prakash and Sparrow [3] have analyzed the free convection from a staggered array of discrete vertical plates. They compared the performance of a staggered array of discrete vertical plates with that of a parallel flat channel, considering the wall at uniform temperature. Their results indicated that larger spacing, shorter plate and smaller heights of the channels provide enhancement of heat transfer. Anug et al. [4] attempted to derive a general expression to account for the effect of flow restriction, while still considering the governing equation to be parabolic. Flow restrictions encountered in Aung's study are in the form of staggered cards and baffles. Capobianchi and Aziz [5] analyzed natural convective flows over vertical surfaces and found that the local Nusselt number is an implicit function of the Biot number characterizing the convective heating on the backside of the plate. The order of magnitude of the local Nusselt number was therefore evaluated numerically for three values each of the Boussinesq, Prandtl, and Biot number. Jha and Ajibade [6] found that the amplitudes and phases of temperature and velocity as well as the rate of heat transfer and the skin-friction on the plates. In presence of viscous dissipation, fluids of relatively small Prandtl number has higher temperature than the channel plates and as such, heat is being transferred from the fluid to the plate. For air in free convection on a vertical flat late, the critical Grashof number has been observed by Eckert and Soehngen [7] to be approximately 4×10^8. Values ranging between 10^8 and 10^9 are observed for different fluids and environment. Nayak et al. [8-20] offered heat flow possessions inside perpendicular pipes. The enhancement of heat transfer in a vertical pipe is presented, possibly due to the installation of internal barriers; in their work, rectangular rings were taken as internal barriers. They presented some innovative methods towards sustainability.

2. Experimental set-up and procedure

Fig. 1, shows the overall experimental set-up, which consists of the entire apparatus and the main instruments. The experimental set-up consists of a test section, an electrical circuit of heating and a measuring system. The test section is a cylindrical tube. In this study a hollow tube is made of aluminium which is 45mm in diameter and 3.8mm thick. Nine Copper-Constantan thermocouples are fixed to monitor temperatures on the internal surface at various locations as shown in the figure. Holes of 0.8 mm diameter are drilled at these locations for inserting the thermocouples.

After inserting the thermocouple beads, the holes are filled with aluminium powder for getting good thermal contact with the tube. Then the opening of the thermocouple wells is closed by punching with a dot punch. Epoxy is used for sealing the opening of the thermocouple wells and for holding the thermocouples in position. Wall temperatures at different locations are found out from the millivoltmeter readings to which thermocouples are connected. The fluid temperatures at the channel exit and entrance are found out at various radial distances by two traversing type thermocouples provided at the top and bottom of the channel respectively. The electric power input to the test section is determined from the measured voltage drop across the test section and the current along the test section.

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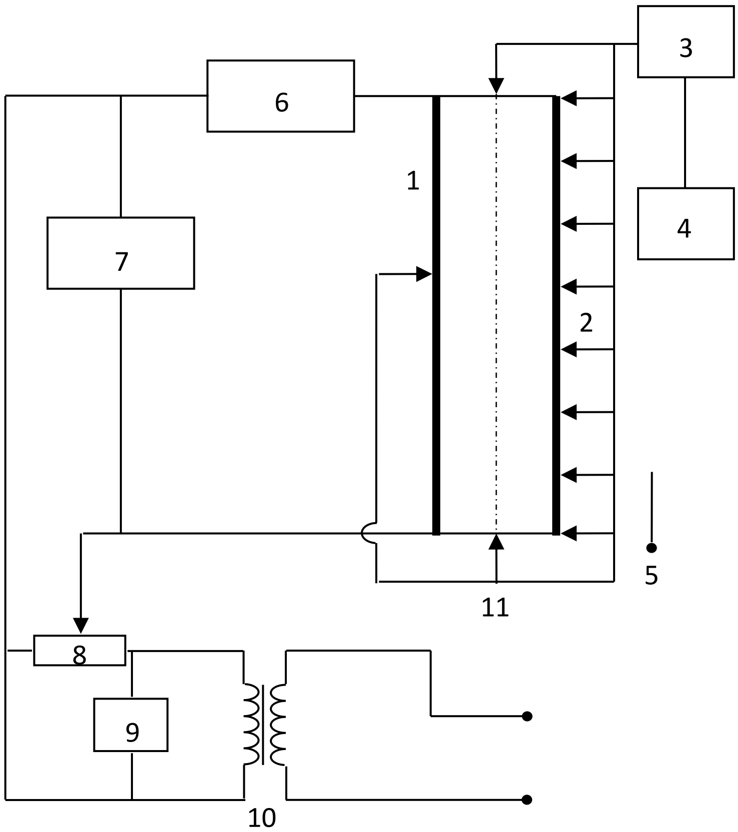

