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# Turbulent Natural Convective Heat Transfer from Narrow Plates

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## Abstract:

Forced convection also named as heat advection, fluid movement results from external surface forces such as a fan or pump. Forced convection is typically used to increase the rate of heat exchange. Many types of mixing also utilize forced convection to distribute one substance within another. Forced convection also occurs as a byproduct to other processes, such as the action of a propeller in a fluid or aerodynamic heating. Fluid radiator systems, and also heating and cooling of parts of the body by blood circulation, are other familiar examples of forced convection.

Forced convection may happen by natural means, such as when the heat of a fire causes expansion of air and bulk air flow by this means. In microgravity, such flow (which happens in all directions) along with diffusion is the only means by which fires are able to draw in fresh oxygen to maintain themselves. The shock wave that transfers heat and mass out of explosions is also a type of forced convection. The main objective of the paper presents an analysis based on the investigations done on the fluid characteristics and heat transfer characteristics while flowing on a narrow vertical plate.

The comparison is made when the flow is considered as natural or forced convection and also for the type of flow is laminar or turbulent using CFD analysis. CFD analysis is done in Ansys. Thermal analysis is done on the vertical plates by using two materials Aluminum alloy 7075 and Copper for both natural convection and forced convection.

## Index terms:

Natural and forced convection, narrow plates, turbulent flow.

## I.INTRODUCTION:

Convection is the concerted, collective movement of groups or aggregates of molecules within fluids (e.g., liquids, gases) and rheids, through advection or through diffusion or as a combination of both of them. Convection of mass cannot take place in solids, since neither bulk current flows nor significant diffusion can take place in solids. Diffusion of heat can take place in solids, but that is called heat conduction. Convection can be demonstrated by placing a heat source (e.g. a Bunsen burner) at the side of a glass full of a liquid, and observing the changes in temperature in the glass caused by the warmer fluid moving into cooler areas.

Convective heat transfer is one of the major types of heat transfer, and convection is also a major mode of mass transfer in fluids. Convective heat and mass transfer take place both by diffusion – the random Brownian motion of individual particles in the fluid – and by advection, in which matter or heat is transported by the larger-scale motion of currents in the fluid. In the context of heat and mass transfer, the term "convection" is used to refer to the sum of advective and diffusive transfer. In common use the term "convection" may refer loosely to heat transfer by convection, as opposed to mass transfer by convection, or the convection process in general. Sometimes "convection" is even used to refer specifically to "free heat convection" (natural heat convection) as opposed to forced heat convection.

However, in mechanics the correct use of the word is the general sense, and different types of convection should be qualified for clarityConvection can be qualified in terms of being natural, forced, gravitational, granular, or thermo magnetic. It may also be said to be due to combustion, capillary action, or Marangoni and Weissenberg effects. Heat transfer by natural convection plays a role in the structure of Earth's atmosphere, its oceans, and its mantle. Discrete convective cells in the atmosphere can be seen as clouds, with stronger convection resulting in thunderstorms. Natural convection also plays a role in stellar physics.

## Types of convection:
## 1. Natural convection

Natural convection, or free convection, occurs due to temperature differences which affect the density, and thus relative buoyancy, of the fluid. Heavier (more dense) components will fall, while lighter (less dense) components rise, leading to bulk fluid movement. Natural convection can only occur, therefore, in a gravitational field. A common example of natural convection is the rise of smoke from a fire. It can be seen in a pot of boiling water in which the hot and less-dense water on the bottom layer moves upwards in plumes, and the cool and more dense water near the top of the pot likewise sinks. Natural convection will be more likely and/or more rapid with a greater variation in density between the two fluids, a larger acceleration due to gravity that drives the convection, and/or a larger distance through the convecting medium.

Natural convection will be less likely and/or less rapid with more rapid diffusion (thereby diffusing away the thermal gradient that is causing the convection) and/or a more viscous (sticky) fluid.The onset of natural convection can be determined by the Rayleigh number (Ra). Note that differences in buoyancy within a fluid can arise for reasons other than temperature variations, in which case the fluid motion is called gravitational convection (see below). However, all types of buoyant convection, including natural convection, do not occur in microgravity environments. All require the presence of an environment which experiences g-force (proper acceleration).

