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Effect of forced convection on temperature distribution and velocity profile in a rectangular room

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Abstract: The research project gives a study of forced convection in a three dimension rectangular enclosure with heaters placed at the lower part on opposite walls, a window on one of the adjacent walls and a fan placed along the other wall. In the study, the speed of rotation of the fan was considered constant. To analyze the flow and heat transfer rate, a set of non-dimensionalized equations governing Newtonian fluid and boundary conditions were recast into vector form. The governing equations with boundary conditions were discretized using central difference approximations. The resulting finite difference equations (FDE) were then solved using MATLAB simulation software. The results were presented in tables and graphs to show velocity profile and temperature distribution in the room. It was revealed in the results that an increase in Reynolds number leads to an increase in velocity. It was also realized that temperature increases with decrease in Reynolds number. The results also show that an increase in Richardson number leads to a decrease in velocity.

I. INTRODUCTION

A. Background information

Heat transfer by forced convection makes use of a fan, pump or blower to provide high velocity fluid. The high velocity fluid results in a decreased thermal resistance across the boundary from the fluid to the heated surfaces. This in turn increases the amount of heat that is carried away by the fluid. In designing most electronic equipment, fans have been used to enhance heat exchange. The devices do dissipate heat while in operation and therefore require cooling system that hastens fluid mixing. In civil engineering, structures are designed putting into consideration proper air circulation. Air conditioners and convectional heaters are fixed in the structures to help in temperature regulation and air flow within the structures. Convection is a mode of heat transfer in fluids by movement of the currents from one region to another. It occurs between the surfaces of the moving fluid when at different temperature. It is sustained by both movement of molecules and bulk of the fluid within the boundary layer. Boundary layer is a thin layer of flowing fluid in contact with surface. The fluid motion influences the heat transfer; the higher the velocity the higher the rate of heat transfers. Convection of heat depends on viscosity, thermal conductivity, specific heat and density of fluid. Viscosity affects the velocity profile of the fluid flow; fluids that flow readily have smaller viscosities than thick fluids. Viscosity is a function of temperature, it increases with increasing temperature. Convection is also defined as the mechanism of heat transfer through a fluid in the presence of bulk motion. Convection is categorized as either natural (or free) and forced convection according to how the fluid motion is initiated. In natural convection, any fluid motion is caused by natural means as the buoyancy effect (the rise of warmer fluid and fall of cooler fluid). The fluid flow in convection is because of density variation as a result of thermal gradient. In forced convection, the fluid is made to flow over a surface or through a tube by external means such as a pump or fan. (Momanyi, 2015).The convective heat transfer depends on the fluid properties, roughness of the solid surface and the type of fluid flow (laminar or turbulent). The fluid velocity is assumed to be zero at the wall (no-slip condition), for this reason, the heat transfer from the solid surface to the fluid layer adjacent to the surface is by pure conduction, since the fluid is motionless. Generally, the convective heat transfer coefficient changes along the flow direction. The average convection heat transfer coefficient for a surface is obtained by averaging the local heat transfer coefficient over the entire surface. The flow in boundary layer region (region where the viscous effects and the velocity changes are significant) starts as smooth and streamlined which is called laminar flow. At a given distance from the surface the flow changes into turbulent flow and is characterized by velocity fluctuation and highly disordered motion. Fluid flow from laminar to turbulent occurs over the transition region. In laminar region, the profile is approximately parabolic and becomes flatter in turbulent flow. Turbulent region can be considered of three regions; laminar sub-layer (where viscous effects are dominant), buffer layer (where both laminar and turbulent effects exist) and turbulent layer. The intense mixing of the fluid enhances heat and momentum transfer between fluid particles, which then increases the friction force and convection heat transfer coefficient. In forced convection the heat transfer is complicated as it involves motion of particles as well as heat conduction. The fluid motion enhances heat transfer. Forced convection regime corresponds to configurations where the flow is driven by external phenomena or devices such as fans or pumps that dominate

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buoyancy effects. In this case the flow regime can be characterized, similarly to isothermal flow, using the Reynolds number as an indicator.

B. Geometry of the model

Turbulent forced convection in a room is as a result of heating and cooling. It is experienced in a number of practical occurrences such as use of convectional heaters and cooling fans in rooms. Fig. 1 is a model of a room of rectangular cross-section with heaters placed on opposite walls (on x-y plane) a window on one of the adjacent walls (on y-z plane) and a fan fitted along the other adjacent wall (y-x plane). Temperature and velocity fields in a room depend on temperature of any heat source, window as well as any other cooling agent such as cooling fan.

