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Multi-Phase Flow Analysis in Nuclear Reactors Using Ansys Fluent

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Abstract: ***Multiphase flow is the instantaneous flow of mixture of different phases. There are three types of phases- gas, liquid, solid. Water has 3 different phase; water-liquid , water-vapour , water-ice. Sometimes multiphase can also be referred as multi component flow where a substance do not have a distinguished phase but it is a uniform thorough out its existence. Two phase flow is completely different in every aspect to single phase flow say from its governing equations to flow characteristics. It gets complicated and complex as we move from 2 phases to 3phase flow and so on. The multiphase flow depends mainly on the flow rate, cross section, fluid characteristics and boundary conditions. The study of multiphase flow is very important because the chemical and flow properties vary strongly over the flow regime which accounts for the design and safety of the subsystems in the nuclear plant.. Volumetric model of Ansys fluent categorises the elements of multiphase to be primary and secondary. Primary phase is generally gas or liquid and Secondary phase is solid or liquid. The present study involves understanding the multiphase flow dynamics and performs simulations of multi phase flow in horizontal pipe with friction pressure drop taken into account using Ansys Fluent solver.***

Keywords*:Multiphase flow, Horizontal pipe analysis, Thermal Hydraulics in Nuclear reactors, Ansys fluent, CFD,*

I. INTRODUCTION

The force of gravity plays a vital role in in understanding the behaviour of multiphase flow. This can be illustrated by taking vapor and liquid phases of water. The density of water is more than the water vapour and force of gravity depends on the density of the material. The concentration gradient of different phases induces greater pressure on the structure. The chaotic situation can lead to phase change and consequently increase the spatial organization of different phases. The efflux velocities can be altered irregularly across the flow channel. Multiphase flows occur in vertical pipes , horizontal pipes or inclined pipes similar to those in single phase flow. The flow is also analysed depending on the presence of heat flux across the flow channel. They are adiabatic in which heat transfer is zero and other is where there is considerable amount if heat transfer occurs across the boundary. The multiphase flow is also analysed depending upon the direction of flow phases ; parallel flow and counter flow. The different types of multiphase flow are homogenous equilibrium model, Homogeneous Flow Friction Pressure Drop , Separated Flow Model, Separated Flow Model flow friction pressure drop models. The flow can be amalgamation of laminar and turbulent characteristics. Flow regimes in horizontal pipes can be categorised into Bubbly flow, Plug flow, Stratified flow, Wavy flow, Slug flow, annular flow. The multiphase flow analysis helps in developing passive safety system nuclear reactors or gravity driven reactor flows.

A. Flow Governing Equations

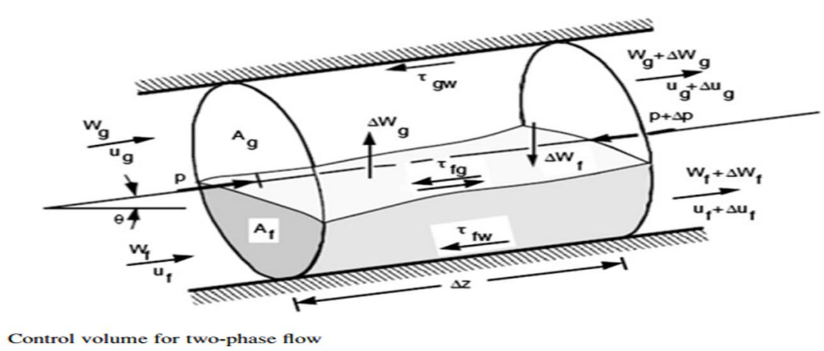

Fig. 1 Control Volume of 2 phase flow (Ref #1)

The equations to deduce different properties pertaining to the control volume are as follows:

