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An Analysis on Various Mechanism of Natural Convection: A Case Study of Heat Transfer

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Abstract – Natural convection heat transfer in a somewhat parceled fenced in area has been researched experimentally utilizing Mach-Zehnder Interferometry strategy. The top and lowest part of the fenced in area are protected while one of the vertical dividers is heated isothermally. The parcels are made of wood fiber and are connected to the heated divider with points transforming from 30^0 to 150^0 in diverse experiments. The length of each one segment is equivalent to the width of the nook, subsequently separating the fenced in area to segregated cells just at 90^0.

The thermal control in many systems is widely accomplished applying natural convection process due to its low cost, reliability and easy maintenance. Typical applications include the heat exchangers, cooling of electronic equipment and nuclear reactors, solar chimneys and Trombe walls in building industry, etc.

Natural convection is observed when density gradients are present in a fluid acted upon by a gravitational field. Our example of this phenomenon is the heated vertical plate exposed to air, which, far from the plate, is motionless.

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INTRODUCTION

In natural convection, the fluid motion occurs by natural means such as buoyancy. Since the fluid velocity associated with natural convection is relatively low, the heat transfer coefficient encountered in natural convection is also low.

There are certain situations in which the fluid motion is produced due to change in density resulting from temperature gradients, which is the heat transfer mechanism called as free or natural convection. Natural convection is the principal mode of heat transfer from pipes, refrigerating coils, hot radiators etc. The movement of fluid in free convection is due to the fact that the fluid particles in the immediate vicinity of the hot object become warmer than the surrounding fluid resulting in a local change of density. The warmer fluid would be replaced by the colder fluid creating convection currents. These currents originate when a body force (gravitational, centrifugal, electrostatic etc.) acts on a fluid in which there are density gradients. The force which induces these convection currents is called a buoyancy force which is due to the presence of a density gradient within the fluid and a body force. Grashoff number (Gr) plays a very important role in natural convection.[1]

In contrast to the forced convection, natural convection phenomenon is due to the temperature difference between the surface and the fluid is not created by any external agency. Natural convection flow pattern for some commonly observed situations is given in Figure 1.

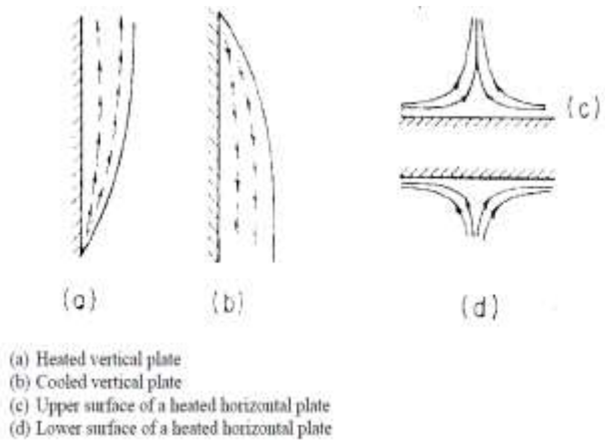

Figure 1 Natural convection flow patterns

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. The present experimental setup is designed and fabricated to study the natural convection phenomenon from a vertical cylinder in terms of the variation of the local heat transfer coefficient and its comparison with the value which is obtained by using an appropriate correlation.

In this document Natural convection is observed as a result of fluid movement which is caused by density gra-dient. A radiator which is used for warming the house is an example of practical equipment for natural convection. The movement of fluid, whether gas or liquid, in natural convection is caused by buoyancy force due to density reduction beside to surfaces in heating process. When an external force such as gravity, has no effect on the fluid there would be no buoyancy force, and mechanism would be conduction. But gravity is not the only force causing natural convection. When a fluid is confined in the rotating machine, centrifugal force is exerted on it and if one or more than one surfaces, with more or less temperature than that of the fluid are in touch with the fluid, natural convection flows will be experienced. The fluid which is adjacent to the vertical surface with con-stant temperature, the fluid temperature is less than the surface temperature, forms a velocity boundary layer. The velocity profile in this boundary layer is completely different with the velocity profile in forced convection. The velocity is zero on the wall due to lack of sliding. Then the velocity goes up and reaches its maximum and finally gets zero on the external border of velocity boundary layer. Since the factor that causes the natural convection, is temperature gradient, the heating bound-ary layer appears too. The temperature profile has also the same value as the temperature of wall due to the lack of particles sliding on the wall, and temperature of parti-cles goes down as approaching to external border of temperature boundary layer and it would reach the tem-perature of far fluid. The initial enlargement of boundary layer is laminar, but in the distance from the uplifting edge, depending on fluid properties and the temperature difference of the wall and the environment, eddies will be formed and movement to turbulent zone will be started.[2]

