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Enclosure Effects on Natural Convection Over a Flat Plat

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ABSTRACT

The study intends physical insight into heterogeneous heat transfer phenomena of laminar free convection over a flat plate. The work aims at understanding the implications of parameters ambient temperature, surface roughness, enclosure effects and flow velocity on heat transfer coefficient at different orientations. Experiments were performed on an existing natural convection experimental setup and the heat transfer characteristics were analyzed. Results show that the heat transfer coefficient exhibits a monotonic slowly but surely reducing behavior with increase in surface inclination under different conditions. The increase in heat source input increases the heat transfer rates. However, the change drops at higher power supply and heat transfer rates converge which primarily governs the enhanced heat losses.

Index Terms— Free convection, flat plate, air, surface roughness, enclosures.

I. INTRODUCTION

Transfer of heat by convection in our ambiences and in most of engineering expedients is a phenomenon of practical and functional significance. The convection heat transfer is widely characterized as: Free and forced convection. Free convection refers to fluid motion by buoyant forces arising owing to density gradients which are because of temperature gradients. In forced convection, the flow of the fluid is enhanced by external sources. In this work, heat transfer characteristics are investigated over a square flat plate in the free convection configuration. The interest in this class of problems is specifically driven by the need to have better understanding of convective heat transfer.

Following the classical work of Ostrich (1952) over laminar free convection on plates, the last five decades research works have contributed significantly to the improvement in the understanding of the convective heat transfer. The contributions have been reported in several reviews like Sparrow et al.,(1956), Kierkus (1968), Pera et al., (1973), Shaukatullah et al., (1978), Yousef et al., (1982). The works provide an excellent review on the developments up to the end of the century. Lewandowski et al., (1983) emphasized on accounting the thermic disturbances which occur above the surfaces of the horizontal plates in shape of vortices and plumes.

Chen et al., (1986) analyzed the laminar free convection with power-law variation of the surface heat flux and found that the local wall shear stress or surface heat transfer rate increases with Grashof number. Suneeta et al., (2006) analyzed the convective heat transfer in an array of fins and observed that total heat flux as well as the heat transfer coefficient increase as the notch depth increases. Tiwari and Malhotra (2013) showed that the convective heat transfer rate for laminar flow over a flat plate exhibit a monotonically reducing behavior with increment in plate orientation.

They observed that the buoyant convection which carried away heat reduces as the plate orientation increases owing to reduction in effective span area in contact and as a consequence the heat transfer rate. In recently, the interactions of thermal radiation and convection have attracted many investigators along with heat transfer from stationary and rotating flat plate. While there is abundant literature available, but complexity of the problem had prevented a complete understanding due to interaction between flow, heat and mass transfer.Therefore, a systematic study is needed to understand mechanisms controlling the convective heat transfer. In the light of above mentioned works, the present work focuses on effect of plate orientation and power input on convective heat transfer coefficient.

II. EXPERIMENTAL SETUP AND SOLUTION METHODOLOGY

A simple apparatus (Fig. 1(a)) was adapted for this study. The apparatus consisted of base made of mild steel plates which supported the assembly. The smooth plate assembly comprised of a glass enclosure bounded along the sides but open from both the ends to remove the external influences which can affect heat transfer rate. The aluminium plate specimen (Fig. 1(b)) is (15 cm x 15 cm) which was heated using electrical power at desired rate for 2 hours prior to experiments. The rate of heating the plate can be adjusted with the help of a knob and is displayed on a digital display.

Thermocouples (5 in numbers) are embedded in plate (shown in Fig. 1(c)) and located equidistance. In order to facilitate the heat transfer at different orientations, the plate assembly can be adjusted with the help of a handle and attached protractor. The readings were taken systematically in proper time interval. The plate is enclosed from two sides by glass sheets and opens only from top and bottom sides.The convective heat transfer coefficient is determined as electrical power supplied is equated to the heat power lost due to convection.

$$h A \Delta T = V I \tag{1}$$

And

Where, $h = \dfrac{V \times I}{A \times \Delta T}$

$\Delta T = (T_{av} - T_1)$

$T_{av} = \left(\dfrac{T_2 + T_3 + T_4 + T_5 + T_6}{5}\right)$

h = Heat transfer coefficient (W/m^2-K)

V = Voltage supplied (Volt)

I = Current intensity (Ampere)

A = Area of square plate (m^2)

T_{av} = Average thermocouples temperature (K)

T_1 = Ambient temperature (K)

θ = Surface orientation (Degrees)

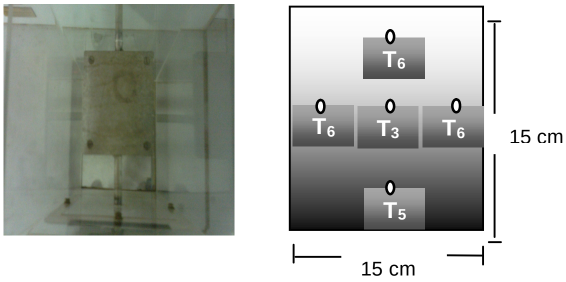

Fig 1: Pictorial view of the apparatus (a) Front view (b) Top view of square plate (c) schematic of square plate with location of embedded equidistant thermocouples (shown by circles).