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The *static void fraction* is given by the cross-sectional areas of gases and liquids, A_g and A_f:

$$\alpha = \frac{A_g}{A}, \quad (1-\alpha) = \frac{A_f}{A}.$$

The *flow void fraction* is given by the volumetric flows of gases and liquids, Q_g and Q_f:

$$\beta = \frac{Q_g}{Q_g + Q_f}, \quad (1-\beta) = \frac{Q_f}{Q_g + Q_f}.$$

The *static flow quality* is given by the mass of each component in a control volume:

$$x_s = \frac{\alpha\rho_g}{\alpha\rho_g + (1-\alpha)\rho_f}, \quad (1-x_s) = \frac{(1-\alpha)\rho_f}{\alpha\rho_g + (1-\alpha)\rho_f}.$$

The *mass quality* is given by the individual phase flow rates W_g and W_f:

$$x = \frac{W_g}{W_g + W_f}, \quad (1-x) = \frac{W_f}{W_g + W_f}.$$

The *equilibrium flow quality* is given by the mixture enthalpy h:

$$x_E = \frac{h - h_f}{h_{fg}}, \quad (1-x_E) = \frac{h_g - h}{h_{fg}}.$$

The *mass velocity* is given by the mean velocity u, density ρ, and specific volume υ:

$$G = \frac{W}{A} = \rho u = \frac{u}{\upsilon}.$$

Governing equations of multiphase flow are:

Continuity:

$$W_g + W_f = W = \text{constant} \qquad dW_g = -dW_f \text{ (steady state)}$$

Conservation of momentum:

$$\frac{d}{dz}(W_g u_g) - (u_g - u_f)\frac{dW_g}{dz} = -A_g\frac{dp}{dz} - P_{gw}\tau_{gw} - P_{fg}\tau_{fg} - A_g\rho_g g\cos\theta \quad \text{(vapor)}$$

$$\frac{d}{dz}(W_f u_f) + (u_g - u_f)\frac{dW_f}{dz} = -A_f\frac{dp}{dz} - P_{fw}\tau_{fw} + P_{fg}\tau_{fg} - A_f\rho_f g\cos\theta \quad \text{(liquid)}$$

$$\frac{d}{dz}(W_f u_f + W_g u_g) = -A_f\frac{dp}{dz} - P_f\tau_{fw} - P_g\tau_{gw} - \left(A_f\rho_f + A_g\rho_g\right)g\cos\theta \quad \text{(combined)}$$

Conservation of energy:

$$\frac{dq_e}{dz} - \frac{dw}{dz} - W\frac{d}{dz}(h + gz\cos\theta) + \frac{d}{dz}\left(\frac{W_f u_f^2}{2} + \frac{W_g u_f^2}{2}\right) = 0$$

heat work enthalpy potential kinetic

The equations are taken from the Reference 1 mentioned in the references of this paper. The Ansys fluent platform gives the option of choosing multiphase flow characteristics and other boundary conditions .The flow is analysed mathematically by above partial differential equations.

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B. Flow Regime

Different types of flow regime discussed above can be displayed as follows:

