ABSTRACT

The shape effect of a constant surface area isothermal vertical solid or hollow frustum on laminar natural convection heat transfer has been analysed by numerical simulations. The frustum is either kept on the ground or suspended in the air. The thermal plume and flow field around the frustum have been determined by numerically solving the Navier Stokes and energy equations for all the different shapes of the frustum. The current work is divided into four chapters. A review of the literature and an introduction to the subject are included in the first chapter. The second chapter includes a numerical study of the shape effect on natural convection heat transfer from an isothermal vertical solid frustum either suspended in the air or placed on the ground in the laminar range of Ra spanning from 10^4 to 10^8 while keeping the surface area same for all different frustum shapes. A comparison in heat loss has been made between the frustums and corresponding cylinders with the same surface area as the frustums. It has been noted that for any Ra, the heat loss from the cylinders is always greater than that of straight or inverted frustums. The straight frustum always loses more heat energy than the inverted one when both the frustums are placed on the ground. At all Ra and θ, a noticeable difference in the average Nu between the straight and the inverted frustum (on ground) is observed. For both the straight and the inverted frustum kept on the ground, the average Nu varies with θ, the inclination of the lateral surface. For Ra < 10^7, however, the inverted frustum loses more heat energy than the straight one when both of them are suspended in the air. For a Ra of 10^8, the straight frustum's heat loss exceeds the heat loss of the inverted one. The third chapter also presents the numerical study of the shape effect on laminar natural convection under the same conditions of Ra ($10^4 \leq \mathrm{Ra} \leq 10^8$) and for the same positions, either hung in the air or placed on the ground, but for a vertical hollow frustum that is isothermal. All the shapes of the frustum are having same surface area. Heat loss from both the inner and the outer surfaces of frustums is compared with the corresponding equal area cylinders. It is observed that both straight and inverted frustums consistently lose less heat energy from their outer surfaces compared to the corresponding cylinders across all Ra values. The inner surface of a frustum behaves similarly for both the frustums suspended in the air and specifically for the inverted frustum placed on the ground. The Nu of the inner and the outer surface for both the straight and the inverted frustum varies as a function of the surface orientation, θ. When both the frustums are hanging in the air, the inverted frustum's outer surface has a lower Nu value in comparison to the straight one at all Ra and the opposite is true for the inner surface. If both the frustums are sitting on the ground, the outer surface takes a greater Nu value for an inverted frustum than for a straight one and reverse holds true for the inner surface. In second and third chapters, both the solid and hollow frustums have been studied by performing a 2D numerical analysis. However, the fourth chapter presents a 3D numerical study of the shape effect of a vertical hollow louvered frustum (isothermal) on laminar natural convection keeping the conditions of Ra and positions of the frustum same as in the case of the second and third chapter. The surface area is also maintained same for all different shapes of the louvered frustum. Here, the shape effect on natural convection heat transfer is obtained by the variation of Nu (both the inner and the outer surface) with the surface orientation, θ. The Nu is compared between the inner and the outer surface, as well as between a straight and an inverted frustum. For a straight frustum in air, the Nu of the outer surface is always significantly higher than that of the inner surface. This behavior of Nu remains consistent across all values of θ and Ra for an inverted frustum kept on the ground. Similarly, the same behavior of Nu is observed for a wide range of θ when a straight frustum is positioned on the ground. Additionally, the inner surface consistently exhibits a larger Nu value for a straight frustum compared to an inverted one when both the frustums are sitting on the ground. However, except for $Ra = 10^8$ and $\theta = 30^0$, the opposite trend is observed when both the frustums are suspended in the air.

Finally, the correlations for average Nu as a function of Ra and θ have been proposed for each position (in the air and on the ground) of an isothermal vertical solid, hollow and "hollow louvered" frustum.

Key words: shape effect, natural convection, Nusselt number, buoyancy force, solid frustum, hollow frustum, hollow louvered frustum, straight frustum, inverted frustum, inner surface, outer surface, in the air, on the ground.