III. RESULTS

An experimental parametric study was carried out to study the heat transfer characteristics of a flat plate. The effect of variables viz. ambient temperature, surface roughness, enclosure effects and flow velocity on heat transfer coefficient at different plate orientations in laminar flow was investigated. It must be noted that all the readings presented here represent the repeatability of results obtained. First, we look at the effect of ambient temperature on convective heat transfer coefficient. Figure 2 shows variation of heat transfer rate with varying ambient temperature.

The study was carried out for heater input of 100 volt and 0.45 ampere with plate kept horizontal and smooth surface facing upward. Experiments show that the heat transfer rates are higher with plate kept horizontal and exhibits a monotonically reducing behavior with increment in ambient temperature.

Small increment in ambient temperature (here in range of 29-32 degrees) is seen to result in drastic decrement in rate of heat transfer. The reason for this may be attributed to increased overall linear temperature difference owing to continuous heat power supply resulting in increased average plate temperature which probably is the reason for significantly reduced rate of heat transfer.

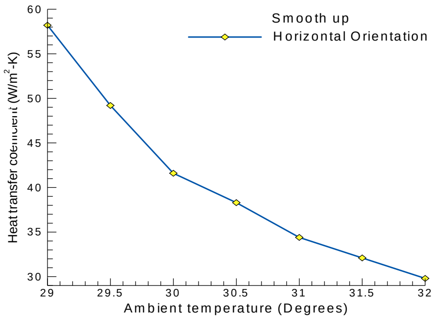

Fig 2: Variation of heat transfer coefficient with ambient temperature for horizontal plate orientation and smooth surface facing upward.

Next, we look at the effect of surface roughness on heat transfer rate for selected heater input and varying plate orientation. Figure 3 shows variation of heat transfer coefficient with plate orientation for selected voltages of 75, 100, 125, 150 volts respectively. In these reading the effect of enclosure is paralleled for with top end closed for smooth surface facing upward (fig.3) and rough surface facing upward (fig.4). Looking at the plots one can note that for both cases, the rate of heat transfer increases with increase in voltage at all orientations. The heat transfer rate shows a strong increase with heater input voltage more than 75 volt. However, the magnitudes of heat transfer coefficient are higher for rough surface facing upward. The reason for this may be attributed to the circulation region formed by hot gases owing to strong heat interaction with walls consequently becoming denser and carrying additional heat in absence of exit at top. In case of rough surfaces, the friction generates more heat among the hot buoyant gases and assists in carrying additional heat at higher power input in absence of exit.

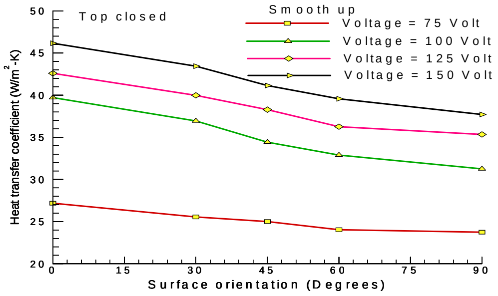

Fig 3: Variation of heat transfer coefficient with selected heater input and surface orientation for

smooth surface facing upward with top end closed.

This above mentioned effect is noted more for plate with low orientation and it recedes with increase in orientation. In case of smooth surface, the rate of change in magnitudes at higher input is distinct and confines after 100 volt. But, for the rough surfaces the growth in magnitude drops at higher input (here 125 volts) and beyond that critical value, the heat transfer rate confines to a close range with top end enclosed. It indicates that the heat transfer coefficients are effective and higher with rough surfaces. However, beyond a certain value, the change at higher voltages reduces so it may return with diminishing returns.

Table1: Variation of heat transfer coefficient with induced velocity and plate orientation for smooth surface facing upward

Plate orientation (Degrees)	**Forced air velocity (0 m/s)**	**Forced air velocity (0.40 m/s)**	**Forced air velocity (0.80 m/s)**
0	33.96	61.12	56.99
30	32.17	59.4	52.05
45	30.4	57.93	47.61
60	28.5	57.09	45.45
90	27.2	55.41	44.31

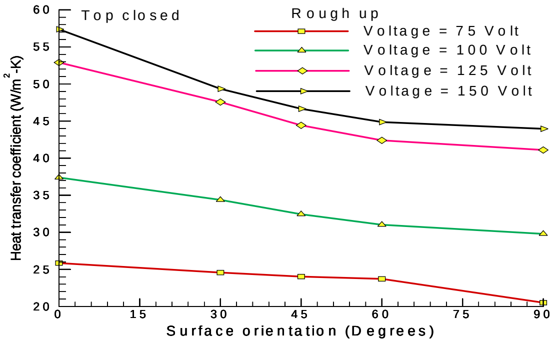

Fig 4: Variation of heat transfer coefficient with ambient temperature for horizontal plate orientation and smooth surface facing upward.Next, we look at the effect of enclosures on the convective heat transfer coefficient. The comparison is made for three different cases with smooth surface facing upward viz., (a) Top and bottom ends open (fig.5) (b) Top end closed (fig. 3) and (c) bottom end closed (fig.6).

