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Performance Improving Techniques for VCR System: A Review

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Abstract: Flow patterns will get influence by tilting and thus the heat transfer and pressure drop during condensation and evaporation in VCR system. Due to application of Magnetic field the molecule gets broken, resulting in the decrease of viscosity of the fluid which result in decreased power required by the compressor to pump the refrigerant as well as enhances the heat transfer rates in the condenser and evaporator due to increased mass flow rates. However, few studies are available on two-phase flows in inclined tubes and magnetic field effect on VCR system. The purpose of the present paper is to review tube inclination and magnetic field effect on heat transfer enhancement for VCR system. It was observed for convective condensation and evaporation in inclined tubes that the inclination angle influences the heat transfer coefficient. Under certain conditions, an inclination angle of -30^0 (slightly downward flow) exists, which leads to an optimum heat transfer coefficient. The effect of magnetic field is more pronounced up to certain magnetic pairs beyond which performance of VCR cycle decreased.
Keywords: Inclination angle, Flow pattern, Magnetic field, Condensation, Evaporation, Heat transfer coefficient.

I. INTRODUCTION

Flow patterns will get influence by tilting and thus the heat transfer and pressure drop during condensation and evaporation in VCR system. Due to application of Magnetic field the molecule gets broken, resulting in the decrease of viscosity of the fluid which result in decreased power required by the compressor to pump the refrigerant as well as enhances the heat transfer rates in the condenser and evaporator due to increased mass flow rates. However, few studies are available on two-phase flows in inclined tubes and magnetic field effect on VCR system. The purpose of the present paper is to review tube inclination and magnetic field effect on heat transfer enhancement for VCR system. It was observed for convective condensation and evaporation in inclined tubes that the inclination angle influences the heat transfer coefficient. Under certain conditions, an inclination angle of -30^0 (slightly downward flow) exists, which leads to an optimum heat transfer coefficient. The effect of magnetic field is more pronounced up to certain magnetic pairs beyond which performance of VCR cycle decreased.

A. Introduction

Condenser and Evaporator selected for air conditioning and refrigeration applications play an important role in system efficiency. The condenser and evaporator used for this purpose are extensively air-cooled and water-cooled, many active and passive techniques are used for heat transfer enhancement. Tube inclination influence the flow pattern and thus the heat transfer and pressure drop. Depending on the angle of inclination and mass flux in the tube, heat transfer can be increased or decreased. Magnetic field breaks the molecule, resulting in the decrease of viscosity of the fluid which result in decreased of pumping power required by the compressor as well as enhances the heat transfer rates in the condenser and evaporator due to increased mass flow rates.

To perform the experimentation all the researchers divided the complete condenser in to four parts, first part was pre-condenser, second was test condenser, third was post condenser and fourth was bypassed condenser and evaporator was also divided into four parts, first was pre-evaporator, second was test evaporator, third was post evaporator and fourth part was bypassed evaporator.

The pre-condenser was used to regulate the inlet vapour quality into the test condenser where test measurements had taken. The post-condenser has been adjusted such that it ensured that there was complete condensation and subcooling. The bypass condenser has been used to control the mass flow rate, temperature and pressure of refrigerant flowing through the test section.

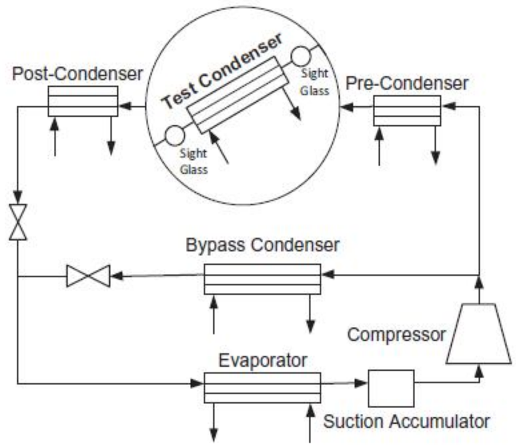

Fig.1.1: VCR cycle with condenser splitting arrangement, adapted from Josua P. Meyer (2014)