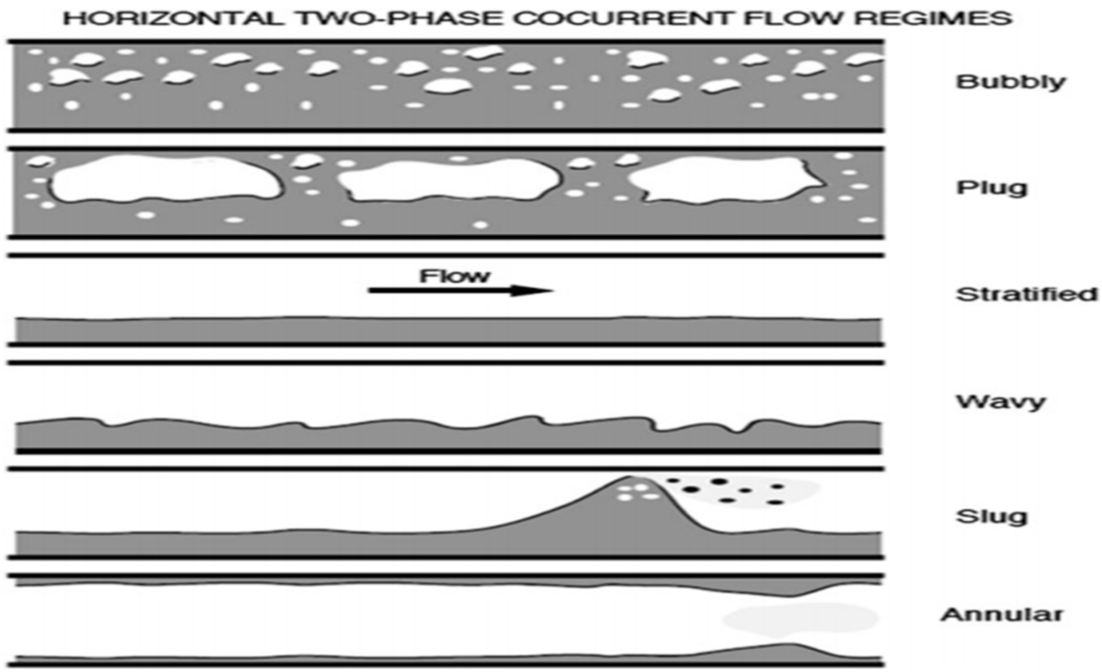
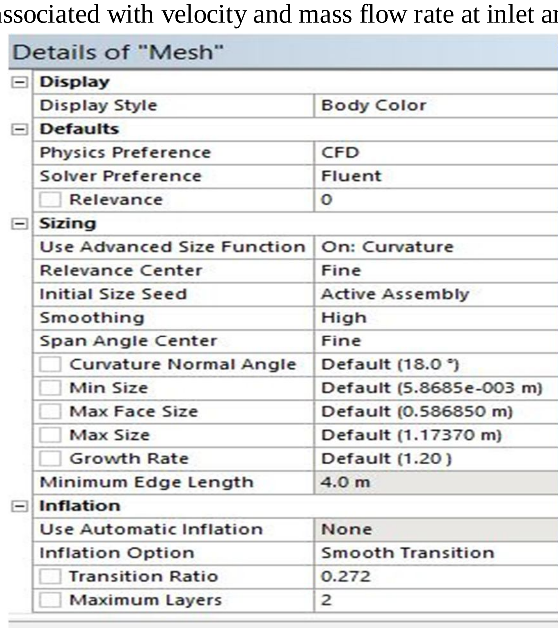


Fig. 2 flow regime in a horizontal pipe

C. Computational Approach

Ansys fluent 16.2 is used for the simulation. The dimensions of the pipe are 4m length, 100mm outer diameter and 60 mm inner diameter . The pipe inlet cross section has 2 holes for the mixture to enter and open end outlet. The inlet velocity of the water-liquid 0.7m/s and air at a velocity of 25 m/s. The mass flow rates of air and water are 0.003 kg/s and 0.1 kg/s respectively. The extreme points are associated with velocity and mass flow rate at inlet and internal flow behaviour .



Details of "Mesh"

Display	
Display Style	Body Color
Defaults	
Physics Preference	CFD
Solver Preference	Fluent
Relevance	0
Sizing	
Use Advanced Size Function	On: Curvature
Relevance Center	Fine
Initial Size Seed	Active Assembly
Smoothing	High
Span Angle Center	Fine
Curvature Normal Angle	Default (18.0 °)
Min Size	Default (5.8685e-003 m)
Max Face Size	Default (0.586850 m)
Max Size	Default (1.17370 m)
Growth Rate	Default (1.20)
Minimum Edge Length	4.0 m
Inflation	
Use Automatic Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0.272
Maximum Layers	2