## 2. Forced convection:

In forced convection, also called heat advection, fluid movement results from external surface forces such as a fan or pump. Forced convection is typically used to increase the rate of heat exchange. Many types of mixing also utilize forced convection to distribute one substance within another. Forced convection also occurs as a by-product to other processes, such as the action of a propeller in a fluid or aerodynamic heating. Fluid radiator systems, and also heating and cooling of parts of the body by blood circulation, are other familiar examples of forced convection.

Forced convection may happen by natural means, such as when the heat of a fire causes expansion of air and bulk air flow by this means. In microgravity, such flow (which happens in all directions) along with diffusion is the only means by which fires are able to draw in fresh oxygen to maintain themselves. The shock wave that transfers heat and mass out of explosions is also a type of forced convection. Although forced convection from thermal gas expansion in zero-g does not fuel a fire as well as natural convection in a gravity field, some types of artificial forced convection are far more efficient than free convection, as they are not limited by natural mechanisms. For instance, a convection oven works by forced convection, as a fan which rapidly circulates hot air forces heat into food faster than would naturally happen due to simple heating without the fan.

## 3. Gravitational or buoyant convection:

Gravitational convection is a type of natural convection induced by buoyancy variations resulting from material properties other than temperature. Typically this is caused by a variable composition of the fluid. If the varying property is a concentration gradient, it is known as solute convection. For example, gravitational convection can be seen in the diffusion of a source of dry salt downward into wet soil due to the buoyancy of fresh water in saline. Variable salinity in water and variable water content in air masses are frequent causes of convection in the oceans and atmosphere which do not involve heat, or else involve additional compositional density factors other than the density changes from thermal expansion (see thermo haline circulation). Similarly, variable composition within the Earth’s interior which has not yet achieved maximal stability and minimal energy (in other words, with densest parts deepest) continues to cause a fraction of the convection of fluid rock and molten metal within the Earth’s interior (see below).Gravitational convection, like natural thermal convection, also requires a g-force environment in order to occur.

## 4. Granular convection:

Vibration-induced convection occurs in powders and granulated materials in containers subject to vibration where an axis of vibration is parallel to the force of gravity. When the container accelerates upward, the bottom of the container pushes the entire contents upward. In con trast, when the container accelerates downward, the sides of the container push the adjacent material downward by friction, but the material more remote from the sides is less affected. The net result is a slow circulation of particles downward at the sides, and upward in the middle. If the container contains particles of different sizes, the downward-moving region at the sides is often narrower than the largest particles. Thus, larger particles tend to become sorted to the top of such a mixture. This is one possible explanation of the Brazil nut effect.

## 5. Thermo magnetic convection:

Thermomagnetic convection can occur when an external magnetic field is imposed on a ferro fluid with varying magnetic susceptibility. In the presence of a temperature gradient this results in a nonuniform magnetic body force, which leads to fluid movement. A ferrofluid is a liquid which becomes strongly magnetized in the presence of a magnetic field.This form of heat transfer can be useful for cases where conventional convection fails to provide adequate heat transfer, e.g., in miniature microscale devices or under reduced gravity conditions.Natural or “Buoyant” or “Free” convection is a very important mechanism that is operative in a variety of environments from cooling electronic circuit boards in computers to causing large scale circulation in the atmosphere as well as in lakes and oceans that influences the weather. It is caused by the action of density gradients in conjunction with a gravitational field. This is a brief introduction that will help you understand the qualitative features of a variety of situations you might encounter. There are two basic scenarios in the context of natural convection. In one, a density gradient exists in a fluid in a direction that is parallel to the gravity vector or opposite to it. Such situations can lead to “stable” or “unstable” density stratification of the fluid. In a stable stratification, less dense fluid is at the top and more dense fluid at the bottom. In the absence of other effects, convection will be absent, and we can treat the heat transfer problem as one of conduction.

In an unstable stratification, in which less dense fluid is at the bottom, and more dense fluid at the top, provided the density gradient is sufficiently large, convection will start spontaneously and significant mixing of the fluid will occur. You should note that density gradients can arise not only from temperature gradients, but also from composition gradients even in an isothermal system.