Fig. 1. Experimental Set-up

1. Test section, 2. System of thermocouples, 3. Selector switch, 4. Millivoltmeter, 5. Thermometer, 6. Ammeter, 7 & 9. Volt meter, 8. Variac, 10. Transformer, 11. Traversing type thermocouples

3. Results and discussion

Typical axial variations of local wall temperatures for L/D ratio 10 and for various heat fluxes are shown in plotted in fig. 2 for smooth tubes. It increases along the height of the cylinder, which is in accordance with the theoretical predictions done by various investigators. But it slightly decreases towards the end, which may be due to the heat rejection from the end of the tubes. Fig. 3 shows the relationships between the experimentally obtained average Nusselt number and modified Rayleigh number, which is plotted with log-log scale. This correction for laminar natural convection in smooth vertical tubes can be expressed as:

$$\overline{Nu} = 0.33 \times \left(Ra^{\#}\right)^{0.31}$$

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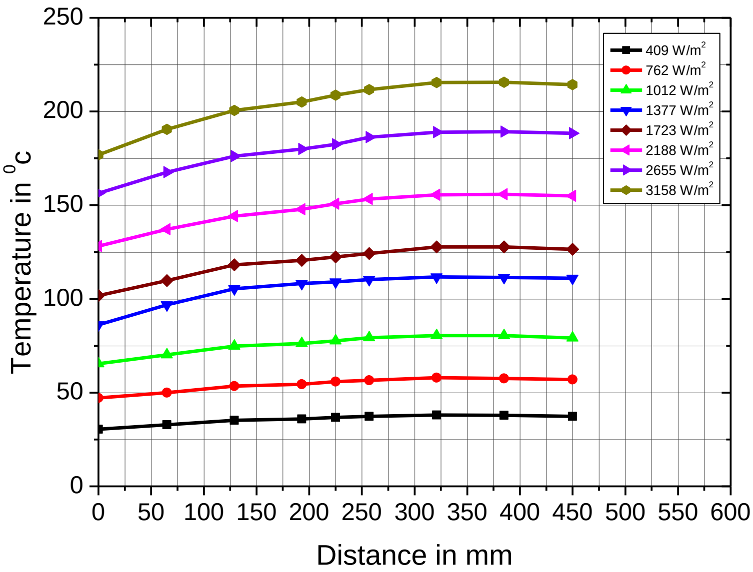

Fig. 2. Variations of local wall

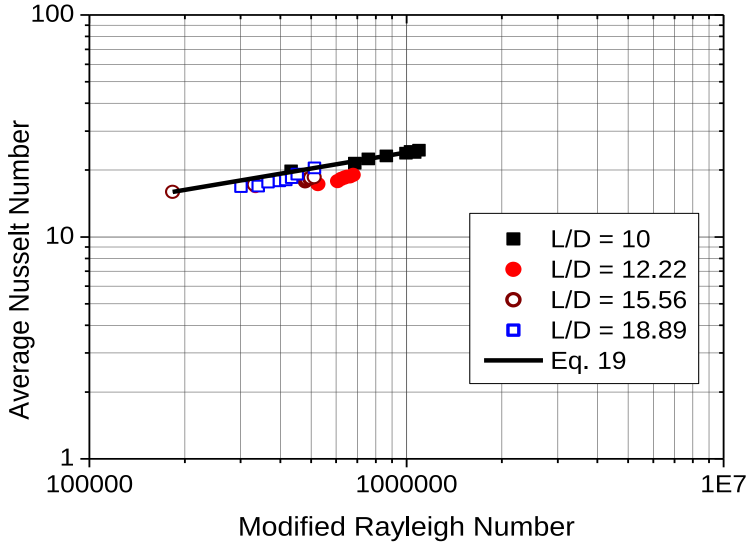

Fig. 3. Variations of local wall

CONCLUSIONS

The natural convection heat transfer in a vertical pipe has been studied experimentally, for smooth tube. The effects of channel length, imposed wall heat flux on the characteristics of natural convection heat transfer are examined in detail. The following conclusions can be drawn from the present investigation.

(i). Average heat transfer rate from the internal surfaces of a heated vertical pipe increases along the direction of heat flow.

(ii). Average heat transfer rate increases with increasing the length of the tube up to a certain limits, beyond which it decreases.

(iii). A correlation between average Nusselt number and modified Rayleigh number was found as: $Nu = 0.33 \times (Ra^{\#})^{0.31}$, which can predict the data accurately within ± 5% error.

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