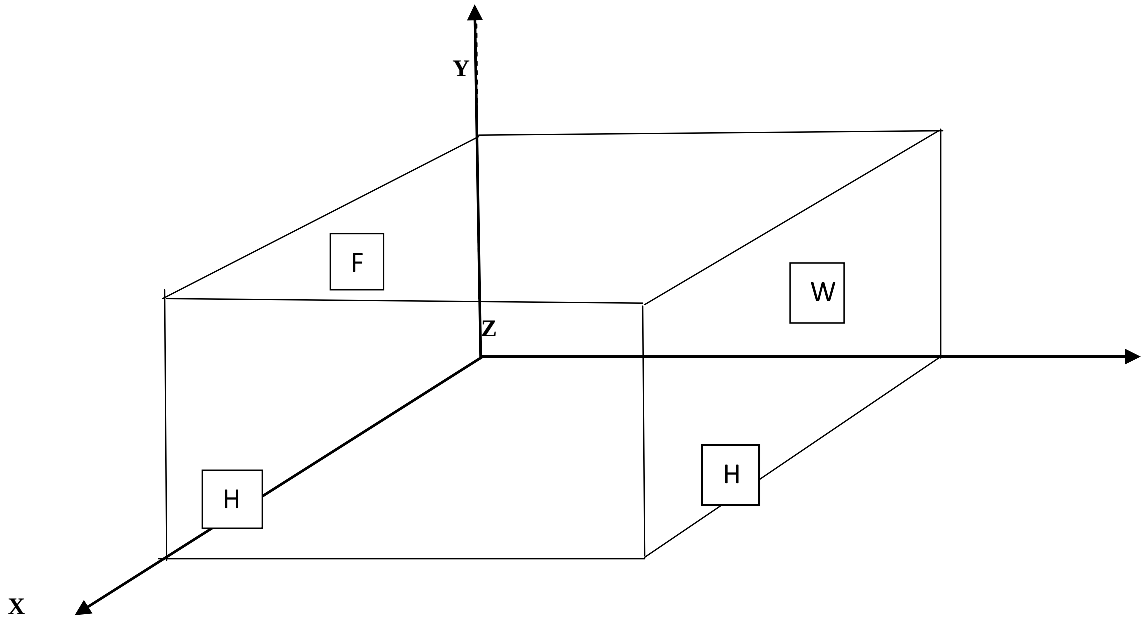

Fig 1: Model showing position of heaters, window and fan in the enclosure

II. LITERATURE REVIEW

There has been an extensive study on the problem of convective heat transfer in an enclosure this is due to the fact that the process has several areas of application in daily life experience. Sigey (2004) Investigated turbulent flow in a three dimensional enclosure in form of a room with convectional heater built into one of the walls and having a window in the same. The results showed that the room is arranged into layers of varied temperature with those near the floor being warmer and distribution reducing differently upwards. Kipn'geno (2006) studied turbulent natural convection with localized heating at the bottom (the floor) and two windows each on the vertical opposite walls of a rectangular enclosure. The study showed that the temperature distribution in the room decreases with increase in room height. Summon (2006) conducted a study on the combined free and forced convection inside a two dimensional multiple ventilated rectangular enclosure. The result of the study showed that heat transfer co-efficient is strongly affected by Reynolds number and Richardson number. Cheng *et al* (2007) conducted a study on the measurement of flow characteristics of a ceiling fan with varying rotational speed. In their geometrical set up, they used a ceiling fan equipped with the fan blades in spindle shape. A series of measuring points were taken horizontally below the fan. The results showed that the air distribution of the fan displayed a unique pattern; that the higher speed occurs below the centre of the blade and velocity declines as the measuring points are gradually away from the centre. Sigey *et al* (2011) in another study of buoyancy driven free convection turbulent heat transfer in an enclosure. They investigate a three dimensional enclosure containing a convectional heater built into one wall having a window in same wall. The heater is located below the window and the other walls are insulated. The result showed that there are three regions formed, a cold upper region, a hot region in the areas between and a warm lower region. Hamid & Mohammed (2011) carried out an investigation of turbulent mixed convection in air filled enclosure. The results showed that when Reynolds number increases the circulation of flow vortices increases and become stronger making the