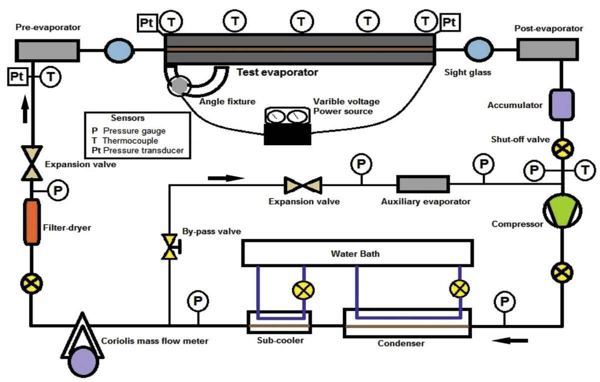

Fig.1.2: VCR cycle with evaporator splitting arrangement, adapted from Arijit Kundu (2014)

Utilization of magnetic field on VCR system is basically taken from magneto caloric effect. The magneto caloric effect (MCE) is defined as the heating or cooling (i.e., the temperature change) of a magnetic material due to the application of a magnetic field.

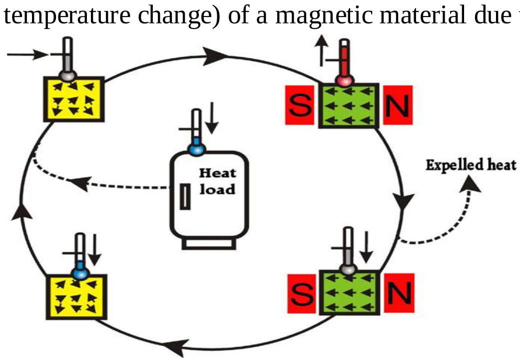

Fig.1.3: Schematic representation of magnetic-refrigeration cycle that transports heat from the heat load to the ambient. Yellow and green depict material in low and high magnetic field, respectively, adapted from E. Bruck (2009)

II. LITERATURE SURVEY

In the past few years, many researchers were tried to find the effect of tube inclination on the flow pattern, heat transfer coefficient and pressure drop, they found that tube inclination will change the flow pattern because of which the heat transfer coefficient will changes. The researchers also found main parameters which effects on pressure drop and heat transfer coefficient, some of them are vapor quality, mass velocity, saturation temperature etc., although tube inclination has a sufficient effect on the heat transfer coefficient, but recently many researchers were tried to find the effect of magnetic field on the heat transfer coefficient and they found that the magnetic field will effects on the heat transfer coefficient and hence on the performance of VCR cycle.

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Josua P. Meyer et al. [1] proposed the effects of saturation temperature and inclination angle on convective heat transfer during condensation of R-134a in an inclined tube of inner diameter of 8.38 mm. Experiments were conducted for inclination angles ranging from -90° to +90° for mass velocities between 100 kg/m² s and 400 kg/m² s and mean vapour qualities between 0.1 and 0.9 for saturation temperatures between 30° C and 50° C. It was concluded that the effect of inclination angle was found to be more pronounced at lower mass velocities of 100 kg/m² s and 200 kg/m² s. There was an optimum angle, within the region of influence of inclination which was between -15° and -30° (downward flow). If saturation temperature increases, then the effect of inclination on two-phase heat transfer also increases.

R. Suliman et al. [2] presents an improved flow pattern map for predicting the heat transfer coefficients during condensation of R-134a inside a smooth horizontal tube. Experimental tests were conducted over the low-mass flux range of 75–300 kg/m²s, at a maximum saturation temperature of 40 °C, and with the test section vapour qualities ranging from 0.76 down to 0.03.

Figure 2.1 shows the heat transfer data plotted as a function of vapour quality at various mass fluxes. There is a similar trend at all the mass fluxes; the heat transfer coefficient decreases with decreasing vapour quality. This trend is expected since as condensation proceeds, the vapour quality and vapour velocity decreases. This corresponds to a decrease in the vapour shear forces at the interface and a resulting lower heat transfer coefficient. This effect is most significant at high mass fluxes and high vapour qualities.

