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Recent Research on Cryogenic Storage Tank: A Review

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Abstract: Cryogenic storage tank is a device for storage and gasification of cryogenic working fluid. Cryogenic storage tank can reduce the cryogenic fluid, safety, suffer against high pressure and high-rate fueling requirements. Usage of guide tube, two side insulation and different insulation are latest research scope on cryogenic tank. This review paper is focused research work which was improve the performance of cryogenic tank. The CFD analysis for cryogenic tank for different arrangement is discussed. This research provides the guidelines for zero boil off cryogenic storage tank and performance of multiple insulation for LAPCAT A2 Mach 5 vehicle's front tank.
Keywords- Cryogenic, Cryogenic storage tank, Hydrogen

I. INTRODUCTION

Energy shortage, environmental pollution and greenhouse effect are latest research area for researcher it requires the new source of clean energy. For fulfill these purposes optimum, non-polluting fuel and energy storage are required to focus. Fluids are stored in compressed gaseous form or liquid form at cryogenic temperatures for special purposes and applications [1]. More perfect constructions of cryogenic storage tank is required for economic and gas and liquid storage. High rate fueling requirements, safety, working fluid leakage and endure high pressure can be required in the cryogenic storage tank. For example Natural gas using working, fluid is filled in the tank at 20 MPa pressure or more. Working fluid is filled in the gas-filling stations by compression. If fueling by compressing is consumed energy [2].At present technology utilization of Liquid Natural Gas LNG is widely. These kind of technologies of working fluid storage and transportation is implemented in the cryogenic liquid condition. Refrigeration systems in aerospace technique is produced by cryogenic liquids. However, It use create certain difficulties in the operational requirements. The usage of hydrogen and their economy is proposed in the past few decades for alternate energy sources so researcher mainly focused about hydrogen gas on the production methods, the storage and the distribution. The hydrogen storage technology will find its utilization in the future, especially for spacecraft with hydrogen propellant and fuel-cell vehicles [3]. Recently studies on hydrogen storage are focused on metal hydrides, gas storage, and chemical hydrides and so on. However, cryogenic liquid storage of hydrogen is studied widely. R-1234yf and R-1234ze (E) refrigerant are also latest refrigerant in Refrigeration and air conditioning application for research [8].

Vapor ejector refrigeration system is also latest research area for refrigeration effect by solar [9]. Long term storage of cryogen in space is very challenging. Numerical modeling tools can be solved to find the critical design and operational issue. It can be verified by comparing with test data. Cryogenic fluid storage, transfer and life support systems must be efficient and reliable for all NASA future human exploration mission. Heat leakages through the insulation and self-pressurization are the main challenges for long-duration storage of cryogens. Thrusters and venting have traditionally been used during short duration missions [4]. Unfortunately, The added propellant and hardware weight to accommodate will become problem in the long duration missions. Low cost, zero boil off or reduced boil off cryogenic storage tank is necessary for future space mission. Computational Fluid Dynamics (CFD) analysis and experimental validation are optimize the design of cryogenic storage tank.

The following are the recent research on cryogenic storage tanks.

II. NEW ZERO BOIL OFF CRYOGENIC STORAGE TANK IN MICROGRAVITY

The guide tube is used instead of the conventional nozzle injection mixing tank for promote the chilling performance and the fluid circulation inside the storage tank. The improved storage tank is shown in Figure. 1. The tank has a cylindrical wall and elliptical top and bottom. The wall is made of aluminum with multi layered blanket of cryogenic insulation (MLI) [5]. It is also reduced the heat leakage. The nozzle head is assembles with a concentric guide tube and extend to the bottom of the tank. Sub cooled hydrogen is pumped to inlet tube and discharged into the tank through nozzles and the forced mixing is achieved in the guide tube and heat is

Volume 5 Issue IV, April 2017
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removed. The guide tube could create sub-cooled liquid to the tank bottom to reduce the high temperature region and cool down the wall effectively.

This research is published in Applied Energy, Volume 162, 15 January 2016, Pages 1678-1686 by Y.W. Liu, X. Liu ,X.Zh. Yuan, X.J. Wang This work is supported by the Chinese National Natural ScienceFoundation and the funding from Key Laboratoryof Vacuum Physics & Cryogenic Technology.