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forced convection effective more dominant for different values of Richardson numbers, also for large Richardson numbers the natural convection is a major parameter heat transfer in a cavity. Salleh (2011) studied numerical solution of forced convection boundary layer flow on a horizontal circular cylinder with Newtonian heating and the result showed that an increase in the value of Prandtl number leads to a decrease in temperature profile. Nogueira *et al* (2011) conducted a study on natural convection in rectangular cavities with different aspect ratio. In their set up, natural study was numerically analyzed in rectangular in rectangular cavity heated on one side and cooled o the opposite side. Temperatures of the heated wall and of the cooled wall were assumed to be constant. Results revealed that Rayleigh number drastically influences the flow profile and heat transfer inside the cavity as well as thickness of the thermal boundary layer. Also, Nusselt number is strongly on the L/D and that this dimensionless variable increases with increase in W/L. Ghadhimi *et al* (2012) studied analysis of free and forced convection in air flow window using numerical simulation of heat transfer. The result showed that air flow influence increases in air flow window in both forced and free convection. It also showed that air flow is proportional to inlet temperature and flow rate. Azizah *et al* (2013) studied forced convection boundary layer flow along a horizontal cylinder in a porous medium filled by nano fluid. Result showed that the presence of nano particles in the base fluid enhances heat transfer rate and temperature profile. Mairura *et al* (2013) studied natural convection in a three dimensional rectangular enclosure with heaters placed on two opposite vertical walls and windows on the other two vertical walls. The results indicated that if Reynolds number of a system is small, the viscous force is predominant and the effects of viscosity are important. However, when the Reynolds number is large the inertial force is predominant and the viscous effects are only important in the narrow layer near the solid boundary. Gareh (2014) conducted a numerical study on forced convection in a rectangular channel and results showed that the velocity profile and calculated temperature has the side effect on the input speed limit for two developing layers extended over a more or less large length according to the value of Reynolds number. Robins *et al* (2014) studied mixed convection flow inside ventilated enclosure with bottom wall uniformly heated, two vertical walls maintained at constant cold temperature and top wall insulated. The results indicated that the strength of circulation increases with the increase in value of Richardson number irrespective of the Reynolds number and Prandtl number and as the value of Richardson number increases, there occurs a transition from conduction to convection dominated flow. Momanyi *et al* (2015) studied effects of forced convection on temperature distribution and velocity profile in in a rectangular enclosure with heaters fitted on opposite walls, two windows on the adjacent opposite walls and a fan centrally fixed at the top. The temperature distribution and velocity profile were studies by varying Prandtl numbers, Reynolds number and pressure. The results showed that temperature and velocity decreases as the particles flow up the room. Also the results showed temperature at a given depth decreases with increase in Reynolds number and increases with increase in Prandtl number. The flow velocity was revealed to be low at high pressure and high at low pressure. Okewa *et al* (2017) conducted a study on the effect of forced convection on the temperature distribution and velocity profile in a rectangular enclosure with varying fan speed. The results showed that temperature increases with increase in room depth. As the fan speed increases, temperature increases with increase in room depth, temperature is higher at lower Reynolds number and lower at high Reynolds number. Temperatures within the room are generally lower when the fan speed is increased. On the other hand, velocity of air within the room decreases with decrease in room's depth. The rate at which velocity decreases is higher at lower Reynolds number. As the fan speed decreases the rate at which velocity decreases lowers. Results also indicated that velocity is lower directly beneath the fan. The lowest velocity is registered when Reynolds number is high. Most scholars have studied temperature distribution and velocity profile in an enclosure considering free convection, others have looked at forced convection with various geometry. This study looked at effects of forced convection on the temperature distribution and velocity profile considering a fan fitted along one of the vertical walls, heaters fitted on other two opposite vertical walls and a window opposite to the wall along which the fan is fixed in a rectangular enclosure.

III. METHODOLOGY

In this section, the equations that govern the flow of fluids with reference to air. Considering the nature of the problem the equations are presented in two dimensions.

A. Conservation Equations

The viscous incompressible flow and the temperature distribution inside the cavity are described by the momentum and energy equations. Systems of Navier-stokes and energy partial differential equations with appropriate boundary conditions governing our problem are solved using a Finite Difference Method. The fluid flow is expressed theoretically by momentum and energy equations under the assumption that the fluid flow is steady, laminar, incompressible and two-dimensional.

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B. Computational Procedure

In this study a hybrid numerical scheme is developed which consist of forward and central schemes. A Finite Difference Method is used to solve the momentum and energy equations. The method obtains a finite system of linear or nonlinear algebraic equations from the momentum and energy equations Partial Differential Equation by discretizing the given equation and coming up with the numerical schemes analogues to the equation, in this case the momentum and energy equations. We solve the equations subject to the given boundary conditions. MATLAB software is used to generate solution values in this study.

