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Study of Thermal Performance of Closed Loop Pulsating Heat Pipe using Computational Fluid Dynamics

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Abstract: Pulsating heat pipe is a heat transfer device which works on two principles that is phase transition and thermal conductivity which transfer heat effectively at different temperatures. Different factors affect the thermal performance of pulsating heat pipe. So, various researchers tried to enhance thermal conductivity by changing parameters such as working fluids, filling ratio, etc. Analysis of heat transfer characteristics of closed loop pulsating heat pipe (CLPHP) is to be carried out by using Computational Fluid Dynamics. The CLPHP is to be modelled on ANSYS Workbench, the flow of CLPHP is to be observed under specific boundary conditions by using ANSYS Fluent software. Acetone and Water are taken as the working fluid with 70% filling ratio at ambient temperature 30° C and the heat flux of 200 W is supplied at evaporator. Also, the analysis has been done to know the behaviour of PHPs under varying supply of heat flux at evaporator (inlet), the output heat flux is obtained at condenser (outlet) and find out how the heat flux is varying at different temperatures. CFD results shows the heat transfer characteristics observing the performance of CLPHP is a numerical manner. The obtained CFD results are compared with the experimental. The outputs of the simulations are plotted in graphs and outlines.
Keywords: Closed Loop Pulsating Heat Pipe, CFD, Heat Transfer, ANSYS.

I. INTRODUCTION

A pulsating heat pipe (PHP) which is also called as oscillating heat pipe is an efficient way of exchanging heat between a hot source and a cold source. It consists of a closed capillary tube which folded into two number of turns and filled with Acetone and Water as the working fluids. One side of the CLPHP is in thermal contact with a hot spot (evaporator section) and the other with a cold spot (condenser section) that is one end of this tube bundle receives heat and transferring it to the other end by a pulsating action of the liquid-vapor or bubble-slug system. The oscillation of the liquid plugs and vapor bubbles occurs by the action at the upper surface of the tube (condenser section) after the start of heating in lower section (evaporator section). The plugs move between hot and cold areas by creating an efficient convective heat exchange. This advantage of PHP makes it highly competitive with respect to other kinds of heat pipes. However, the PHP functioning is non-stationary and depends on many physical and material parameters.

Computational Fluid Dynamics (CFD) technique is used to establish the numerical model of Closed Loop Pulsating Heat Pipe (CLPHP) and analyse the thermal performance. CFD analysis for the CLPHP with working fluids acetone and water, 70% filling ratio, inner diameter 2mm and outer 3mm. At evaporator boundary, the effective thermal conductivity varies with pipe length, and can approach 200 kW. A CFD modelling is done in ANSYS Fluent software with two number of turns of pulsating heat pipe. The temperature distribution across the heat pipe was measured. The performance parameters such as temperature difference between evaporator and condenser, thermal conductivity is to be determined.

II. LITERATURE REVIEW

"Effects of the evaporator and condenser length on the performance of pulsating heat pipes"(2014) JianshengWangHeMa, QiangZhu A two-dimensional single loop closed-loop pulsating heat pipe (CLPHP) is investigated by CFD in present work. The volume of fluid (VOF) method is used to investigate the start-up characteristic and thermal performance of CLPHP with different ratios of the evaporator length to that of the condenser. Considering the action of wall adhesion and the effect of surface tension, the continuum surface force (CSF) model is adopted. The investigation is carried out by changing input power (from 10 W to 40 W) and filling ratio (from 30% to 60%). The numerical results are compared with available experimental results at the same condition.

"CFD Analysis of Copper Closed Loop Pulsating Heat pipe" J. Venkatasuresh, P. Bhramara (2017), CFD analysis for the PHP is tested with different working fluids binary mixtures like water-methanol and water-ethanol for 50% fill ratio viz., for different inner diameters of 2mm and 3mm. At evaporator boundary, heat flux that is equivalent to 10W to 70W is supplied and the condenser boundary is set as heat flux of range 1000w/m^2 and in the adiabatic section heat flux is zero. A CFD modelling is done in ANSYS CFX with two turns of PHP. The temperature distribution across the heat pipe was measured.