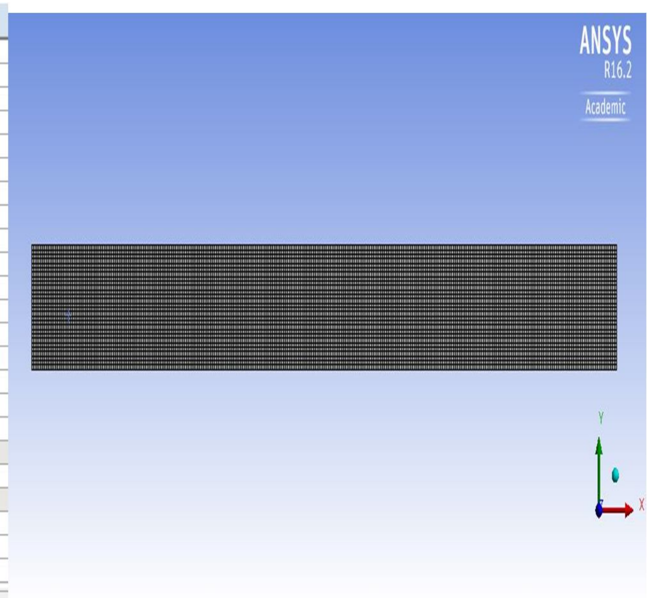
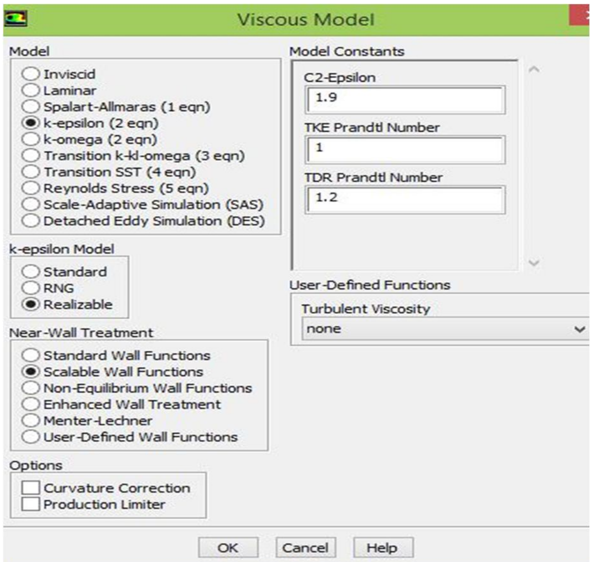


Fig. 3 Mesh setup

Fig. 4 Mesh graphic



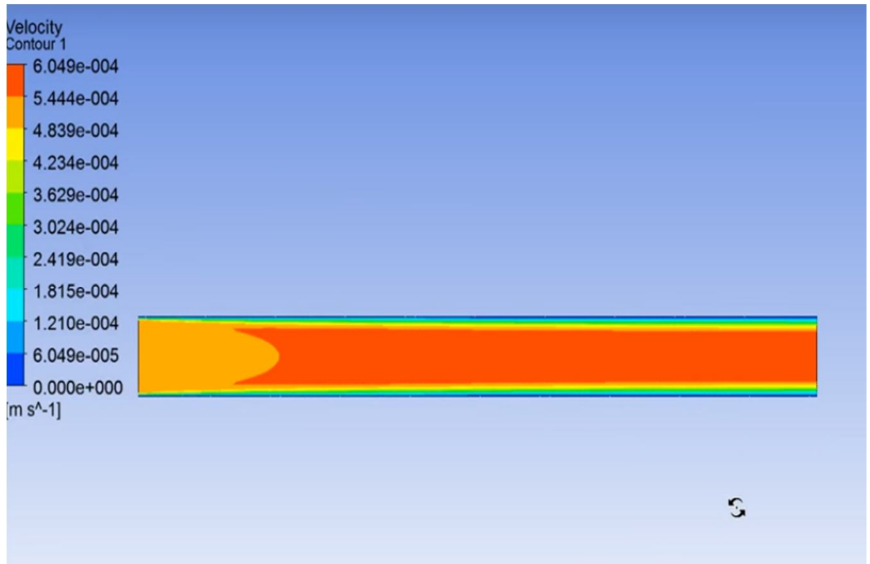
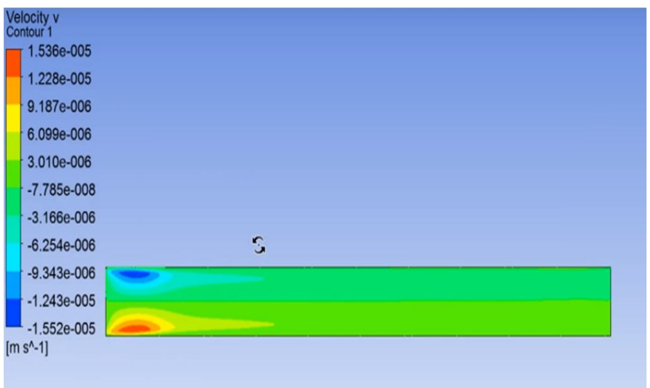