C. The governing equations

Thermo physical properties of the fluid in the flow model are assumed to be constant except the density variations causing body force term in the momentum equation. The Boussinesq approximation is invoked for the fluid properties to relative density changes to temperature changes, and to couple in this way the temperature field to the flow field. The governing equations for the flow using conservation of mass, momentum and energy are as follows;

1. Momentum Equation

The equation is derived from the Newton's second law of motion which states that, the sum of the body and surface forces acting on a system is equal to the rate of change of linear momentum of the system. For forced convection the following momentum equation holds

$$\rho u\frac{\partial u}{\partial x}+\rho v\frac{\partial u}{\partial y}=-\frac{\partial p}{\partial x}+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right) \qquad (1)$$

$$\rho u\frac{\partial v}{\partial x}+\rho v\frac{\partial v}{\partial y}=-\frac{\partial p}{\partial y}+\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right)+g\beta\left(T-T_o\right) \qquad (2)$$

Where p denotes the thermodynamic pressure, μ, g, β and T are kinematics viscosity, gravitational acceleration, thermal expansion coefficient and temperature respectively.

2. Energy Equation

The energy equation is derived from the first law of thermodynamics which states that the rate of energy increase in a system is equated to the heat added to the system and work done on the system. From Currie (1974), assuming no external heat source, the energy equation is written as

$$\rho c_p u\frac{\partial T}{\partial x}+\rho c_p v\frac{\partial T}{\partial y}=\alpha\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right)+\mu\Phi \qquad (3)$$

Where $\Phi=2\left(\frac{\partial u}{\partial x}\right)^2+2\left(\frac{\partial v}{\partial y}\right)^2+\left(\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x}\right)^2$ and α is the thermal diffusivity.

D. Method of Solution

The momentum and energy equations are non- dimensionalized to reduce the complexity of the problem. Dimensional analysis makes the equations more concise from the physical relationship. This process reduces the number of independent variables that defines the problem. Using the following dimensionless variables;

$$X=\frac{x}{L},Y=\frac{y}{L},U=\frac{u}{u_o},V=\frac{v}{v_o},P=\frac{p}{\rho u_o^2},\theta=\frac{T-T_o}{T_1-T_o}$$

The governing equations can be to non –dimensional form as follows.
Consider the x-component of Navier- Stoke's equations and substituting the non-dimensional variables we get;

$$\frac{\rho u_o^2}{L}U\frac{\partial U}{\partial X}+\frac{\rho u_o^2}{L}V\frac{\partial U}{\partial Y}=-\frac{\rho u_o^2}{L}\frac{\partial P}{\partial X}+\frac{\mu u_o}{L^2}\left(\frac{\partial^2 U}{\partial X^2}+\frac{\partial^2 U}{\partial Y^2}\right) \qquad (4)$$

Multiplying (4) by $\frac{L}{\rho\mu_o^2}$ we get

$$U\frac{\partial U}{\partial X}+V\frac{\partial U}{\partial Y}=-\frac{\partial P}{\partial X}+\frac{\mu}{\rho u_o L}\left(\frac{\partial^2 U}{\partial X^2}+\frac{\partial^2 U}{\partial Y^2}\right) \qquad (5)$$

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But $\frac{\rho u_o L}{\mu} = \mathrm{Re}$,therefore the non- dimensional form of the x-component of the Navier- Stoke's equation become

$$U\frac{\partial U}{\partial X}+V\frac{\partial U}{\partial Y}=-\frac{\partial p}{\partial X}+\frac{1}{\mathrm{Re}}\left(\frac{\partial^2 U}{\partial X^2}+\frac{\partial^2 U}{\partial Y^2}\right) \quad (6)$$

In the same manner, the non- dimensional form of the y-component of the Navier-Stoke's equation is

$$U\frac{\partial V}{\partial X}+V\frac{\partial V}{\partial Y}=-\frac{\partial p}{\partial X}+\frac{1}{\mathrm{Re}}\left(\frac{\partial^2 V}{\partial X^2}+\frac{\partial^2 V}{\partial Y^2}\right)+\frac{Gr}{\mathrm{Re}^2}\theta \quad (7a)$$

In this investigation, Richardson number is defined as;

$Ri=\frac{Gr}{\mathrm{Re}^2}$; where Grash of number and Reynolds number are defined as;

$$Gr=\frac{g\beta(T_1-T_o)L^3}{\mu^2},\ \mathrm{Re}=\frac{u_o L}{\mu}$$

Thus equation (3.7) (a) become

$$U\frac{\partial V}{\partial X}+V\frac{\partial V}{\partial Y}=-\frac{\partial P}{\partial Y}+\frac{1}{\mathrm{Re}}\left(\frac{\partial^2 V}{\partial X^2}+\frac{\partial^2 V}{\partial Y^2}\right)+Ri\theta \quad (7b)$$