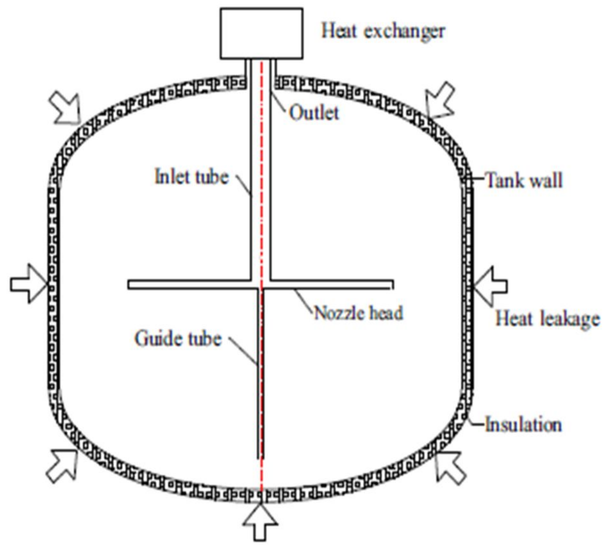

Fig. 1. Schematic graph of the cryogenic storage tank.

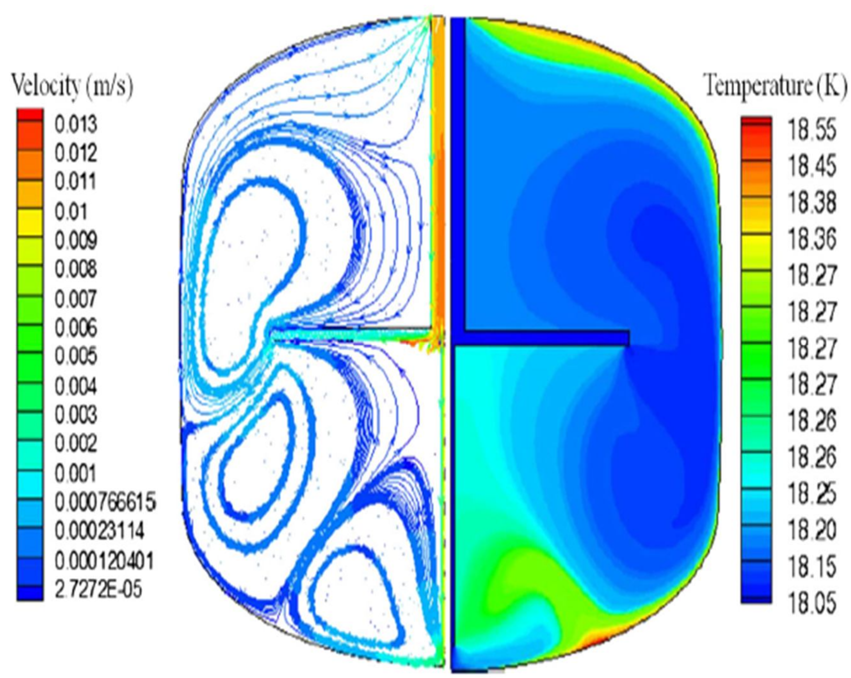

Fig.2 Velocity and temperature distributions of case 1 (streamlines on the left and temperature filed on the right).

Figure 3 shows the fluid circulation and temperature distribution in the basic cryogenic tank which have not guide. Figure 4 shows the analysis of improved cryogenic tank. 0.52K lowered temperature was achieved in improved cryogenic tank. The ration of the temperature region higher than 18.25K to the whole domain is 27.35% in the basic cryogenic storage tank while 3.72% in the improved cryogenic tank. The chilling performance is improved. The optimal the geometry of H= 0.87, L= 0.67 and G= 0.07 achieves the most significant chilling performance.

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This paper is presented the optimizing design guidelines of liquid hydrogen storage tank with guide. It can be adopted for liquid hydrogen as new propellant for space mission in the future.