NATURAL CONVECTION HEAT TRANSFER ENHANCEMENT

The existence of convection in double-diffusive systems, in which heat and salt diffuse at a different rate, was first recognised in the late 1950 s. Since then, this phenomenon has been studied extensively due to the fact that its importance has been recognised in many fields such as geophysics, astrophysics, ocean physics and industrial processes. The first study concerning double diffusion in a binary fluid seems to be that of Nield. Relying on linear stability theory, the onset of motion in an initially motionless, stable concentration and stratified horizontal fluid layer heated from below was predicted by this author. This cross-effect regarding the Rayleigh-Bénard convection dealing with the bifurcation and the possible change in the critical thresholds (i.e. transitional Rayleigh number from conductive to convective motion) was also considered on the same period by Veronis. All the above studies are concerned with the effect of the regular diffusion of each component (heat and salt) on convection. However, in a wide variety of natural and industrial situations, besides the usual diffusion, cross-diffusion between the two agents may also be important. This phenomenon, known as the Soret effect, has been relatively less studied despite its importance for a fluid layer of a binary mixture (convection and stability). In recent studies, the problem of the double thermo-diffusion effects that occurs under natural convection in fluid or porous media was studied; see for example Bennacer et al. [3-6]

During the past ten years, a new class of fluids made up of metal nanoparticles in suspension in a liquid, called nanofluids, has appeared. Nanofluids are composed of nanoparticles that (size in general <100 nm) are suspended in a base fluid, as water or an organic solvent. The formation of extremely stable colloidal systems with very tiny settling is a characteristic feature of some nanofluids, the stability of the suspension is naturally achieved by electrostatic stabilisation by adjusting the pH. The presence of nanoparticles causes a significant modification of thermal properties of the resulting mixture; in particular, nanofluid viscosity and thermal conductivity increase with particle volume fraction. Although the increase in thermal conductivity is a very important interest, there are also increases in the average temperature of nanofluids compared to that of base fluid and that because of the specific heat of nanofluids, which decreases compared to that of base fluid. The abnormal rise of the thermal conductivity in comparison with the pure fluid, especially for low particle concentrations, is not totally understood today. Some assumptions are based on particle deposition on the surface resulting in the formation of nano fins. There are a many recent studies that report experimental measurements of thermophysical properties of nanofluids, including specific heat, thermal conductivity and viscosity; some recent reports include.[7]

NATURAL CONVECTION HEAT TRANSFER FLOW VISUALIZATION

The enhancement of heat transfer is an important subject of thermal engineering. Removal of excessive heat from system components is essential to avoid the damaging effects of burning or overheating. Basically flow is nothing but circulation of the air around the heated fins surface which occurs due to the change in density of air after getting heated when it comes in contact with heated fin. Thus cold air gets sucked inside from the bottom and heated air goes up causing the natural convection currents. Mainly three types of the flow pattern are mentioned in the literature.

i) Single chimney flow pattern: Fig.2a) this pattern is observed in lengthwise short arrays. It is formed by the cold air entering from the two ends of the arrays, traveling lengthwise and coalescing at the center of the arrays. This flow pattern is the most favorable from the heat transfer standpoint.

ii) Sliding Chimney Flow Pattern: Fig. 2b) as the length of the arrays is increased keeping the height and spacing unaltered., it is observed that beyond a certain value of the length, the air entering from the ends is not sufficient to cool the entire arrays and leaves the array before reaching the central zone, and the resulting flow pattern is sliding chimney flow pattern, which is unsteady in nature.