Consider the energy equation (3) and substituting the non-dimensional variables we get

$$\frac{\rho c_p u_o (T_1-T_o)}{L}\left(U\frac{\partial\theta}{\partial X}+V\frac{\partial\theta}{\partial Y}\right)=\alpha\frac{(T_1-T_o)}{L^2}\left(\frac{\partial^2\theta}{\partial X^2}+\frac{\partial^2\theta}{\partial Y^2}\right)+\frac{\mu u_o^2}{L^2}\Theta \quad (8)$$

Where $\Theta=2\left(\frac{\partial U}{\partial X}\right)^2+2\left(\frac{\partial U}{\partial Y}\right)^2+2\left(\frac{\partial U}{\partial Y}+\frac{\partial V}{\partial X}\right)^2$

Simplify equation (8) we get

$$U\frac{\partial\theta}{\partial X}+V\frac{\partial\theta}{\partial Y}=\frac{\alpha}{\rho c_p u_o L}\left(\frac{\partial^2\theta}{\partial X^2}+\frac{\partial^2\theta}{\partial Y^2}\right)+\frac{\mu u_o}{\rho c_p L(T_1-T_o)}\Theta \quad (9)$$

For low velocities, viscous dissipation is negligible.

But $\frac{\alpha}{\rho c_p u_o L}=\frac{\alpha}{\rho c_p u_o L}\left(\frac{\mu}{\mu}\right)=\left(\frac{\alpha}{\mu c_p}\right)\left(\frac{\mu}{\rho u_o L}\right)$

And $\mathrm{Pr}=\frac{\mu c_p}{\alpha},\ \mathrm{Re}=\frac{\rho u_o L}{\mu}$

Equation (9) therefore becomes

$$U\frac{\partial\theta}{\partial X}+V\frac{\partial\theta}{\partial Y}=\frac{1}{\mathrm{Re}\,\mathrm{Pr}}\left(\frac{\partial^2\theta}{\partial X^2}+\frac{\partial^2\theta}{\partial Y^2}\right) \quad (10)$$

E. Vertical Velocity

Equation (7) (b) is discretized to study the effects of Re and Ri for vertical velocity profiles. Using a Hybrid difference numerical scheme, V_x and V_y, are replaced by forward difference scheme while V_{xx} and V_{yy} are replaced by central difference approximation .When these approximations are substituted into equation (7), we get

$$U\frac{V_{i+1,j}-V_{i,j}}{\Delta x}+V\frac{V_{i,j+1}-V_{i,j}}{\Delta y}=-\frac{P_{i,j+1}-P_{i,j}}{\Delta y}+\frac{1}{\mathrm{Re}}\left[\frac{V_{i+1,j}-2V_{i,j}+V_{i-1,j}}{(\Delta x)^2}+\frac{V_{i,j+1}-2V_{i,j}+V_{i,j-1}}{(\Delta y)^2}\right]+Ri\theta \quad (11)$$

We investigate the effect of Re and Ri on the fluid velocity. Taking $\theta=10$, $\Delta x=\Delta y=0.25$,and V=1, U=0 into (11), we get the scheme

$$(\mathrm{Re}-8)V_{i,j+1}+(32-2\mathrm{Re})V_{i,j}-8V_{i,j-1}=\mathrm{Re}P_{i,j+1}-\mathrm{Re}P_{i,j}+8V_{i+1,j}+8V_{i-1,j}+Ri\,\mathrm{Re}\,\theta \quad (12)$$

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Taking i=1and j =1,2…..6 , we form the following systems of linear algebraic equations

$$\begin{aligned}
&(\mathrm{Re}-8)V_{1,2}+(32-2\mathrm{Re})V_{1,1}-8V_{1,0}=\mathrm{Re}P_{1,2}-\mathrm{Re}P_{1,1}+8V_{2,1}+8V_{0,1}+Ri\mathrm{Re}\theta\\
&(\mathrm{Re}-8)V_{1,3}+(32-2\mathrm{Re})V_{1,2}-8V_{1,1}=\mathrm{Re}P_{1,3}-\mathrm{Re}P_{1,2}+8V_{2,2}+8V_{0,2}+Ri\mathrm{Re}\theta\\
&(\mathrm{Re}-8)V_{1,4}+(32-2\mathrm{Re})V_{1,3}-8V_{1,2}=\mathrm{Re}P_{1,4}-\mathrm{Re}P_{1,3}+8V_{2,3}+8V_{0,3}+Ri\mathrm{Re}\theta\\
&(\mathrm{Re}-8)V_{1,5}+(32-2\mathrm{Re})V_{1,4}-8V_{1,3}=\mathrm{Re}P_{1,5}-\mathrm{Re}P_{1,4}+8V_{2,4}+8V_{0,4}+Ri\mathrm{Re}\theta\\
&(\mathrm{Re}-8)V_{1,6}+(32-2\mathrm{Re})V_{1,5}-8V_{1,4}=\mathrm{Re}P_{1,6}-\mathrm{Re}P_{1,5}+8V_{2,5}+8V_{0,5}+Ri\mathrm{Re}\theta\\
&(\mathrm{Re}-8)V_{1,7}+(32-2\mathrm{Re})V_{1,6}-8V_{1,5}=\mathrm{Re}P_{1,7}-\mathrm{Re}P_{1,6}+8V_{2,6}+8V_{0,6}+Ri\mathrm{Re}\theta
\end{aligned} \tag{13}$$

