Experimental Study of Buoyancy Induced Flow and Heat Transfer Through Uniformly Heated Vertical Tube Air Heater

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Abstract: ***The present work is aimed at studying the effect of different system parameters on the heat transfer on vertical circular tube air heater. They include tube length, tube diameter, and heat flux supplied. Constant heat flux boundary condition is created on the tube surface. Experiment is conducted to investigate the effect of different system parameter on heat transfer and buoyancy induced flow. The heat transfer coefficient was found increasing with increase in heat flux supplied, but it reduces with increase in diameter of the tube and its length. The air outlet temperature was found increasing with increase in heat flux, tube length but reduces with increase in tube diameter. Nusselt number is calculated and was found well within 10% of the results given in the literature.***

Keywords: air heater**,** vertical tube, heat transfer coefficient, convection, buoyancy, induced flow.

1. Introduction

Natural convection is the easiest way to heat the fluid flows through vertical open-ended pipes and ducts. Information on the behavior of natural convection flow through confines passage and tubes has been found many applications especially in the thermo-fluid systems encountered in the diverse fields of the storage of cryogenic fluids, condensers, nuclear engineering, and solar thermal devices. Due to its low cost, the natural convection problem has received increasing attention in the literature.

Natural convection air heating system has large number of applications such as solar air heater, solar dryer, cooling of turbine blades etc. In simple air heater using circular tubes, heat is supplied to the inclined or vertical tubes through which air flows. The air inside the tube gets heated and starts moving in upward direction due to buoyancy. It is replaced by cold atmospheric air from the bottom and flow is established. The flow of air and its outlet temperature depends on many parameters such as tube diameter, tube length, tube inclination and heat flux supplied to the tube.

The problem of laminar natural convective flow through confined space was first studied by Elenbaas [1] and established the heat dissipating characteristics of vertical ducts with uniform surface temperatures boundary conditions. Al–Arabi [2] studied experimentally the heat transfer characteristics of the inclined tubes working in natural convection mode with air as the working fluid and subjected to uniform heat flux boundary condition.

Hussain Mohammed [3] has experimentally investigated free convection heat transfer for laminar air flow in a vertical circular pipe by using the boundary condition of constant wall heat flux in the ranges of local Rayleigh number (RaL) from 1.1×10^9 to 4.7×10^9. The surface temperature along the pipe surface for same heat flux was observed higher values for inlet condition with length of 1200 mm and lower values for bell-mouth in let condition. Following correlations are suggested;

$Nu_L = 1.176 (Ra_L)^{0.23}$ for configuration with L/D = 40
$Nu_L = 1.202 (Ra_L)^{0.23}$ for configuration with L/D = 20
$Nu_L = 1.372 (Ra_L)^{0.23}$ for sharp-edge configuration
$Nu_L = 1.462 (Ra_L)^{0.23}$ for bell-mouth configuration
$Nu_L = 1.248 (Ra_L)^{0.23}$ for all inlet configurations

From the literature it is observed that most of the available works deal with inclined and vertical tubes/ducts, parallel plates in special cases only.

The knowledge of heat transfer coefficient in such buoyancy induced flow through inclined tubes is essential for selecting the optimum diameter of the riser tube that will increase the efficiency of the system for a given collection area.

Therefore, the purpose of the present study is to provide experimental data on free convection laminar air heat transfer from open ended vertical circular pipe with a constant wall heat flux boundary condition and with different system parameters and to propose empirical correlations for this problem.

2. Experimentation

2.1 Experimental Set Up

A schematic of the Experimental set-up is shown in Figure 1. It consists of a long copper tube called test section, provided with a heating coil, to create uniform heat flux boundary condition on the tube surface. The test section is mounted in vertical position on a wooden stand. The power supplied is measured directly with the help of pre-calibrated wattmeter (accuracy ±1%). Copper Constantan Thermocouples (accuracy ±0.2^{0}C) were used to measure all the temperatures. When heat supply is given the air in the tube gets heated and flow is established because of buoyancy effect. The test section is properly insulated by two layers of asbestos rope of 8 mm diameter. Thermocouples are also mounted on both inner and outer insulations at various locations along the length of tube for measuring insulation temperature.