The performance parameters such as temperature difference between evaporator and condenser, thermal resistance evaluated. CFD results demonstrate the heat transfer characteristics observing the performance of PHP is a numerical approach. The obtained CFD results are compared with the experimental paper. The CFD analysis is performed and the outputs of the simulations are plotted in graphs and contours.

“Numerical and experimental investigation of flat-plate pulsating heat pipes with extra branches in the evaporator section” Erfan’Sedighi’Ali’Amarloo’Behshad’Shafii (2018) **,**Thermal performances of these two types of heat pipes were investigated at different filling ratios (40, 50, 60, and 70 percent) and heat inputs (from 40 to 200 W). Results showed that the thermal resistance of the AB-FP-PHP was 11–20% lower on average compared to the thermal resistance of the conventional FP-PHP at different examined filling ratios. Additionally, for heat inputs around 80 W and above, thermal performances of both devices were better at 50% filling ratio. Furthermore, flow visualization indicated that additional branches affect the flow regime and enhance flow circulation in PHPs. Also, a numerical procedure was conducted for the two-phase system before the experimental investigation to show the role of additional branches in achieving a better circulation of the working fluid.

“Experimental and numerical investigation of using pulsating heat pipes instead of fins in air-cooled heat exchangers” HassanJafari MoslehMohamad, AliBijarchi Mohammad, BehshadShafii 2019 The goal of this study is the experimental and numerical investigation of using pulsating heat pipes (PHPs) as substitutes for fins in a typical air-cooled heat exchanger. Due to the small temperature difference between the cooling air and internal airflow in the case study, it was necessary that appropriate PHPs with the capability to work in small temperature difference conditions be investigated and an appropriate working fluid be selected. After reviewing various studies, R134a was selected as the best working fluid from the heat transfer standpoint.

“Study on the effect of the adiabatic section parameters on the performance of pulsating heat pipes “2020, QingfengLi ChenhaoWang YananWang ZhengkunWang HuaLi ChenLian In this paper, a numerical model of the Pulsating Heat Pipe (PHP) is established, based on the two-phase flow theory and the Volume of Fluid (VOF) method in Computational Fluid Dynamics (CFD). Under the condition that the structure, liquid Filling Rate (FR) and heating power of the PHP remain unchanged, the effect of the length and the convective heat transfer coefficient of the adiabatic section on the start-up performance, heat transfer performance and anti-dry-out ability of the PHP are studied by changing the adiabatic section parameters

III. OBJECTIVE

A. Modelling of Closed Loop Pulsating Heat Pipe using ANSYS workbench.
B. To stimulate CLPHP using ANSYS FLUENT software.6
C. To validate the obtained CFD results.
D. To find out how heat flux varying with different temperatures.

IV. METHODOLOGY

A. Geometry

The closed loop pulsating heat pipe is modelled using ANSYS workbench. The simplified geometry of closed loop pulsating heat pipe is shown in fig 1. The geometry imported in ANSYS FLUENT and perform CFD analysis in which 70% filling ratio of working fluid acetone and water as base fluid. The dimensions of closed loop pulsating heat pipe are shown in table 1.

Table 1: Geometry details

Specifications	Dimensions
Inner Diameter	3 mm
Outer Diameter	5 mm
Length of Evaporator section	116.56
Length of Condenser section	51.708
Length of Adiabatic section	48