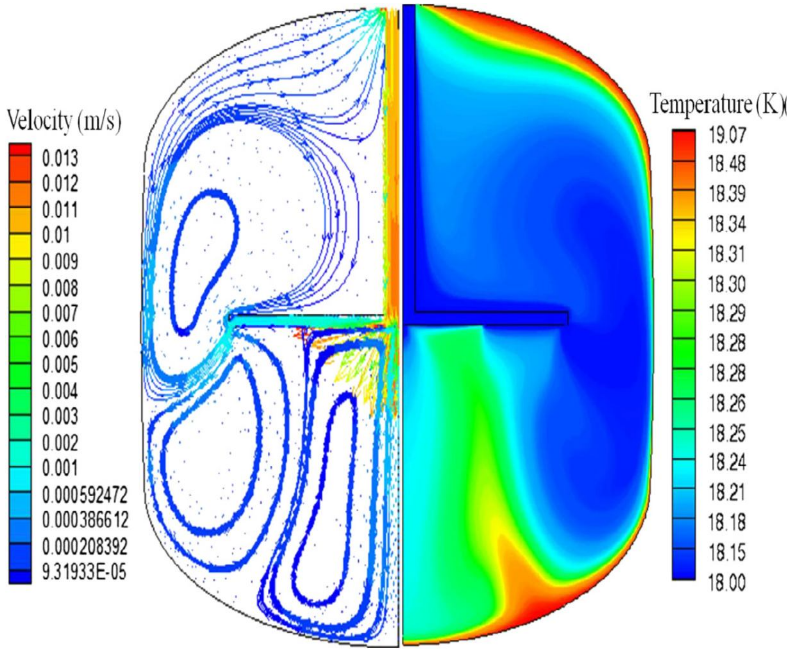

Fig. 3. Velocity and temperature distributions of the base case (streamlines on the left and temperature filed on the right).

III. TWO-SIDE-INSULATED CRYOGENIC TANK

The tank inside and outside surfaces are covered by insulation layers. Thermal behaviors and pressurization performance is investigated by Computational fluid dynamic approach. The energy distributions, temperature distributions and pressure gas requirement are analyzed.

A cryogenic propellant lunch vehicle is required efficient pressurization system. Liquid propellant is discharged to the tank bottom during rocket flight period. Simultaneously ullage space is hold pressurant gas and maintain sufficiently high pressure It also prevent cavitation at the rocket pump inlet. For normal operation of pressurization system, Pressurization system is designed to reduce the pressurant gas requirement. A two side insulated tank is analyzed for decrease of pressurant gas and reduce the heat transfer from warm ullage to the cold tank wall [6]. The outside insulation layer is reduced the heat leakage from the surrounding environment. The inside insulation layer is to reduce the gas to wall heat transfer so the more energy is provided at the ullage for pressurization effect. To find the effect of inner insulation layer, a CFD model and the thermal behaviors and pressurant gas requirements are analyzed by Wang Lei. This research is presented in the International Journal of Heat and Mass Transfer 102 (2016) 703–712.

The model of cryogenic propellant tank is shown in the figure. The cylinder of tank had diameter 3.35m and height 10m. The tank is fabricated by 3mm thickness 2219 aluminum alloy plate. For the sufficient diffusion of pressurant gas 0.0314m^2outlet area is applied at a horizontal outlet diffuser within the ullage top region. Foam layer of 20mm thickness is used for outside insulation layer. The spraying foam material is used for the inside insulation with millimeter scale. The spraying foam insulation was used in the Apollo moon mission.

Fig.5 shows the contours of temperature distribution at the end of discharge for the LO_2–He cases with 0 mm, 1 mm, and 3 mm inner foam layers, respectively. For without inner foam layer is injected with the maximum gas amount, its average temperature is apparently lowest among the three cases[6]. Also, for 3 mm thick inner foam layer has a higher ullage temperature. After the sufficient diffusion of horizontal outlet diffuser, the temperature radial distribution in most ullage space is slightly weak and the gas temperatures are approximately equal at the same height, which is also observed.

Two side insulated tank are covered by insulation layers and a computational fluid dynamic (CFD) is introduced to investigate its thermal behaviors and pressurization performance. The energy distributions within the tank system, pressurant gas requirement and temperature distributions are obtained and analyzed. During the liquid discharge period the inner insulation layer can remarkably reduce the gas requirement. For the pressuring a liquid oxygen tank with 300K helium gas, 16% gas requirement could be decreased

Volume 5 Issue IV, April 2017
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by using a 3mm thickness foam layer at the tank interior surface. For the pressuring a liquid hydrogen tank with 300K hydrogen gas, 14.2 % gas requirement could be decreased for same foam layer. Reducing gas requirement has more significant for inner insulation layer with the increase of inlet gas temperature.23.2% gas requirement is decreased by a 1 mm thickness foam layer in comparison with the tank without inner layer, when 600 K helium gas is used to pressure the liquid oxygen tank. Moreover, the energy distribution, occupied by ullage, wall, inner insulation layer and liquid propellant is also changed. Temperature drop within the insulation layer between the ullage to insulation layer is reduced, resulting in more energy left in ullage to pressurization effect.