The above algebraic equations can be written in matrix form as when we take initial conditions boundary conditions V(0,y) = V(x,1) = V(2,y) = 1 and P(x,y)=10^5 .Eqn (13) becomes

$$\begin{bmatrix}
(32-2\mathrm{Re}) & (\mathrm{Re}-8) & 0 & 0 & 0 & 0\\
-8 & (32-2\mathrm{Re}) & (\mathrm{Re}-8) & 0 & 0 & 0\\
0 & -8 & (32-2\mathrm{Re}) & (\mathrm{Re}-8) & 0 & 0\\
0 & 0 & -8 & (32-2\mathrm{Re}) & (\mathrm{Re}-8) & 0\\
0 & 0 & 0 & -8 & (32-2\mathrm{Re}) & (\mathrm{Re}-8)\\
0 & 0 & 0 & 0 & -8 & (32-2\mathrm{Re})
\end{bmatrix}
\begin{bmatrix} V_{1,1}\\ V_{1,2}\\ V_{1,3}\\ V_{1,4}\\ V_{1,5}\\ V_{1,6}\end{bmatrix}
=
\begin{bmatrix} -10^5+16+Ri\theta\mathrm{Re}\\ -10^5+16+Ri\theta\mathrm{Re}\\ -10^5+16+Ri\theta\mathrm{Re}\\ -10^5+16+Ri\theta\mathrm{Re}\\ -10^5+16+Ri\theta\mathrm{Re}\\ -10^5+16+Ri\theta\mathrm{Re}\end{bmatrix} \tag{14}$$

Solving the above matrix equation (14), we get the solutions for varying values of Ri and Re with $\theta = 10^o$ we get results as shown in Fig 2.

F. Temperature Distribution

The energy Equation (3.10) is discretized to study the effects of Re for temperature profiles. Using a hybrid numerical scheme, we get

$$\frac{\theta_{i,j+1}-\theta_{i,j}}{\Delta t}+U\frac{\theta_{i+1,j}-\theta_{i-1,j}}{2\Delta x}+V\frac{\theta_{i,j+1}-\theta_{i,j-1}}{2\Delta y}=\frac{1}{\Pr\mathrm{Re}}\left[\frac{\theta_{i+1,j}-2\theta_{i,j}+\theta_{i-1,j}}{(\Delta x)^2}+\frac{\theta_{i+1,j+1}-2\theta_{i,j+1}+\theta_{i-1,j+1}}{(\Delta x)^2}\right] \tag{15}$$

We investigate the effect of Re, on the fluid velocity. We take Pr = 0.71 since the fluid is air. Taking $\Delta x = \Delta t = 0.1$,Re=100 and V=1, U=1, we get the scheme

$$(\mathrm{Re}-11.4)\theta_{i,j+1}+55.6\theta_{i,j}-(\mathrm{Re}+11.4)\theta_{i,j-1}=(11.4-\mathrm{Re})\theta_{i+1,j}+(11.4+\mathrm{Re})\theta_{i-1,j} \tag{16}$$

Taking i=1 and j=1,2,3…6 we form the following systems of linear algebraic equations