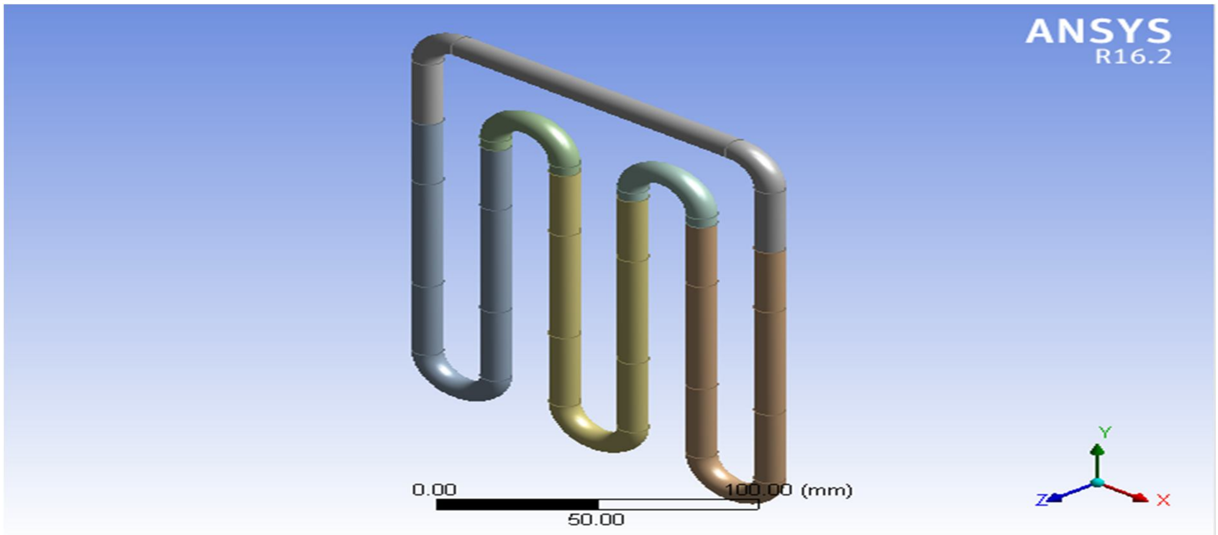

Fig. 1. Model of Closed Loop Pulsating Heat Pipe

B. Meshing

A mesh is a network which is formed by cells and points. Meshing is an engineering simulation process in which complex geometries are divided into simple elements mesh can be in any shape and size depending on geometry. Meshing plays an important role to depict flow pattern in the tube. Fine meshing is to be done with the size of 0.3 mm. Meshing elements size near wall taken as small to find out the results near boundary walls of closed loop pulsating heat pipe. So, coarse mesh is generated.

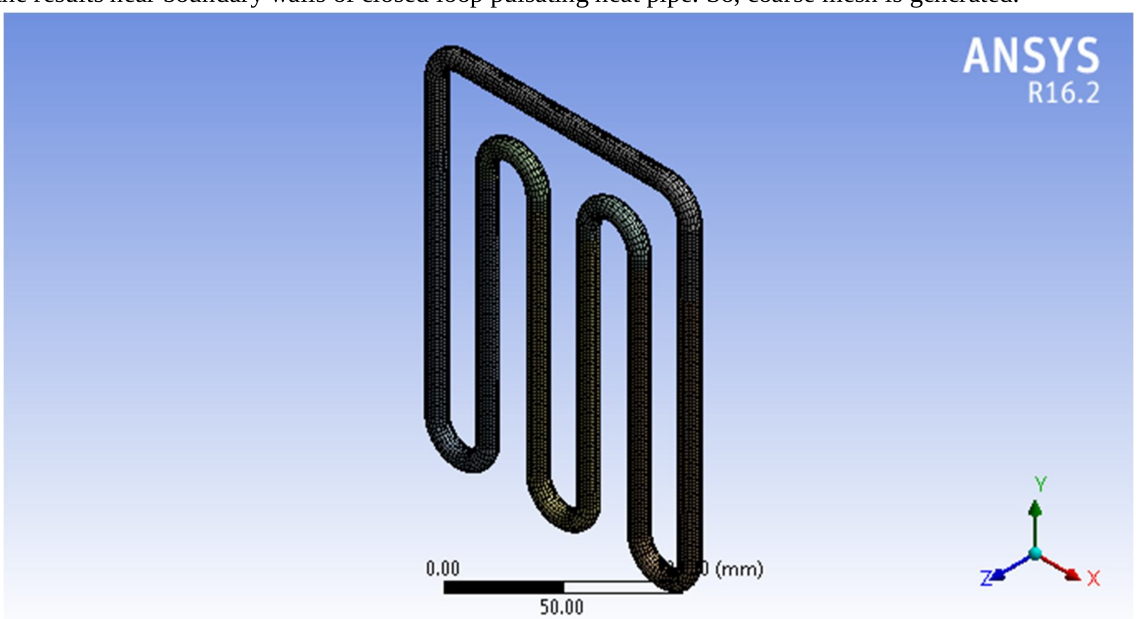

Fig 2. Meshing model

C. Setup

The mesh was checked. Check the report quality to know the maximum aspect ratio and minimum orthogonal quality. In General, set solver type as pressure based, velocity as absolute and time as transient. In Model, we use multiphase to analyse because it has three no. of phases liquid, vapour, gas.