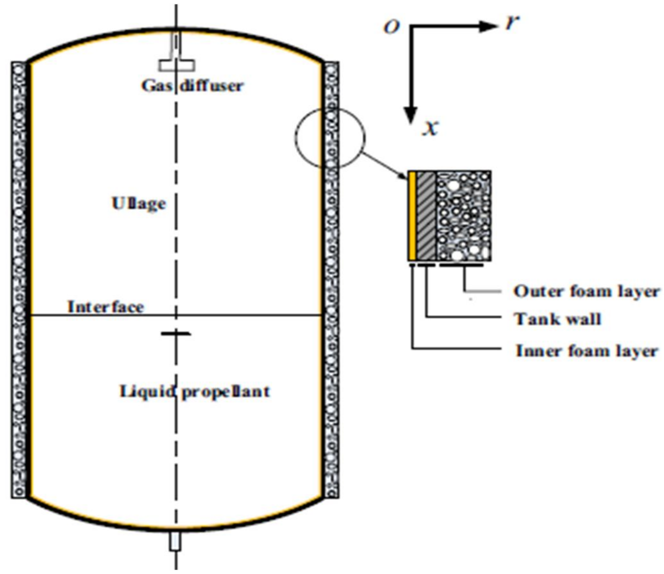

Fig-4. Schematic diagram of cryogenic tank.

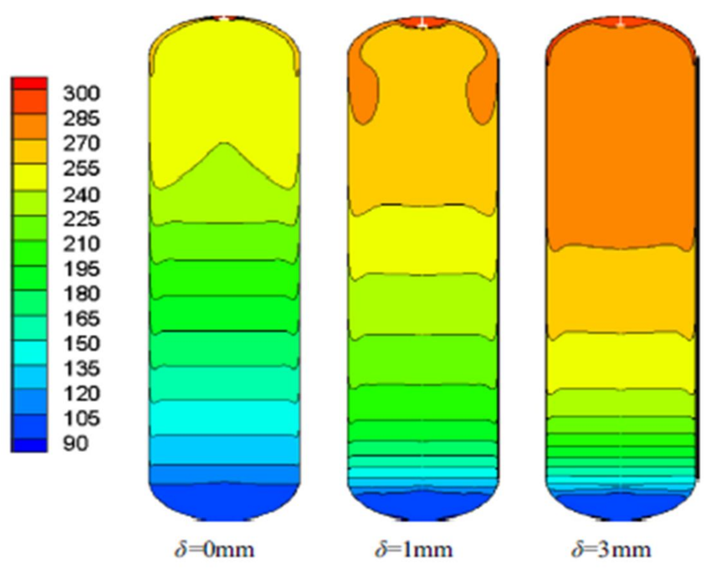

Fig. 5 Comparison of final temperature distribution contours among tanks with different inner foam thickness (LO_2–He, T_{in}= 300 K)

IV. CRYOGENIC HYDROGEN FUEL TANKS FOR LARGE HYPERSONIC CRUISE VEHICLES

Hydrogen (H_2) is potential option of aviation fuel to considerable reduce the environmental impact of aviation. Hydrogen is not produced $CO_2$and very low NOx. The adoption of hydrogen can alternate against convectional fuel for aviation. Specific energy of hydrogen is 120MJ/kg which is 2.7 times then kerosene.

This research aims to fill the gap of design method for cryogenic liquid hydrogen tanks to the hypersonic flight regime. It was presented on International Journal of hydrogen energy (2015) 1-13 by Shayan Sharifzadeh. The use of different insulation systems

International Journal for Research in Applied Science & Engineering Technology (IJRASET)

is investigated for cryogenic hypersonic tanks. The combination of foam and fully load bearing aerogel blanket is lightest tank for Mech 5 flight with a gravimetric efficiency of 73%. Also the combination of foam and fibrous insulation materials is performed well with a gravimetric efficiency of 70.3%.The performance of foam-fibrous insulation is sensitive to the external skin temperature so that a foam-multilayer insulation system is more efficient at speed beyond Mach 9 [7].