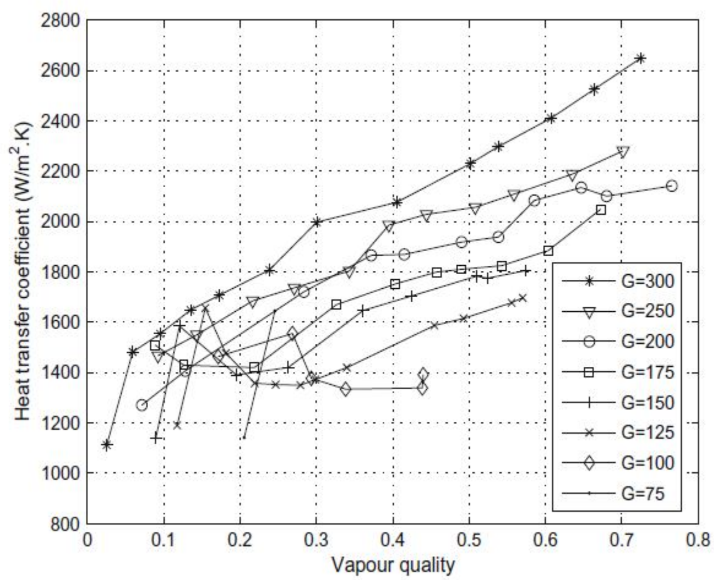

Fig 2.1: Experimental heat transfer coefficients plotted against vapour quality.

When experimental heat transfer coefficients analysed against mass flux, vapour quality and temperature difference, it was found that the majority of the data are ΔT-dependent, indicating stratified-wavy flow and also an improved flow pattern map with a 'transition' region between stratified-wavy and annular or intermittent flows was developed.

A. Cavallini et al. [3] reports experimental heat transfer coefficients and pressure drops measured during condensation inside a smooth tube when operating with pure HFC refrigerants (R134a, R125, R236ea, and R32). The experimental runs are carried out at a saturation temperature ranging between 30 and 50 °C, and mass velocities varying from 100 to 750 kg/m²s, over the vapour quality range 0.15 to 0.85. The effects of vapour quality, mass velocity, saturation temperature and temperature difference between saturation and tube wall on the heat transfer coefficient are investigated by analysing the experimental data. A predictive study of the condensation flow patterns occurring during the tests was also presented.

Stéphane Lips et al. [4] present a review on two-phase flow in inclined tubes with specific reference to condensation. Tilting influences the flow patterns and thus the heat transfer and pressure drop during condensation in smooth tubes. However, few studies are available on diabatic two-phase flows in inclined tubes. Firstly, the paper reviews convective condensation in horizontal tubes. Secondly, an overview was given of two-phase flow in inclined tubes. Thirdly, a review was conducted on condensation in inclined tubes. It is shown for convective condensation in inclined tubes that the inclination angle influences the heat transfer coefficient. The heat transfer coefficient can be increased or decreased depending on the experimental conditions, and especially the flow pattern.

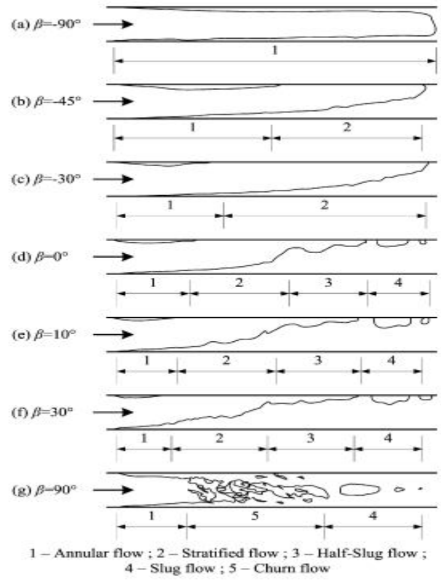

Fig 2.2: Schematic drawings of condensation flow patterns for orientations, adapted from Wang et al. (1998).

Under certain conditions, an inclination angle may exist, which leads to an optimum heat transfer coefficient. Furthermore, this paper highlights the lack of experimental studies for the prediction of the inclination angle effect on the flow pattern, the heat transfer coefficient and the pressure drop in two-phase flows during phase change. The literature showed that the inclination angle can have a significant effect on the heat transfer coefficients. It seems that for specific configurations, an optimum inclination angle can be found, but once more, no general correlation has been developed. The study of pressure drops during inclined two-phase flows is complicated by the need of separating the momentum, frictional and static pressure drops. The momentum and static pressure drops are strongly dependent on the void fraction, which is quite difficult to measure accurately. There are few studies available which deal with the pressure drop in inclined tubes.