Here, we restrict our discussion to the case when temperature gradients are the source of the density gradients. The more common situation that we encounter in heat transfer is one in which there is a density gradient perpendicular to the gravity vector. Consider a burning candle. The air next to the hot candle flame is hot, whereas the air laterally farther from it is relatively cooler. This will set up a natural convection flow around the candle, in which the cool surrounding air approaches the surface of the candle, rises, and flows in a hot plume above the flame. It is this flow that causes Fluid Hot Cold T Stable Fluid Hot Cold T Unstable 2 the visible flame to take the shape it does. In the absence of gravity, a candle flame would be spherical. Another example is the flow of air at the tip of a lit cigarette; in this case, the smoke from the cigarette actually traces that flow for us. In a common technique used for home heating, the baseboard heater consists of a tube through which hot water flows, and the heater is placed close to the floor.

The tube is outfitted with fins to provide additional heat transfer surface. The neighboring air is heated, and the hot air rises, with cooler air moving in toward the baseboard at floor level. This natural convection circulation set up by the hot baseboard provides a simple mixing mechanism for the air in the room and helps us maintain a relatively uniform temperature everywhere. Clearly, the convection helps the heat transfer process here. Natural Convection adjacent to a heated vertical surface Consider a hot vertical surface present in a fluid. The surface is maintained at a temperature Ts , which is larger than the ambient temperature in the fluid Te .

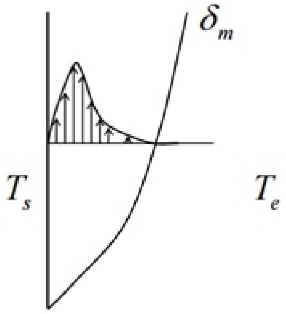

Fig 1: Figure of sketch of the momentum boundary layer along the plate

As shown in the sketch, the cold fluid rises along the plate surface, becoming heated in the process, and the momentum boundary layer grows in thickness with distance along the plate.

A sample velocity profile in the momentum boundary layer is shown. Note that in this type of boundary layer, the velocity must be zero not only at the solid surface, but also at the edge of the boundary layer. Because the profile was sketched free-hand in PowerPoint, I am unable to show the smooth approach to zero velocity with a zero slope at the edge of the boundary layer properly, but that is how the correct velocity profile would appear. Compare this velocity profile with that in a momentum boundary layer that forms on a flat plate when fluid approaches it with a uniform velocity U∞ . We can try to make a sketch of the thermal boundary layer on the same plate when the fluid is air, for example, and also when it is a viscous liquid with a Prandtl number that is large compared with unity

## II. RELATED WORK:

The analysis work carried out on proposed design of turbulent natural convective heat transfer from narrow plates are done on the fluid characteristics and heat transfer characteristics while flowing on a narrow vertical plate