Gravimetric efficiency and volumetric efficiency are used to compare different tank designs and insulation materials.

The gravimetric efficiency, η_{grav} which is defined as:

$$\eta_{grav} = \frac{W_{fuel}}{W_{fuel} + W_{tank}}$$

W_{fuel} = Wight of fuel and W_{tank}= Wight of tank. It represent the fraction of the total tank system mass that is occupied by fuel. For large LH_2 tanks, gravimetric efficiencies are in the range of 0.65-0.85, depending on the aircraft type and mission.

The volumetric efficiency is, on the other hand, defined as follows:

$$\eta_{vol} = \frac{W_{fuel} / \rho_{ref}}{V_{available}}$$

Whereρ_{ref} is taken as the density of saturated liquid hydrogenat 1 bar (70:847 kg/m^3). The volumetric efficiency is not solely a function of the available internal volume$V_{available}$, since the fill pressure, venting pressure and the ullage volume are mean parameter of mean storage density.

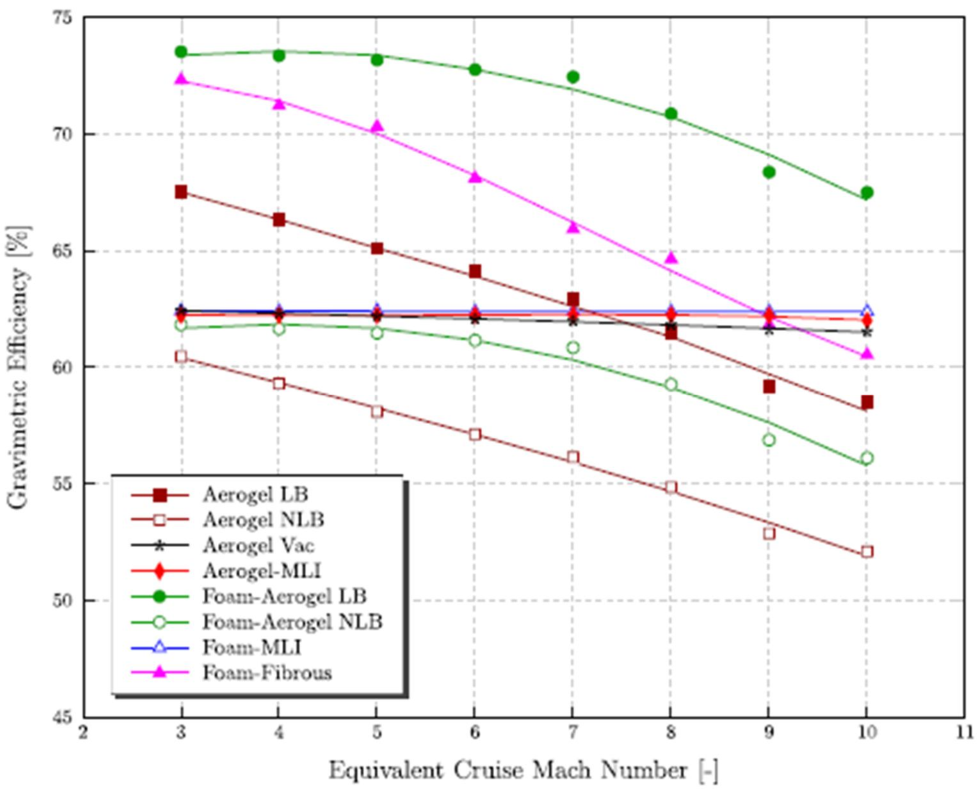

Fig-6. Influence of external temperature on the design of cryogenic tanks

Fig-6 shows the performance of different insulation with different Mach number. For hot boundary temperature the most sensitive configurations were foam MLI and foam fibrous. Drop of gravimetric efficiency of Foam-MLI is 0.1% and 10% about foam-fibrous [7].

Single and double material insulations (Foam, fibrous, aerogel and MLI) are compared for the LAPCAT A2 Mach 5 vehicle's front tank. Aerogel blanket offers the best performance of all investigated system for a Mach 5 flight with a gravimetric efficiency of $\pm$73% and a volumetric efficiency of $\pm$78%.But aerogel materials cannot carry the full load with a gravimetric efficiency of $\pm$70% and a volumetric efficiency of 76%. The foam-fibrous configuration leads to the best for that condition.