Fig. 5 Mathematical model set up Fig. 6 Velocity contour for slug flow



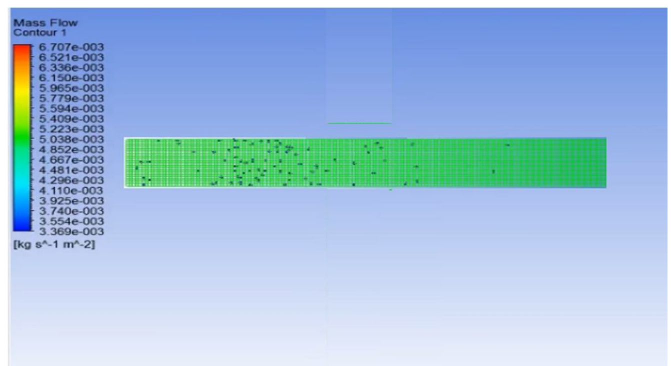
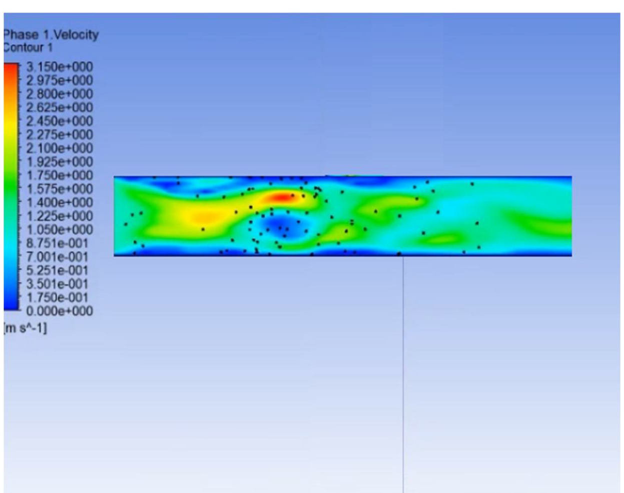


Fig 7 : Velocity contour for wavy

Fig 8: mass flow gradient contour



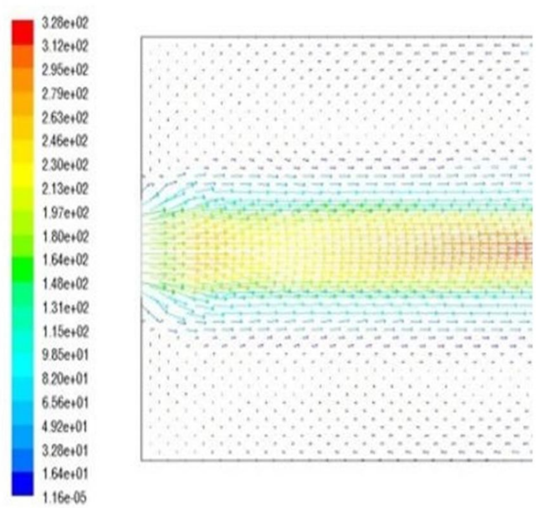


Fig 9:Velocity contour for plug flow

Fig 10 Pressure variation vector representation

II. CONCLUSION

The model is analysed using k-Epsilon turbulence model for given boundary conditions and various flow regimes have been visualised for different pressure conditions and velocities using interpolation of graphs. Contours are generated for mass flow rate, pressure and velocity in the reactor conditions. Flow analysis is performed and analytical results can be compared in the further work with experimental values.