D. Models

Energy was set as ON position and choose various models as k-epsilon model with enhance wall treatment.

E. Material Selection

We used acetone and water as working fluids. Fluid properties are shown below in table 2:

Table 2: Properties of fluids at various concentrations:

Fluid	Density(kg/m³)	Specific heat (J/kg-k)	Thermal Conductivity (W/m-k)	Viscosity (kg/m-s)
C_3H_6O	761	2160	0.18	0.000331
Acetone-Vapour	2.37	2160	0.18	0.014
Water	998	4181	0.644	0.001003

V. RESULT AND DISCUSSION

A. Acetone Volume Fraction

1) With 60 % Acetone

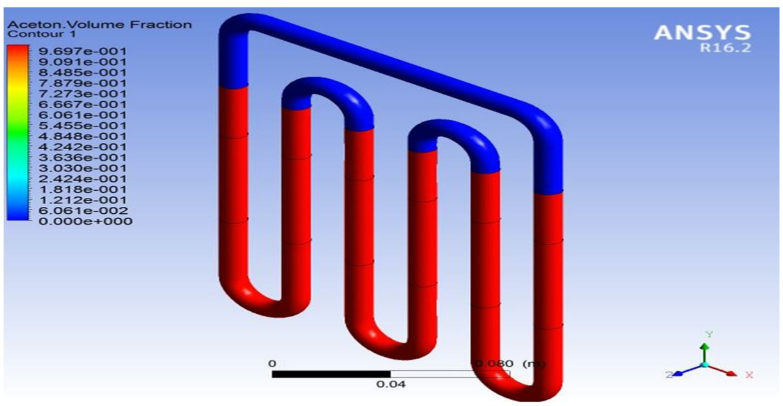

Fig 3. Acetone volume fraction with 60% concentration

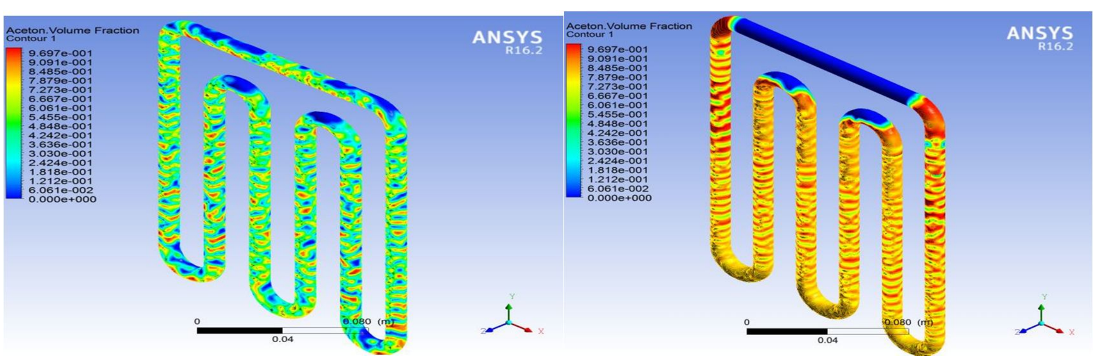

Fig 4. Vapourise form of Acetone

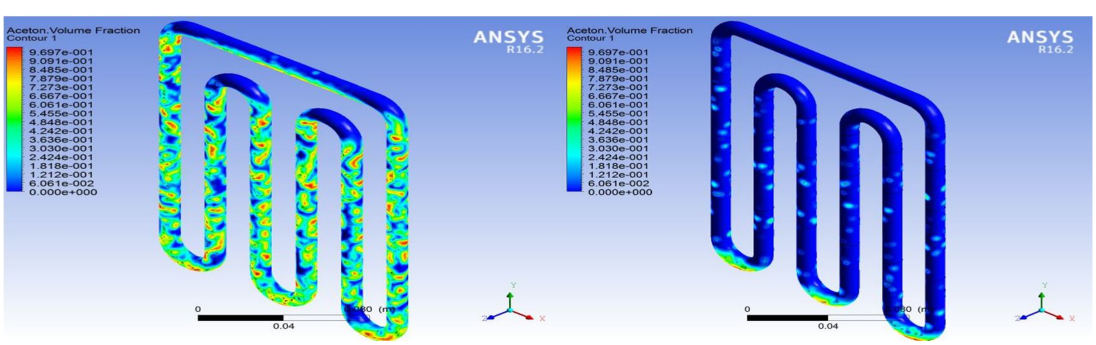