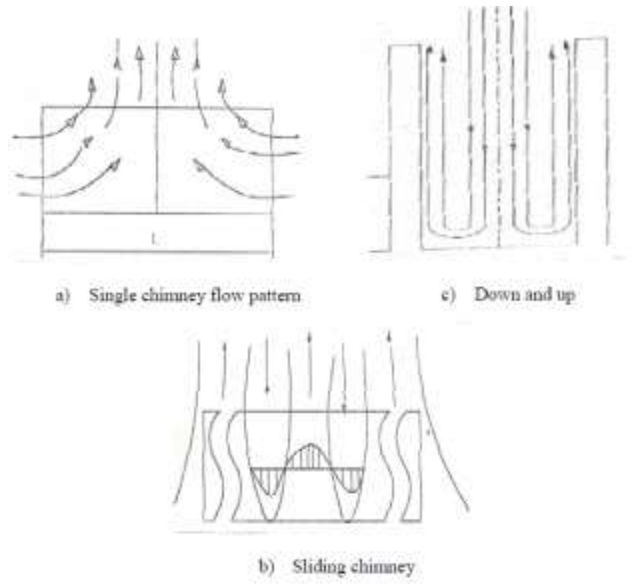

Fig-2: Types of Flow Patterns.

iii) Down and Up Flow Pattern: Fig 2c) if the length of the array is further increased so that the array can be considered infinite in the longitudinal direction, the resulting flow pattern has cold air entering at the central portion of the array, turning through 180°. developing boundary layers along the height of the fin flats and leaving the array in the upward direction.

It has been reported that the cross component of velocity (along the direction of the spacing) is negligible in single chimney flow pattern. The down and up flow pattern are mostly hypothetical situation and hence has little practical significance.

Abdullah H. AlEssa et al. studied the heat dissipation from a horizontal rectangular fin embedded with square perforation, rectangular perforations with an aspect ratio of two. equilateral triangular perforations of bases parallel and towards its fin tip. by using the finite element technique under natural convection.[8,9]

MECHANISMS OF NATURAL CONVECTION

Consider a hot object exposed to cold air. The temperature of the outside of the object will drop (as a result of heat transfer with cold air), and the temperature of adjacent air to the object will rise. Consequently, the object is surrounded with a thin layer of warmer air and heat will be transferred from this layer to the outer layers of air.

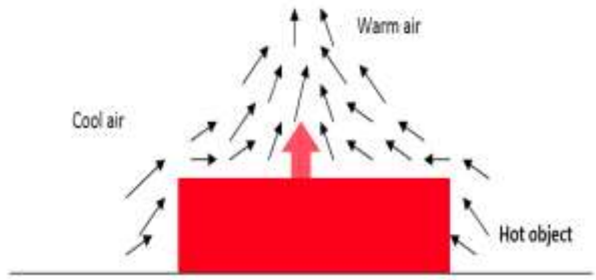

Fig. 3: Natural convection heat transfer from a hot body.

The temperature of the air adjacent to the hot object is higher, thus its density is lower. As a result, the heated air rises. This movement is called the *natural convection current*. Note that in the absence of this movement, heat transfer would be by conduction only and its rate would be much lower.

In a gravitational field, there is a net force that pushes a light fluid placed in a heavier fluid upwards. This force is called the *buoyancy force*.

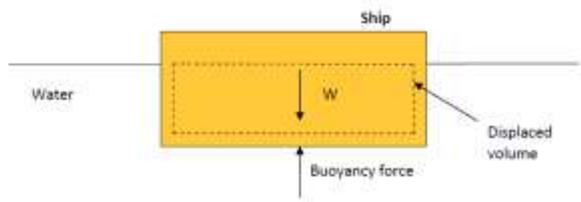

Fig. 4: Buoyancy force keeps the ship float in water.