### The Grashof and Rayleigh Numbers:

In natural convection situations, an important dimensionless group is the Grashof number. To provide some physical significance to this group prior to defining it, we use a simple order of magnitude estimate of the natural convection velocity in the above examples. When fluid with a density ρ moves at a velocity V , the kinetic energy per unit volume can be written as 1 2 2 ρV . This must come from some other form of energy, namely, potential energy lost by the fluid. Over a vertical distance L , the difference in potential energy between the less dense fluid in the boundary layer and the more dense fluid outside it can be approximately expressed as g L Δρ , where g is the magnitude of the acceleration due to gravity, and Δρ is a characteristic density difference between the boundary layer fluid and that far away. We can equate these two order of magnitude estimates, and neglect the factor of 1/2 , because this is only an order of magnitude analysis. Steady free convection boundary layer flow past a horizontal plate is a very practical and basically issue that is worthy enough to be discussed perfectly. So researchers in the heat transfer field paid tangible attention toward this problem. Here, because of the significant effect of buoyancyon the flow field, going through depth of the layer pressure gradient change Despite being predate reminded at the edge of the boundary layer, it should be founded as a part of solving process in accordance with velocity and temperature. Former studies verified the effect of buoyancy for this problem, and in their effort it is gotten that they focused on flows over plates which are smoothly cooled or heated. Stewart son (1958) concentrated on an isothermal horizontal semi-infinite plate and his results, which were later discussed by Gill et al. (1965), announced the existence of similarity solutions just for below and above a cooled and heated surface, respectively. Rotemand Claassen (1969) and Raju et al. (1984) discussed on the heated downward-facing cooled upward facing plates numerically. Identically, Clifton and Chapman (1969) utilized an integral method for this problem. Jones (1973), and Pera and Gebhart (1973) performed their study onan inclined plate with a isothermal condition. Also Yu and Lin (1988), and Lin et al. (1989)verified an arbitrary inclined plate. Afzal et al. (1986), Lin and Yu (1988), Brouwers (1993)and Chen et al. (1993) studied the influence of suction or blowing on the free convection of a horizontal flat plate. Ackroyd (1976) surveyed the non-Boussinesq effects. Chen et al. (1986) verified different occasions for a plate (horizontal, inclined, and vertical)with changing wall temperature or surface heat flux. A finite-difference method was applied to have a numerical solution for the non-dimensional form of the governing equation. Mahajanand Gebhart (1980) and Afzal (1985) studied higher order effects in free convection flow over horizontal surfaces. Daniels (1992) studied an insulated horizontal wall over which there was at thermal boundary layer flowing. In this flow, the velocity and temperature fields are coupled by buoyancy Many researchers worked on free convection and made great effort on this issue such as Rotem and Classen (1969), Goldstein et al. (1973) and Kitamura and Kimura (1995) who had technical papers.1002.

### Description of the problem and governing equations:

Consider the problem of free convection boundary layer flow on a heated horizontal flat plate facing upward when the non-dimensional surface temperature is given by Tw(x) = xM, where x is the coordinate measured along the plate from the leading edge and M is a constant. In this document Natural convection is observed as a result of fluid movement which is caused by density gradient. 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 constant 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 particles goes down as approaching to external border of temperature boundary layer and it would reach the temperature 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.

However, relatively little information is available on the effect of complex geometries on natural convection. Numerous experimental and numerical studies of rectangular fin heat sinks have been carried out . Since the pioneering experimental work of Ray in 1920, natural or free convection has developed into one of the most studied topics in heat transfer. Joffre and Barron obtained data for heat transfer to air from vertical ex-tended surface.At RaL = 109 they quoted an improvement in the average Nussle number of about 200Bhavnani and Burgles after several experiments proved that making special changes on vertical surfaces (horizontal little fins) reduces heat transfer in the natural convection heat transfer process. This conclusion can cause changes in the ways of insulating heat repelling surfaces and in this respect is of great importance. Nu-merical solution of the governing equations of boundary zones for vertical surfaces has been done by Helus and Churchill and step changes of surface temperature has been achieved .

### Natural convection heat transfer above heated horizontal surfaces MASSIMO CORCIONE :

An extensive reasoned review of the results available in the literature for free convection heat transfer from a heated flat plate facing upwards, is conducted. The review is organized in the form of a table, so as to give the reader the opportunity to compare the heat transfer data, expressed through dimensionless equations, as well as the conditions under which these data were obtained. A comparative survey of the results which may be derived at different Rayleigh numbers by the use of the heat transfer correlations presented, is also reported, showing that in some cases the discrepancies may amount to ±50%.

## CALCULATIONS OF VELOCITIES FOR NATURAL AND FORCED CONVECTIVE NARROW PLATES

### Natural Convection

### Velocity calculation

$$U_r = \frac{\alpha}{h}\sqrt{RaPr}$$

$$\alpha = 90$$

$$h = 100$$

$$R_a = 100$$

$$P_r = 0.7$$

$$U_r = \frac{90}{100}\sqrt{100 \times 0.7}$$

$$= \frac{9}{10}\sqrt{70}$$

$$= 0.9\sqrt{70}$$

$$= 0.9 \times 0.8366$$

$$= 0.75264 m/s$$

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**Forced convection**

$$\text{Velocity} = \frac{\text{viscosity}}{\text{density}}$$

$$= \frac{1.7894e-05}{1.225}$$

$$= \frac{1.085325962}{1.225}$$

$$= 0.8859 \ \text{m/s}$$

## III.ANALYSIS AND RESULTS OF PROPOSED MODEL

In this paper we presented a thermal analysis on vertical narrow plates for Natural and forced convection