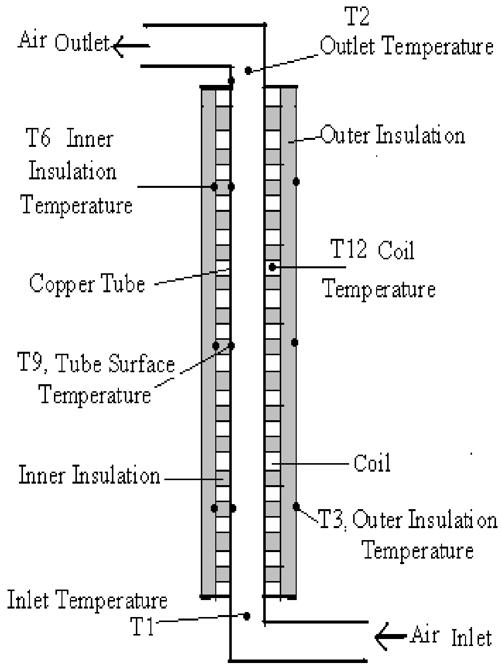

Figure 1: Experimental set-up

2.2 Experimental Procedure

The open ended copper tube of different diameters and length is fixed in vertical position. Initially when heat is not supplied to the pipe, the temperature near the inlet and exit of the pipe is same. Constant heat flux along the tube length is supplied to the tube. The temperature of the air along the tube length is start increasing and causes air to flow in the upward direction due to buoyancy. The hot air is replaced by cold air from the bottom end of the tube, and flow is established. The readings of all thermocouples have been recorded every half an hour until the reading became constant, and then the final reading has been recorded. The energy balance is checked between the heat gained by the flowing air and the heat supplied minus the heat loss. The results are accepted only when the agreement was within ± 5% of the mean. Same procedure was repeated for different parameters. Parameters varied during the experimentations are length of tube, diameter of a tube and heat flux supplied.

3. Results and Discussion

The steady state data generated on the experimental set-up for different values of tube length, tube diameter and heat supplied is correlated for heat transfer and flow characteristic as described below.

3.1 Local temperature variation along the tube length

Figure 2 shows the change in local surface temperature along the tube length. Figure also shows the air temperature along the tube length. Air temperature along the tube length is drawn by measuring inlet and exit temperature and assuming linear variation along the tube length. It is observed that surface temperature of the tube increases along the tube length. The difference between the surface temperature and fluid temperature is found low near the entry of the tube and it goes on increasing up to length of 0.5 m and then it become approximately constant. It indicates that flow become fully developed after this length. For tube of 12 mm diameter 1.5 m length, shows temperature difference of 5.3 ^{0}C at 2120 W/m^2 heat flux supplied. It increases to 8.4^{0}C at length of 0.75 m and then it becomes approximately constant. The surface temperature increases from 21.1^{0}C near the entry of a tube, it increases to 63.7^{0}C at the exit of the tube. Constant temperature difference indicates fully developed flow.

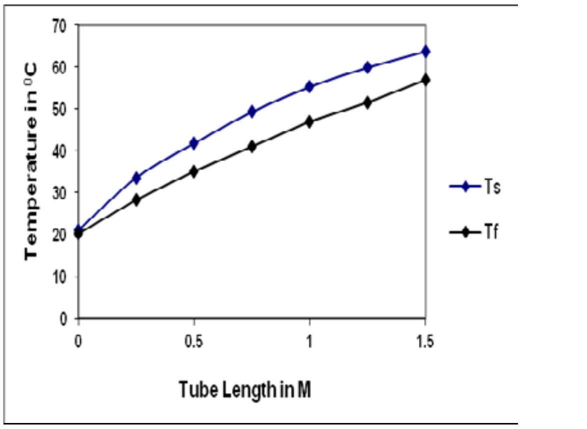

Figure 2: Change in surface temperature along the tube length

3.2 Air Outlet Temperature

The temperature of the air at the outlet increases with increase in tube length. It also increases with increase in diameter of a tube. This is shown in figure 3. The air outlet temperature for 1 m tube length and 12 mm diameter at 2120 W/m^2 heat flux is observed to be 60.5^{0}C and it increases to 66^{0}C for 1.5 m tube length. This increase in outlet temperature is due to more availability of surface area for heating the tube. Temperature of air at the outlet is also increases with increase in tube diameter. For 1.5 m tube length, temperature if air at the outlet is 66^{0}C for 12 mm tube diameter, it reduces to 54^{0}C for 24 mm diameter tube for same heat flux. This is due to fact that small diameter tube passage available to flow the air is small, hence develop resistance to flow. By doubling the diameter of the tube, fluid outlet temperature is decreases by about 20%.

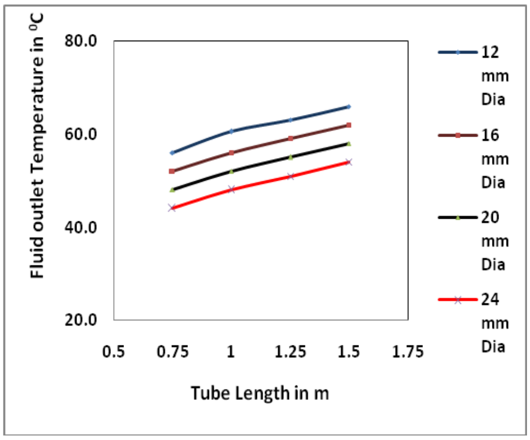

Figure 3: Air outlet temperature with tube length for different tube diameter

3.3 Local Heat Transfer Coefficient

Local heat transfer coefficient is calculated by dividing heat flux with difference between surface temperature and average fluid temperature along the tube length. Typical variation of local heat transfer coefficient along the tube length for different tube diameter (2120 w/m^2 heat flux and 1.5 m tube length) is shown in figure 4.