Fig 5. Vaporise form of Acetone

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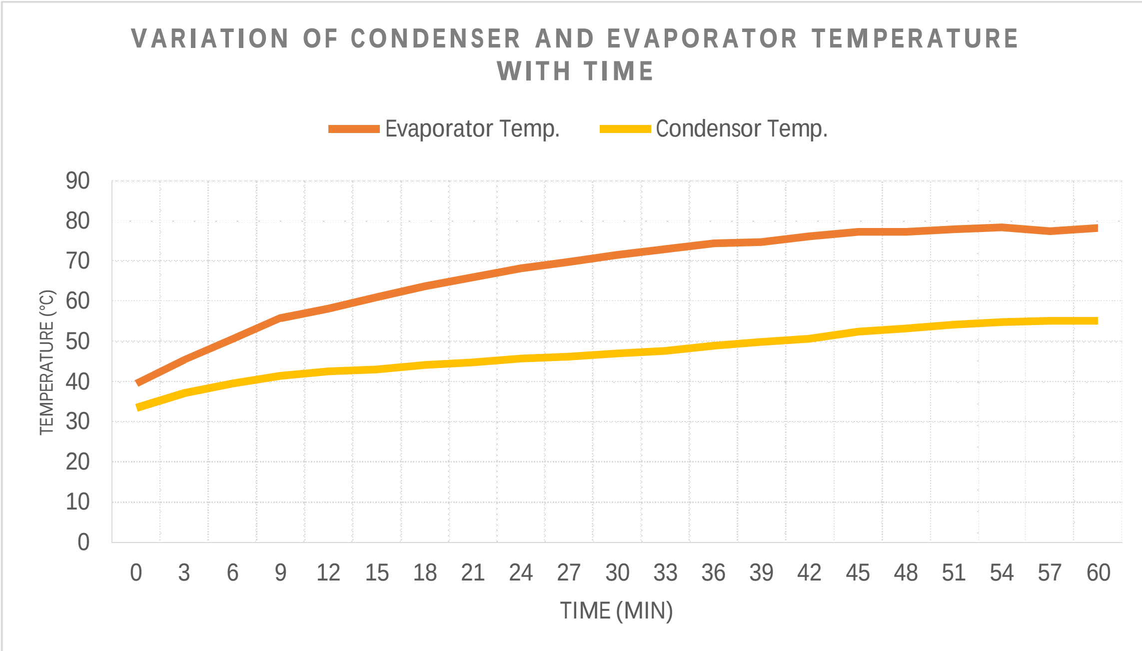

Fig. 6. Variation of condenser and evaporator temperature with respect to time

The above graph shows the comparison of variation of condenser and evaporator temperature with respect to time. Both the condenser and evaporator temperatures are gradually increasing with respect to time. The rate of temperature rise is gradual at the beginning of heat transfer. But as the increases the rate of temperature rise decreases and it becomes almost constant when steady state is reached. The difference between evaporator temperature and condenser temperature is less at the beginning and it increases gradually with time.