## A. THERMAL ANALYSIS OF VERTICAL NARROW PLATES
## NATURAL CONVECTION
## MATERIAL – ALUMINUM ALLOY 7074

Material properties
Thermal conductivity: 0.173w/mmk
Specific heat: 960 J/kgk
Density: 0.00000281 kg/mm3

### Imported model

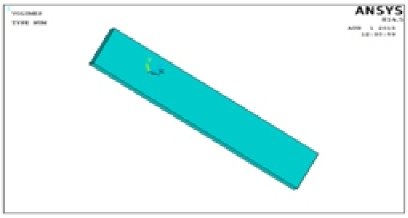


Fig 2: Figure of Imported model of narrow plates

### Meshed model

Fig 3: Figure of Meshed model of narrow plates

Temperature – 303K
Loads – define Loads – Apply – Thermal – Convection – on areas
Bulk Temperature – 313 K
Film Coefficient – 0.222W/mm2 K

## B. CFD ANALYSIS USING NATURAL CONVECTIVE HEAT TRANSFER WITH TURUBLENT FLOW

Velocity 7.5264 m/s

### Geometry model

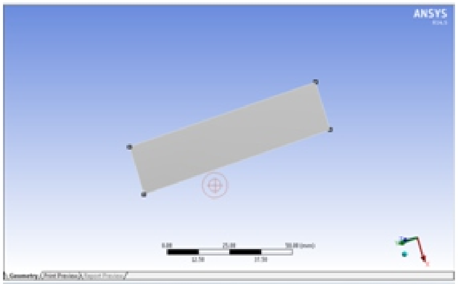


Fig 4: Figure of narrow plates with geometry model

Select faces → right click → create named section → enter name → air inlet

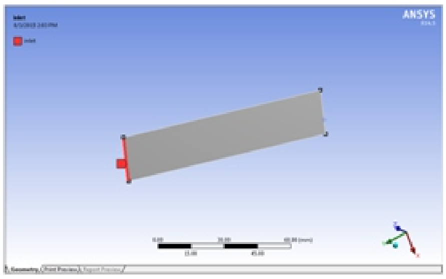


Fig 5: Figure of narrow plates with air inlet in CFD analysis

Select faces → right click → create named section → enter name → air outlet

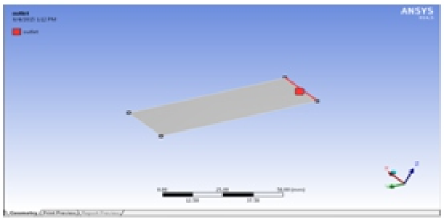
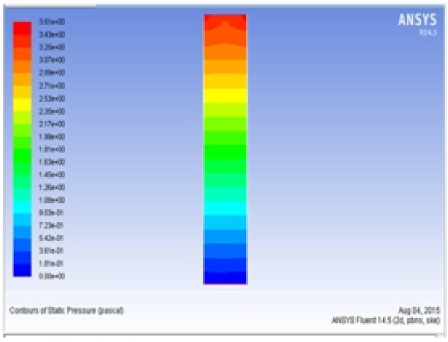


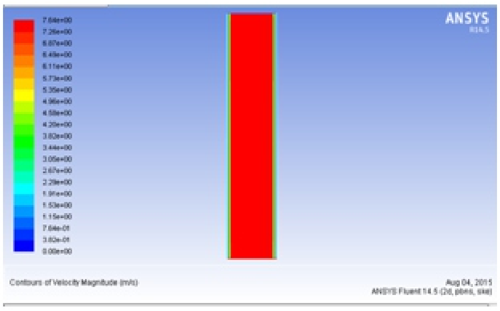
Fig 5: Figure of narrow plates with air outlet in CFD analysis