M.A.Akhavan-Behabadi et al. [5] proposed experimental heat transfer studies for a single microfin tube through which pure R-134a was flowing, here specific reference was given to condensation and heat transfer coefficient during condensation was obtained at a different tube inclination. For getting results in a range of -90^0 to $+90^0$ seven different tube inclinations are used and for each inclination angle during condensation of R-134a vapor three mass velocities of 54, 81, and 107 kg/m^2s are used. The results indicate that there were significant effects of the tube inclination angle on the condensation heat transfer coefficient at low vapor quality and mass velocity. The heat transfer coefficient was maximum at an inclination angle of $+30^0$. For predicting the condensing side heat transfer coefficient a correlation has also been developed for different vapor qualities and mass velocities.

Adekunle O.Adelaja et al. [6] present experimentally the pressure drops during condensation in inclined tubes at different saturation temperatures. The test section was 8.38 mm diameter copper tube having a length of 1.704 m. For vapour qualities ranging between 0.1 and 0.9 more than 700 condensation experimental data points were collected with the refrigerant R-134a. Measurements were taken at saturation temperatures of 30^0 C, 40^0 C and 50^0 C with varied mass fluxes between 100 kg/m^2s and 400 kg/m^2s and inclination angles ranging from -90^0 to $+90^0$. Differential pressure transducer was used to measure the pressure drop, which is connected to the inlet and the outlet of the test section over a length of 1.704 m. recently developed void fraction drift model was used to determine frictional pressure drop. It was found that inclination angle and saturation temperature have considerable effect on the pressure drop. The highest pressure drops were obtained during the upward flow while lower pressure drops were obtained for downward flow. The void fraction and pressure drops were increased with increase in quality and mass flux.

S.G. Mohseni et al. [7] present flow pattern and heat transfer during evaporation in an 8.9 mm diameter smooth tube in this paper. The experiments were performed for seven different tube inclinations in a range of −90° to +90° and five refrigerant mass velocities in a range of 53 to 170 kg/m^2 s for each tube inclination angle. The experimental results show that the tube inclination influenced the vapor and liquid distribution as well as the evaporation heat transfer coefficient.

During evaporation inside a smooth tube with different tube inclinations seven different flow regimes are observed. The experiments were carried out over the given range of inclination angle, but at an inclination angle of +90° the highest heat transfer coefficient is attained in the case of evaporation heat transfer. A correlation has developed to predict the heat transfer coefficient inside a smooth tube with different tube inclinations during flow boiling.

Arijit kundu et al. [8] presents an experimental investigation on two phase flow evaporative heat transfer of refrigerants R134a and R407C, in a smooth copper tube inclined at five different angles between 0^o and 90^o. The experimentation was carried over a mass velocity range of 100–300 kg/m^2 s, heat flux range of 3–10 kW/m^2, inlet temperature range of 5–9^o C and vapor quality varied from 0.1 to 0.9. The test section was 1.2 m long, smooth copper tube with inner diameter of 7.0 mm and outside diameter of 9.52 mm. The comparison is made for the effects of mass velocity, heat flux, and vapor quality and tube inclinations on evaporative heat transfer coefficient of both refrigerants. The experimental heat transfer coefficients obtained were also compared with some existing correlations. The experimental results indicate that mass velocity and heat flux was effecting the heat transfer coefficients. In increase with mass velocity and heat flux, heat transfer coefficient was also getting increased for both refrigerants. There was a vapor quality range between 30% and 40% for R407C and 65–75% for R134a for which heat transfer coefficient is maximum