The magnitude of the buoyancy force is the weight of the fluid displaced by the body.

$$F_{buoyancy} = \rho_{fluid}\, g\, V_{body}$$

where V_{body} is the volume of the portion of the body immersed in the fluid. The net force

is:

$$F_{net} = W - F_{buoyancy}$$

$$F_{net} = (\rho_{body} - \rho_{fluid})\, g\, V_{body}$$

Note that the net force is proportional to the *difference in the densities* of the fluid and the body. This is known as *Archimedes' principle*.

We all encounter the feeling of "weight loss" in water which is caused by the buoyancy force. Other examples are hot balloon rising, and the chimney effect. Note that the buoyancy force needs the gravity field, thus in space (where no gravity exists) the buoyancy effects does not exist.

Density is a function of temperature, the variation of density of a fluid with temperature at constant pressure can be expressed in terms of the volume expansion coefficient β, defined as:

$$\beta = -\frac{1}{\rho}\left(\frac{\partial \rho}{\partial T}\right)_P \quad \left(\frac{1}{K}\right)$$

$$\beta \approx -\frac{1}{\rho}\frac{\Delta\rho}{\Delta T} \rightarrow \Delta\rho \approx -\rho\beta\Delta T \quad \text{(at constant P)}$$

It can be shown that for an ideal gas

$$\beta_{\text{ideal gas}} = \frac{1}{T}$$

where *T* is the absolute temperature. Note that the parameter $\beta\Delta T$ represents the fraction of volume change of a fluid that corresponds to a temperature change ΔT at constant pressure.

Since the buoyancy force is proportional to the density difference, the larger the temperature difference between the fluid and the body, the larger the buoyancy force will be.

Whenever two bodies in contact move relative to each other, a friction force develops at the contact surface in the direction opposite to that of the motion. Under steady conditions, the air flow rate driven by buoyancy is established by balancing the buoyancy force with the frictional force.

NATURAL CONVECTION HEAT TRANSFER FROM INCLINED PLATE-FINNED HEAT SINKS

Heat sinks are often used in electronics cooling when high heat fluxes should be dissipated. In most of the electronics cooling applications, the final heat transfer medium is air, thus, the forced convection takes precedence over the natural convection. For the purposes of conserving energy and increasing reliability, however, the natural convection may be the right choice; especially, if the generated heat can be spread over a larger surface using heat spreaders or heat pipes. Recently, possibilities of dissipating enough heat by natural convection and radiation were shown for the vertical orientation of plate-finned heat sinks in two separate applications. In general, the vertical and upward facing horizontal orientations of a heat sink are preferred for maximizing the natural convection heat transfer rate. As a result, these two orientations were investigated extensively. In contrast, there are only a few works investigating inclined orientations.

Inclined orientations are important for at least two reasons: one, vertical or horizontal surfaces may not be available due to design constraints; two, an originally vertical or horizontal heat sink may become inclined during its operation when the cooled electronic device is rotated, intentionally or otherwise. The possibility of intentional or unintentional rotation by itself is enough a reason to investigate inclined orientations because of the associated decline from the maximum heat transfer rate, which is only obtainable either for the vertical or the upward horizontal cases.

In the case of forced convection, the possible heat dissipation rate from a heat sink highly depends on the remaining components of the cooling system, such as the fan and the enclosure; therefore, obtaining general dimensionless heat transfer correlations is not possible. In contrast, in natural convection, it is possible to make generalizations and obtain application independent correlations.[10,11]

CONCLUSION

The solution of the natural convection heat transfer in a partitioned, inclined, porous layer with uniform wall heat flux is derived. The limiting case of a single layer can be recovered, and this compare well with known results. The problem is solved for the case of constant-flux boundary conditions. Results obtained for this special case should be useful for estimating heat transfer in a system with more general boundaries conditions.

In this study, combined heat and mass transfer effects on MHD free convection flow past an oscillating plate embedded in porous medium is presented. Results are presented graphically to illustrate the variation of velocity, temperature, concentration, skin-friction and Nusselt number with various parameters.

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