$$\begin{aligned}
&(\mathrm{Re}-11.4)\theta_{1,2}+55.6\theta_{1,1}-(\mathrm{Re}+11.4)\theta_{1,0}=(11.4+\mathrm{Re})\theta_{2,1}+(11.4+\mathrm{Re})\theta_{0,1}\\
&(\mathrm{Re}-11.4)\theta_{1,3}+55.6\theta_{1,2}-(\mathrm{Re}+11.4)\theta_{1,1}=(11.4+\mathrm{Re})\theta_{2,2}+(11.4+\mathrm{Re})\theta_{0,2}\\
&(\mathrm{Re}-11.4)\theta_{1,4}+55.6\theta_{1,3}-(\mathrm{Re}+11.4)\theta_{1,2}=(11.4+\mathrm{Re})\theta_{2,3}+(11.4+\mathrm{Re})\theta_{0,3}\\
&(\mathrm{Re}-11.4)\theta_{1,5}+55.6\theta_{1,4}-(\mathrm{Re}+11.4)\theta_{1,3}=(11.4+\mathrm{Re})\theta_{2,4}+(11.4+\mathrm{Re})\theta_{0,4}\\
&(\mathrm{Re}-11.4)\theta_{1,6}+55.6\theta_{1,5}-(\mathrm{Re}+11.4)\theta_{1,4}=(11.4+\mathrm{Re})\theta_{2,5}+(11.4+\mathrm{Re})\theta_{0,5}\\
&(\mathrm{Re}-11.4)\theta_{1,7}+55.6\theta_{1,6}-(\mathrm{Re}+11.4)\theta_{1,5}=(11.4+\mathrm{Re})\theta_{2,6}+(11.4+\mathrm{Re})\theta_{0,6}
\end{aligned} \tag{17}$$

Taking the initial and boundary conditions θ(x,0)=0 ,θ(0,y)=θ(2,y) =1, the above system of algebraic equation becomes

$$\begin{bmatrix}
55.6 & (\mathrm{Re}-11.4) & 0 & 0 & 0 & 0\\
-(\mathrm{Re}+11.4) & 55.6 & (\mathrm{Re}-11.4) & 0 & 0 & 0\\
0 & -(\mathrm{Re}+11.4) & 55.6 & (\mathrm{Re}-11.4) & 0 & 0\\
0 & 0 & -(\mathrm{Re}+11.4) & 55.6 & (\mathrm{Re}-11.4) & 0\\
0 & 0 & 0 & -(\mathrm{Re}+11.4) & 55.6 & (\mathrm{Re}-11.4)\\
0 & 0 & 0 & 0 & -(\mathrm{Re}+11.4) & 55.6
\end{bmatrix}
\begin{bmatrix}\theta_{1,1}\\ \theta_{1,2}\\ \theta_{1,3}\\ \theta_{1,4}\\ \theta_{1,5}\\ \theta_{1,6}\end{bmatrix}
=
\begin{bmatrix}11.4+\mathrm{Re}\\ 0\\ 0\\ 0\\ 0\\ 0\end{bmatrix} \tag{18}$$

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Solving the above matrix equation, we get the solutions for varying values of Re as represented in Fig 4.

IV. RESULTS AND DISCUSSION

Introduction

The simulation results given focus on the effects of the Ri number and Re number on velocity and temperature.

A. Effects of Richardson number on vertical velocity of fluid flow

We solve equation (14) using MATLAB and get the results of the effects of Ri number on velocity of fluid as shown in fig 2 below

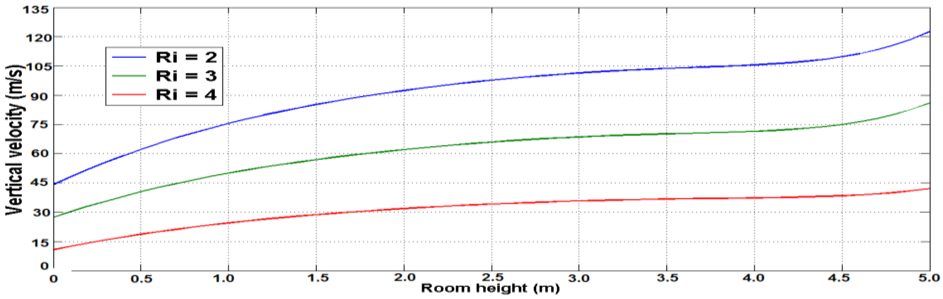

Fig 2: Graph of vertical velocity against room height at varying Ri number

It is observed in fig.2 that as the Richardson number is increased vertical velocity decreases. This is because buoyancy effect is low as the flow is forced. For a particular Richardson number; at height near the floor of the room, y=0,the air is cold and heavy and therefore the velocity is lower as seen in the graph. As the height increases to y= 2.5m to y=3m, the air gets warmed up and rises with increased velocity since warm air is lighter. Also, at this height the rotating fan fixed at the wall further increases the air speed which makes speed continue increasing steadily as height of room increases.