The result indicated that heat transfer coefficients of pure fluid R134a are higher than that of refrigerant R407C for all mass velocities, heat fluxes and tube inclinations. The average heat transfer coefficient for vertical up flow boiling of. For R134a the average heat transfer coefficient is about four times more than that for R407C for mass velocity G = 300 kg/m^2 s with heat flux applied of 6 kW/m^2 for vertical up flow boiling, where at 0^o and 45^o, it is about 325% and 300%, respectively. For mass velocity G = 100 kg/m^2 s, the average heat transfer coefficient for horizontal flow evaporation of R134a with the heat flux applied of 6 kW/m^2 is about 234% more than that for R407C; where at 60^o, it is about three times. M.A. Akhavan-Behabadi et al. [9] studied an experimental heat transfer during evaporation of R-134a inside a corrugated tube. For performing experiment seven different tube inclinations were selected which are in a range of −90° to +90° and four mass velocities of 46, 81, 110 and 136 kg/ m^2 s for each tube inclination angle during evaporation of R-134a was used. Data analysis demonstrate that there was significant effect of the tube inclination angle on the boiling heat transfer coefficient. The effect of tube inclination angle on heat transfer coefficient is more considerable at low vapor quality and mass velocity than high vapor quality and mass velocity.

The heat transfer coefficient for the +90° inclined tube is about 62% more than that of the −90° inclined tube in the low vapor quality region. The results also showed that, the highest average heat transfer coefficient were achieved for inclination angle of +90° at all mass velocities. For predicting the heat transfer coefficient during flow boiling inside a corrugated tube with different tube inclinations an empirical correlation was also developed. Until a vapor quality reaches 70–85% there was increase in heat transfer coefficient for all tube inclination angles.

Pralhad Tipole et al. [10] presents experimentally how magnetic field effects on energy savings in vapour compression system. Due to application of Magnetic field the molecule get breaks, resulting in the decrease of viscosity of the fluid which result in reduction of power required by the compressor to pump the refrigerant as well as enhances the heat transfer rates in the condenser and evaporator due to increased mass flow rates. The net impact was improvement in the COP of the system. The main cause of this phenomenon was de-clusterization of molecules resulting in drop in viscosity of the circulating fluid. Result also showed that up to a certain magnetic field strength there was enhancement in COP of the refrigeration system and beyond that there was decrement in COP, hence maximum magnetic pairs used are three.

Figure 2.3 represent effect of magnetic field on the power consumption of compressor and refrigeration effect. It was found that input power required by the compressor decreases with increase in magnetic pairs. It has been reported that viscosity of the refrigerants is the function of applied magnetic field, as the magnetic field strength increases viscosity keeps on decreasing; hence lower compressor power was required to pump the same amount of the refrigerant. As the number of magnetic pair increases, the refrigerating effect also increases up to third magnetic pair, because more amount of refrigerant was circulated per unit time due to a decrease in the specific volume of the refrigerant, which leads to improvement in the heat transfer rate and refrigerating effect.

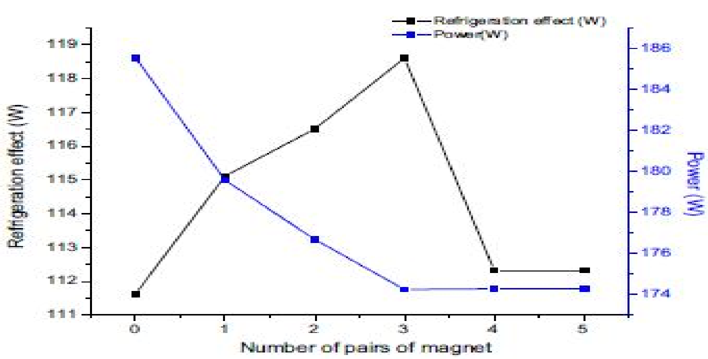

Fig 2.3: Effect of number of magnetic pairs on power consumption and refrigeration effect (R-134a).

Steven l. russek et al. [11] present the cost effective magneto caloric air-conditioning systems. The most unique features of magnetocaloric air conditioners are the AMR matrix made of the Nd2Fe14B permanent magnets and magnetocaloric material. The hermetic compressor/motor and valve found in conventional vapor compression systems is replace by AMR matrix along with its housing, a motor, a fluid pump, valves, and permanent magnet. The cost of the permanent magnet and magnetocalori material was lay well below the total manufactured costs for vapor compression based air conditioner. For magnetic refrigeration to attain widespread acceptance its costs must be made competitive with vapor cycle technology. After doing a preliminary assessment of the costs for the residential air conditioning application it was found that the permanent magnet cost is of greatest importance. The volume of the magnetocaloric material matrix is proportional to the cost of the permanent magnet and also magnetic flux density is exponentially proportional to the cost of the permanent magnet. It also conclude that there is a greater potential for cost reduction for a transition metal based magnetocaloric material series with a first order magnetic transition and a large latent heat, such as La $(Fe_{1-x}Si_x)_{13}H_y$.