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V. CONCLUSION

It is found that the guide tube improve the performance of tank by cool down the tank wall to a lower temperature.A thinner foam layer can reach an optimal pressurization performance by the increase of inlet temperature. The best performance of each insulation material for LAPCAT A2 Mach 5 vehicle's front tankis very critical to use.

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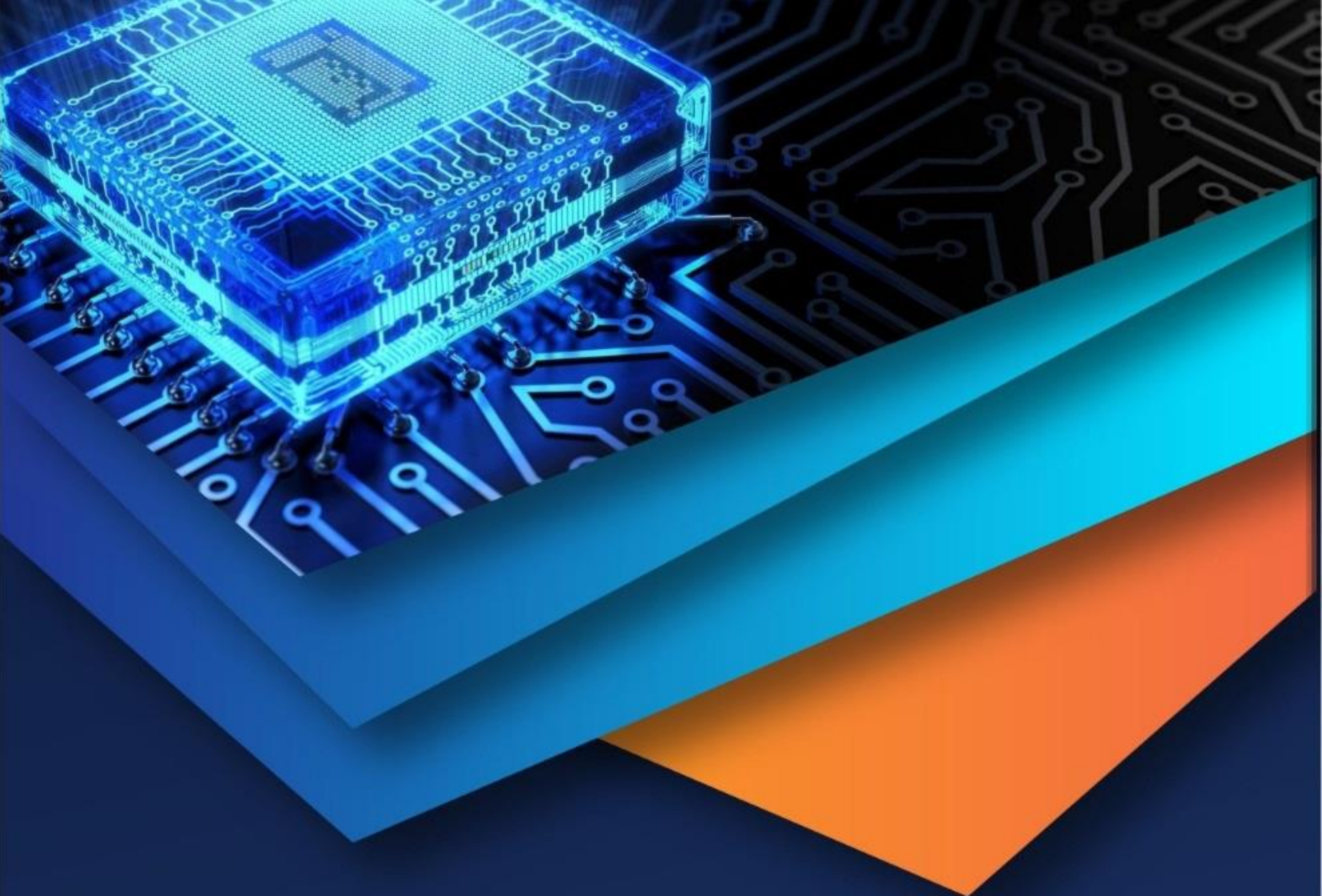

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