## CFD analysis of narrow plates with pressure, velocity and Temperature

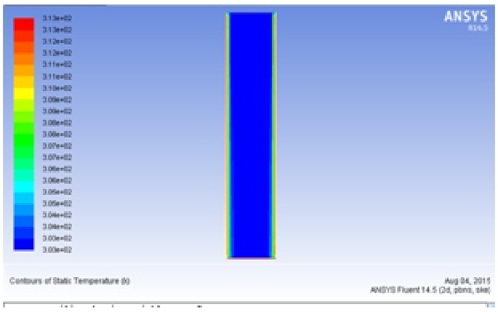
### a. Pressure



### b. Velocity

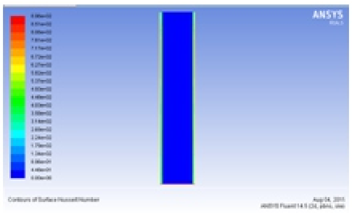


### c. Temperature

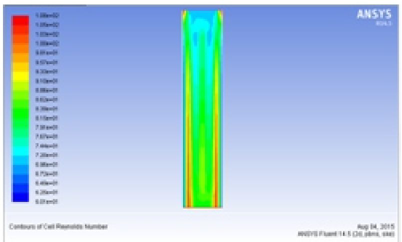


## CFD analysis of narrow plates for Nusslet's, Reynolds number

### 1. Nusslet's number



### 2. Reynolds number



## RESULTS TABLES

### Thermal analysis on natural convective plates

| Material | Nodal temperature (K) | Thermal gradient (K/mm) | Thermal flux (W/mm$^2$) |
|---|---|---|---|
| AL 7075 | 312.34 | 13.0839 | 2.26351 |
| COPPER | 311.341 | 9.51646 | 3.66384 |

### Thermal analysis on forced convective plates

| Material | Nodal temperature (K) | Thermal gradient (K/mm) | Thermal flux (W/mm$^2$) |
|---|---|---|---|
| Al 7075 | 331.013 | 22.2754 | 3.85364 |
| Copper | 331.37 | 15.354 | 5.91128 |

## CFD results on natural convective narrow plates

| Flow | Pressure (Pa) | Velocity (m/s) | Temperature (K) | Nusselt's number | Reynolds number |
|---|---|---|---|---|---|
| **Laminar** | $3.61e^{+00}$ | $7.64e^{+00}$ | $3.13e^{+02}$ | $8.96e^{+02}$ | $1.08e^{+02}$ |
| **Turbulent** | $1.94e^{+00}$ | $7.59^{+00}$ | $3.13e^{+02}$ | $5.31e^{+02}$ | $8.38e^{+02}$ |

## CFD results on forced convective narrow plates

| Flow | Pressure (Pa) | Velocity (m/s) | Temperature (K) | Nusselt's number | Reynolds number |
|---|---|---|---|---|---|
| **Laminar** | $2.61e^{+01}$ | $9.64e^{+01}$ | $3.60e^{+02}$ | $1.01e^{+02}$ | $1.04e^{+02}$ |
| **Turbulent** | $2.15e^{+01}$ | $9.39^{+01}$ | $3.60e^{+02}$ | $1.01e^{+02}$ | $5.06e^{+01}$ |