It is interesting to note that variation of heat transfer coefficient with plate orientation for all three cases follows similar trend as dictated by Tiwari and Malhotra (2013). With both ends open, the rate of heat transfer and it's variation with surface orientation depicts a crossover in heat transfer rates for higher voltages (here above 125 volts) and low orientations (below 30^{o}).

As discussed earlier, when the top end is closed, the heat transfer rates at higher voltages confine themselves in a closed region and follow the gradually reducing trend with variation in plate orientation. It also indicates that after a certain critical value of power input, the heat transfer rate may return with diminishing returns as the increase in heat transfer growth rate recedes at higher voltages. While, when the bottom end is closed, highest heat transfer rates are obtained.

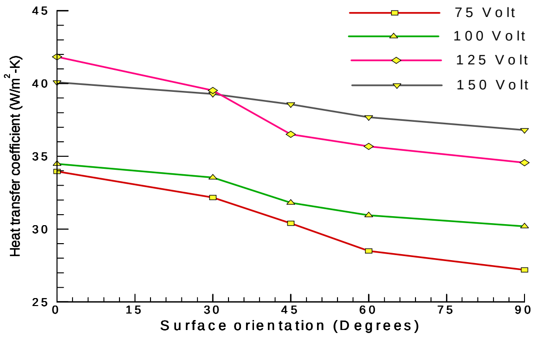

Fig 5: Variation of heat transfer coefficient with selected heater input and surface orientation for smooth surface facing upward with both ends open.

Here, in absence of suction created by earth's gravity, the surrounding air carries away more amount of heat than the other two configurations. Moreover, as the heater input is increased, the rate at which heat is transferred from plate increases. It signifies that for the requirement of enhancing natural convection, it is recommended to use a configuration with three sides closed and only top end open.

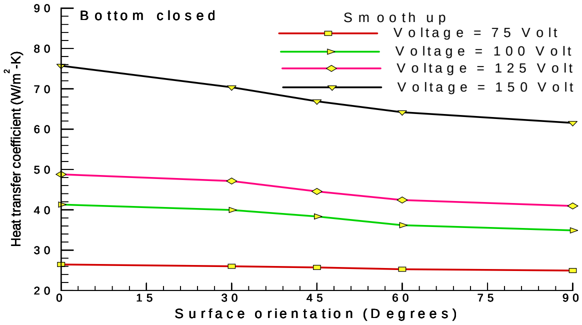

Fig 6: Variation of heat transfer coefficient with selected heater input and surface orientation for smooth surface facing upward with bottom end closed.

The work was further extended to explore the effect of parameter induced flow velocity on the heat transfer rates. Table 1 shows the comparison of free convection (zero induced velocity) with variable induced velocity of 0.40 m/s and 0.80 m/s respectively. As expected, the value of heat transfer coefficient is more with assisting flow velocity. It is worth noting that, though the magnitude of heat transfer coefficient increases with flow velocity, yet it directs to a critical value above which it starts decreasing as One can also note that the heat transfer coefficient values are more for flow velocity of 0.40 m/s than 0.80 m/s. Interestingly, the heat transfer coefficient for forced convection follows a trend similar to free convection for variation with plate orientation. However, the change in heat transfer coefficients is more for flow velocity of 0.80 m/s as the plate orientation changes. This particular study also validates some of the benchmark studies on forced and free convection.

IV. CONCLUSIONS

An experimental exploration was carried out to understand the implications of parameters, ambient temperature, surface roughness, enclosures effect and flow velocity on heat transfer coefficient at different orientations. Based on results obtained following conclusions may be drawn from this study: The transfer of heat due to convection is more effective in horizontal surfaces owing to stronger buoyant forces leading to better cooling applications. The increase in ambient temperature drastically reduces the heat losses, thus dictates situations under which the present mode cannot be used. The heat transfer coefficient increases with heater input but it results in diminishing returns beyond a critical value and thus indicates that a critical power input is adequate to remove sufficient heat and further increase may be redundant. The results validate that the rough surfaces loses heat easily by free convection. If application demands enhancing natural convection then, it is better to use a configuration with bottom end closed. Force convection is a faster mode of losing heat however it conveys a range where it will be maximum.

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