VI. CONCLUSION

CFD analysis (ANSYS FLUENT) was used to study heat transfer characteristics of closed loop pulsating heat pipe and the results was determined. We simulate closed loop pulsating heat pipe by using acetone and water as working fluids in this pulsating heat pipe. The thermal resistance for the PHP decreases with the increase in the heat input. The time decreased with the increase in heat flux for the closed loop pulsating heat pipe.

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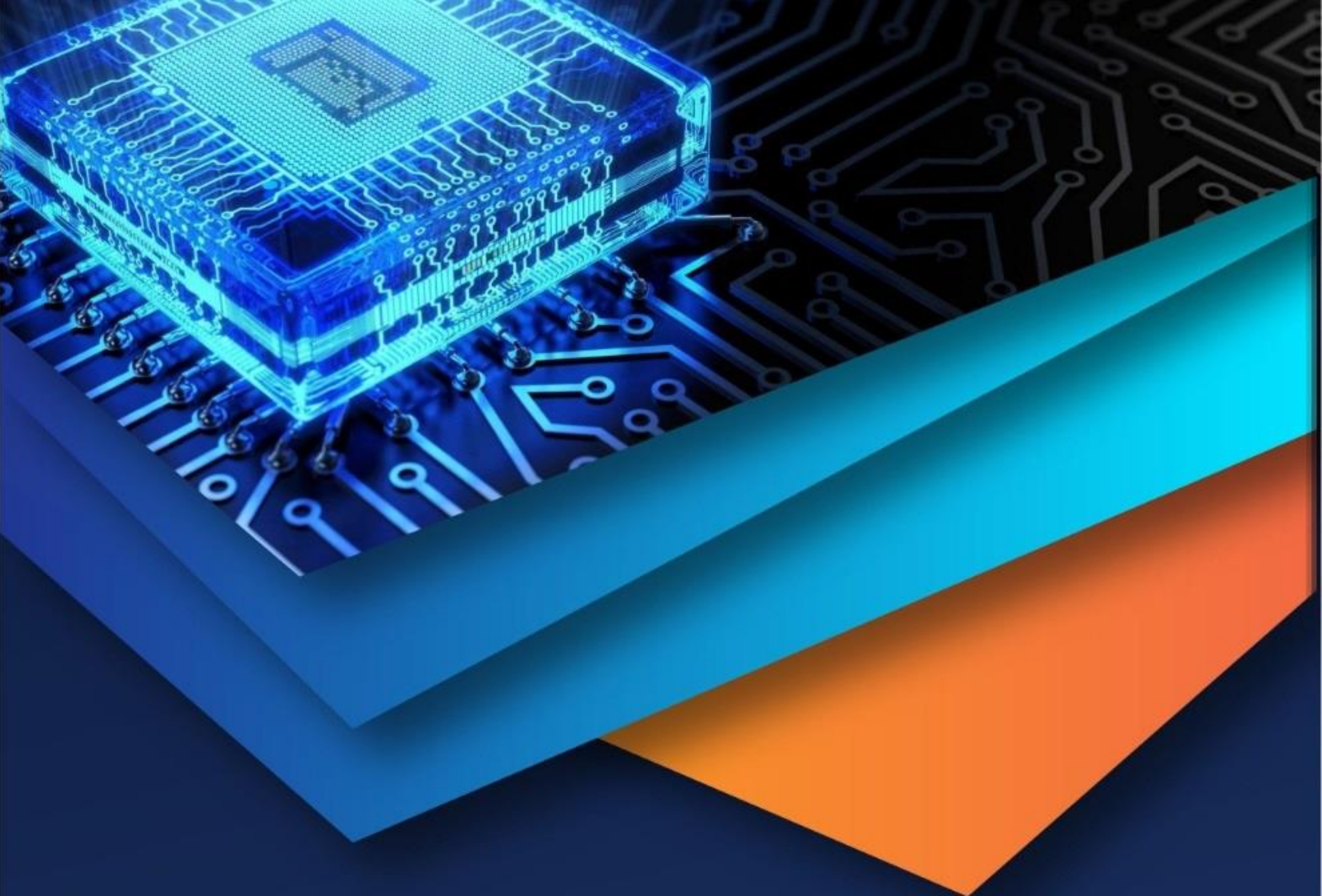

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