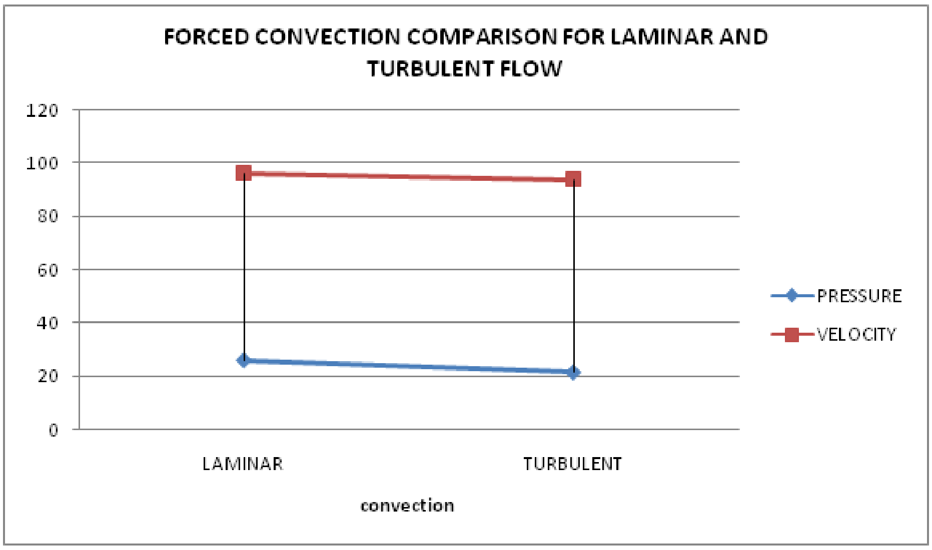


Fig 6: Graph of Forced convection comparison for laminar and turbulent flow

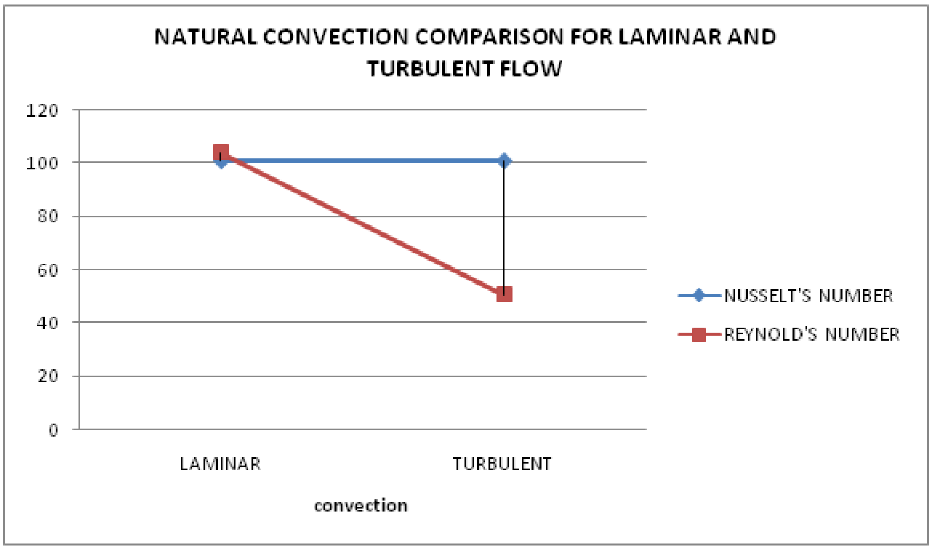


Fig 7: Graph of Natural convection comparison for laminar and turbulent flow

## IV.CONCLUSION:

The existed investigated analysis on “TURBULENT NATURAL CONVECTIVE HEAT TRANSFER FROM NARROW PLATES” provides on the fluid characteristics and heat transfer characteristics while flowing on a narrow vertical plate. The comparison is made when the flow is considered as natural or forced convection and also for the type of flow is laminar or turbulent using CFD analysis. CFD analysis is done in Ansys. Thermal analysis is done on the vertical plates by using two materials Aluminum alloy 7075 and Copper for both natural convection and forced convection. By observing the results, for natural convection, heat transfer rate is more for copper almost by 38.22% than aluminum alloy, for natural convection, heat transfer rate is more for copper almost by 34.8% than aluminum alloy. But the main disadvantage of using Copper is its high density than aluminum alloy.

The weight of the plate is increased almost by 65% when copper is used. So by taking in to account both the factors better material should be selected depending on the application. The comparison is made when the flow is considered as natural or forced convection and also for the type of flow is laminar or turbulent using CFD analysis. By observing the results, for natural convection, the pressure is about 46%, Nusselt’s number is 40.73% and Reynold’s number is 87.11% are more for laminar flow than turbulent. By observing the results, for forced convection, the pressure is about 17%, Nusselt’s number is same and Reynold’s number is 51.3% are more for laminar flow than turbulent. Since the Nusselt’s number is more, so the heat transfer coefficient is more thereby more heat transfer rates for laminar flow in natural convection. For forced convection the heat transfer rates are almost similar.

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