III. ACKNOWLEDGMENT

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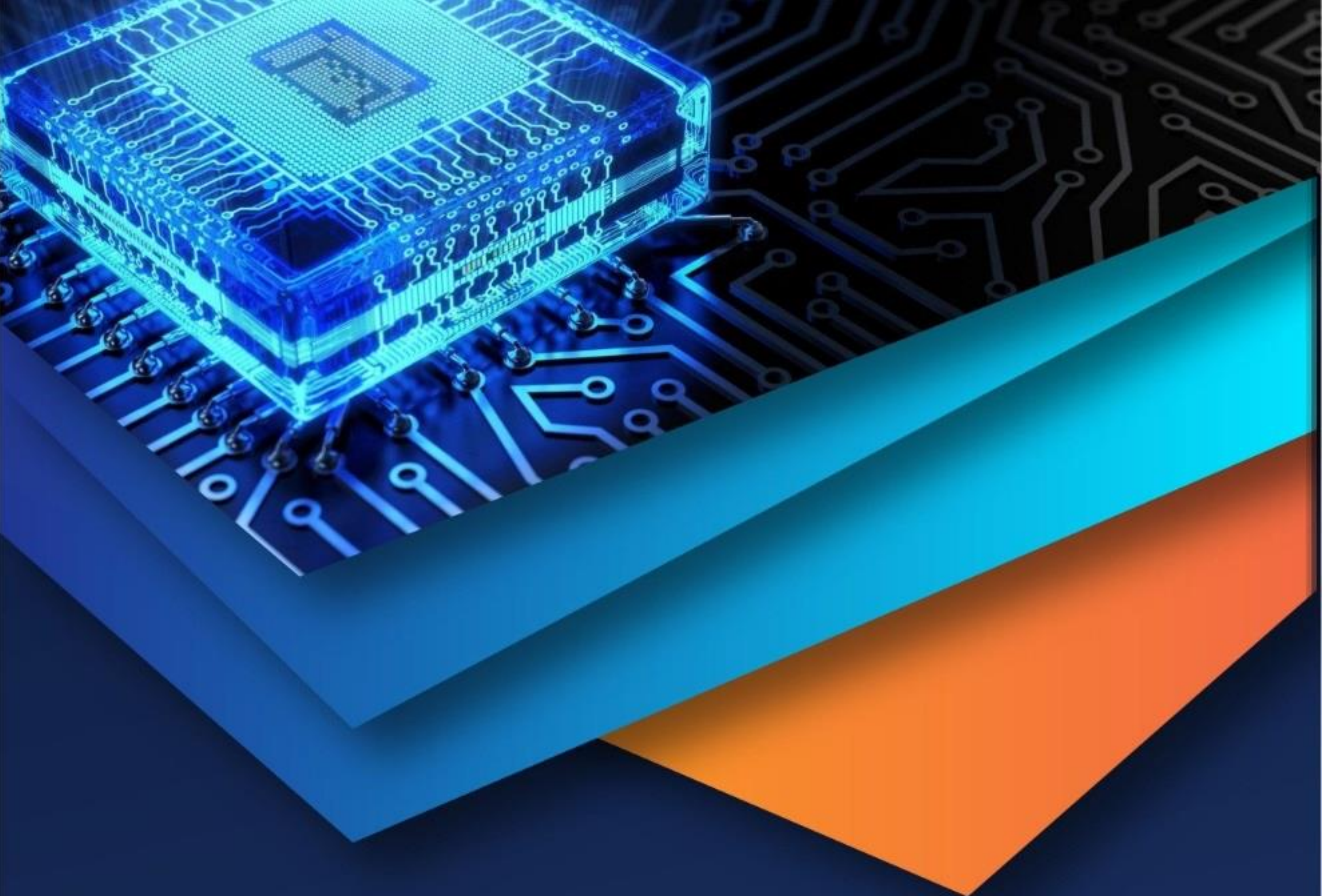

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