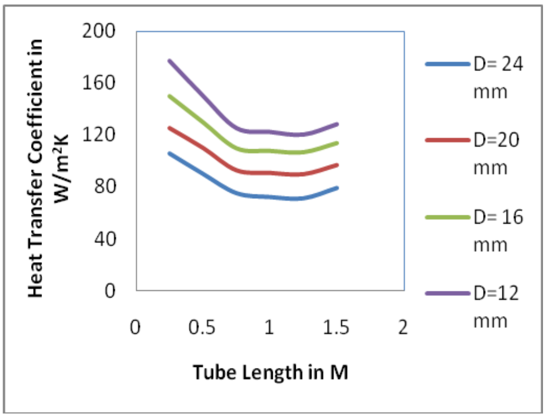

Figure 4: Local heat transfer coefficient along the tube length

It is observed that local heat transfer coefficient is highest near the tube entry, it goes on reducing up to length of 0.75 m, and hen it became constant. The constant value of heat transfer coefficient shows fully developed flow. Small rise in heat transfer coefficient at the outlet of tube is due to extension of pipe which was exposed to atmosphere and was not properly insulated.

3.4 Change in Heat Transfer Coefficient with Heat Flux

Constant value of heat transfer coefficient obtained with respect to heat flux is shown in figure 5. It shows that heat transfer coefficient increases with increase in heat flux supplied. This is obvious as heat flux increases more heat is obsorbed by the air and hence heat transfer coefficient increases. Figure 4 also shows that heat transfer coefficient reduces with increase in diameter of a tube. For tube of 12 mm diameter, 1.5 m length ad heat flux of 1060 W/m^2, heat transfer coefficient is observed to be 322 W/m^{2}K, which reduces to 230 W/m^{2}K for tube diameter of 24 mm. This is due to fact that more area is available to flow the air for large diameter than small diameter of a tube.
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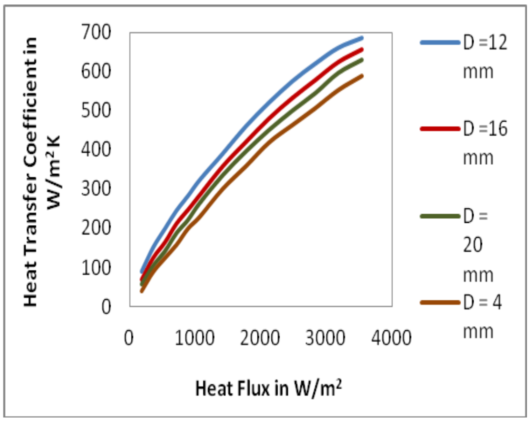

Figure 5: Change in heat transfer coefficient with change in heat flux for different diameter of tube

3.5 Nusselt Number

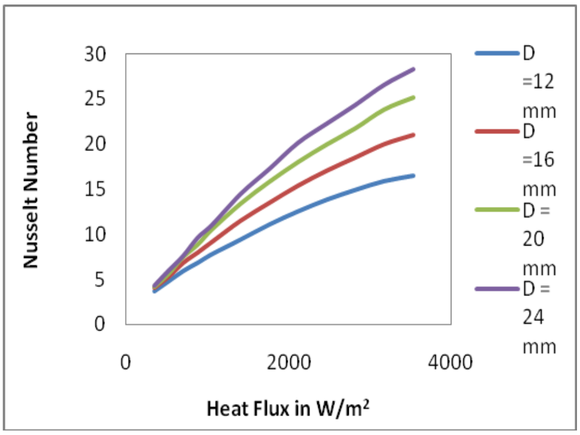

Figure 6: Change in Nusselt number with change in heat flux and tube diameter

Nusselt number is calculated by using heat transfer coefficient obtained as discussed above in section 3.4 and is shown in figure 6. It is observed that Nusselt number is increases with increase in heat flux. Nusselt number reduces with increase in diameter of the tube and also with increase in length of the tube. Nusselt number obtained by experiment is compared with the literature [2,4,6] and is found within 10% to 15%.

4. Conclusion

From the above discussion it is concluded that

- Fluid outlet temperature, heat gained by the fluid, fluid outlet velocity increases with increase in heat flux supplied to the tube.
- Fluid outlet temperature increases with increase in length of the tube but reduces with increase in diameter of a tube.
- Heat transfer coefficient increases with increase in heat flux but reduces with increase in length of the tube and also reduces with increase in diameter of a tube.

- Nusselt number increases with increase in heat flux but reduces with increase in diameter of the tube and its length.

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