B. Effects of Reynolds number on vertical velocity of fluid flow

We solve equation (14) using MATLAB and get the results of the effects of Re number on velocity of fluid as shown in fig 3 below

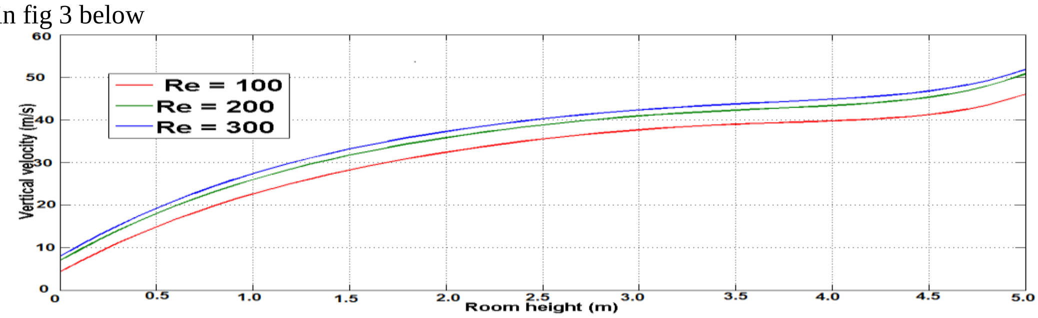

Fig 3: Graph of vertical velocity against room height at varying Re number

In fig.3 above it is observed that increase in Reynolds number leads to increase in vertical velocity. At high Reynolds number the velocity is higher as inertia forces are predominant. At a given Reynolds number it is seen that the velocity is low near the floor as air in this region is cold and heavy, as the height increases to the middle of the room air gets warmed up and flows with increased velocity, the rotating fan fixed in the wall further increases the air speed which makes the velocity to continue increasing steadily as height of the room increase.

C. Effects of Reynolds number on temperature of fluid

We solve equation (18) using MATLAB and get the results of the effects of Re number on temperature of fluid as shown in fig 4 one below

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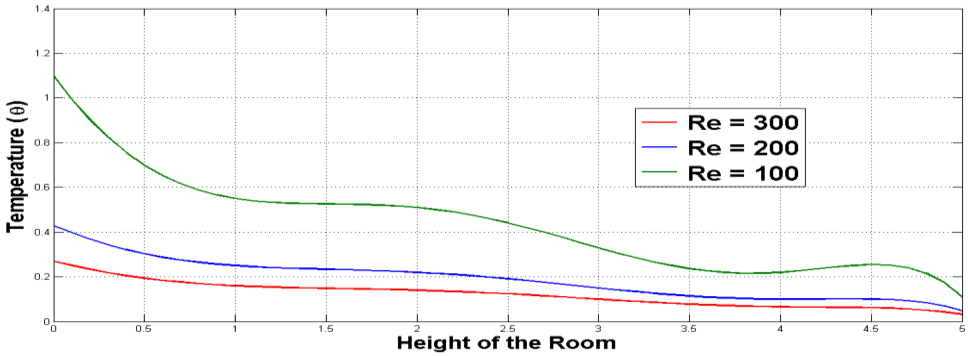

Fig 4: Graph of temperature against room height at varying Re number

As the height of the room increases, the temperature decreases. It can be seen from fig. 4 that, as the Re number increases the temperature along y axis decreases. The amount of heat transfer is high at high Re number than low Re number. At high Re number inertial forces were predominant. Similarly this was also reflected at high Re number initial velocity was high than when Re number was low since at high Re number inertial forces were predominant.

D. Validation

The results obtained in this study are in agreement with other related studies as shown in Momanyi *et al* (2015) in there study 'Effect of Forced Convection on Temperature Distribution and Velocity Profile' investigated variation of velocity and temperature in a rectangular room with Reynolds number. Their result indicated that velocity of air within the room is high at high Reynolds number than at low Reynolds number. It also showed that temperature decreases up the room.

V. CONCLUSION AND RECOMMENDATIONS

A. Conclusion

In fig.2; the horizontal velocity of the fluid across the room was high at high Reynolds number than at low Reynolds number. This is due to predominant inertial forces at high Reynolds number. Similarly, in fig. 4; the vertical velocity was also high at high Reynolds number than at low Reynolds number. Therefore, Reynolds number affects the velocity profile in the room. In fig.3, the velocity of the fluid is high at low Richardson number than at high Richardson number, since the flow is forced the buoyancy effect on the flow is low. Thus, the velocity increases as the Richardson number decreases. In fig.4, temperature decreased up the room and reduction of pressure by the fan lead to low temperatures. The temperature was highest near the heater region followed by the window regions and then the fan area had the lowest temperature. The results show that forced convection affects velocity profiles and temperature distribution in a room.

B. Recommendations

(i) Investigate forced convection when the fan is fixed along the vertical wall with varying speed.
(ii) Investigate forced convection when the fan is placed at the center of the room.
(iii) Investigate any environmental impact on forced convection.

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