S.M. Sami et al. [12] present the effect of magnetic field during boiling of refrigerant mixtures R- 404A, and R407C as well as R-507 on two phase flow pressure drop characteristics. Very limited information is available on the prediction of heat transfer and pressure drop properties inside enhanced surface tubing under magnetic field. This research work has been undertaken so that there is further enhancement on understanding of this subject and it will provide new information on the evaporative heat transfer and pressure drop characteristics of some of the newly refrigerant mixtures. This paper compose of an experimental setup which consist of refrigerant vapor compression heat pump with a 3 kW compressor, oil separator, condenser, pre-condenser, pre-evaporator, adjustable expansion device, and condenser/evaporator test sections. The boiling heat transfer characteristics of some alternatives to R-502 such as R-404A, R-507 and R-407C, inside enhanced surface tubing were investigated. Various magnetic elements with gauss flux varying from 4000 to 10,000 each have been employed. It was concluded that the magnetic field has insignificant impact on the pressure drop on the basis of the boiling data. The correlation form proposed by Blasius was use to describe the series of friction factor tests performed.

S.M. Sami et al. [13] present condensation heat transfer characteristics of refrigerant mixtures R-404A, R407C and R507 as well as R-410A for two phase flow under magnetic field. The experimental set up was composed mainly of a 3 kW compressor, condenser, pre-condenser, pre-evaporator, oil separator, adjustable expansion device, and condenser/evaporator test sections. Various permanent magnetic elements having magnetic flux density at gauss level of 4000 each have been employed in this study. The data clearly indicated that values of the condensation heat transfer coefficient of refrigerant mixtures under investigation were significantly influenced by the Magnetohyrdodynamic (MHD) effects depending upon the type of refrigerant mixture. Result showed that at lower Reynolds numbers magnetic field tends to enhance the condensation characteristics. The correlation was also proposed to predict the heat transfer coefficient with an average deviation of ±10.

S.M. Sami et al. [14] present the behaviour of new refrigerant mixtures such as R-404A, R-410A and R-507 under various condition of magnetic field. An experimental set-up used was air-source vapour compression heat pump, which consists of a 3 kW compressor, oil separator, condenser, pre-condenser, post-condenser, pre-evaporator, capillary tube and evaporator. The set-up also consisted of three magnetic element with gauss level of 4000 each. After experimentations it were concluded that the effect of magnetic field on mixture behaviour varies from one mixture to another, depends upon its boiling point and mixture composition. Thermal capacities of the condenser and evaporator gets influenced by the magnetic field in positive sense. It were also concluded that refrigerant mixtures are less likely to respond to magnetic field, if it have higher thermal properties, specific heat and thermal conductivity. When viscosity of refrigerant mixture is higher, then mixture will responds quickly to magnetic field. R-407C responded magnetic field very well compared to other as it have higher viscosity.

III. CONCLUSION

This review considered the effect tube inclination and magnetic field on flow pattern maps, heat transfer coefficients and pressure drops. The inclination effect on the flow patterns has been studied for the whole range of inclination angles only for air–water flows. For convective condensation, flow patterns have been studied only for horizontal or vertical downward flows. The literature showed that the inclination angle can have a significant effect on the heat transfer coefficients. It seems that for specific configurations, an optimum inclination angle can be found, but once more, no general correlation has been developed.

It is conclude from the literature that magnetic field has positive effect on the heat transfer coefficient, but there is no such a general correlation has been developed yet which can relate magnetic field intensity and heat transfer coefficient. Use of inclination and magnetic field are both effective techniques for enhancing the heat transfer coefficient but as application of magnetic field has insignificant effect on pressure drop whereas inclination has the significant effect on pressure drop the magnetic treatment is more effective techniques for enhancing the heat transfer rates than inclination.

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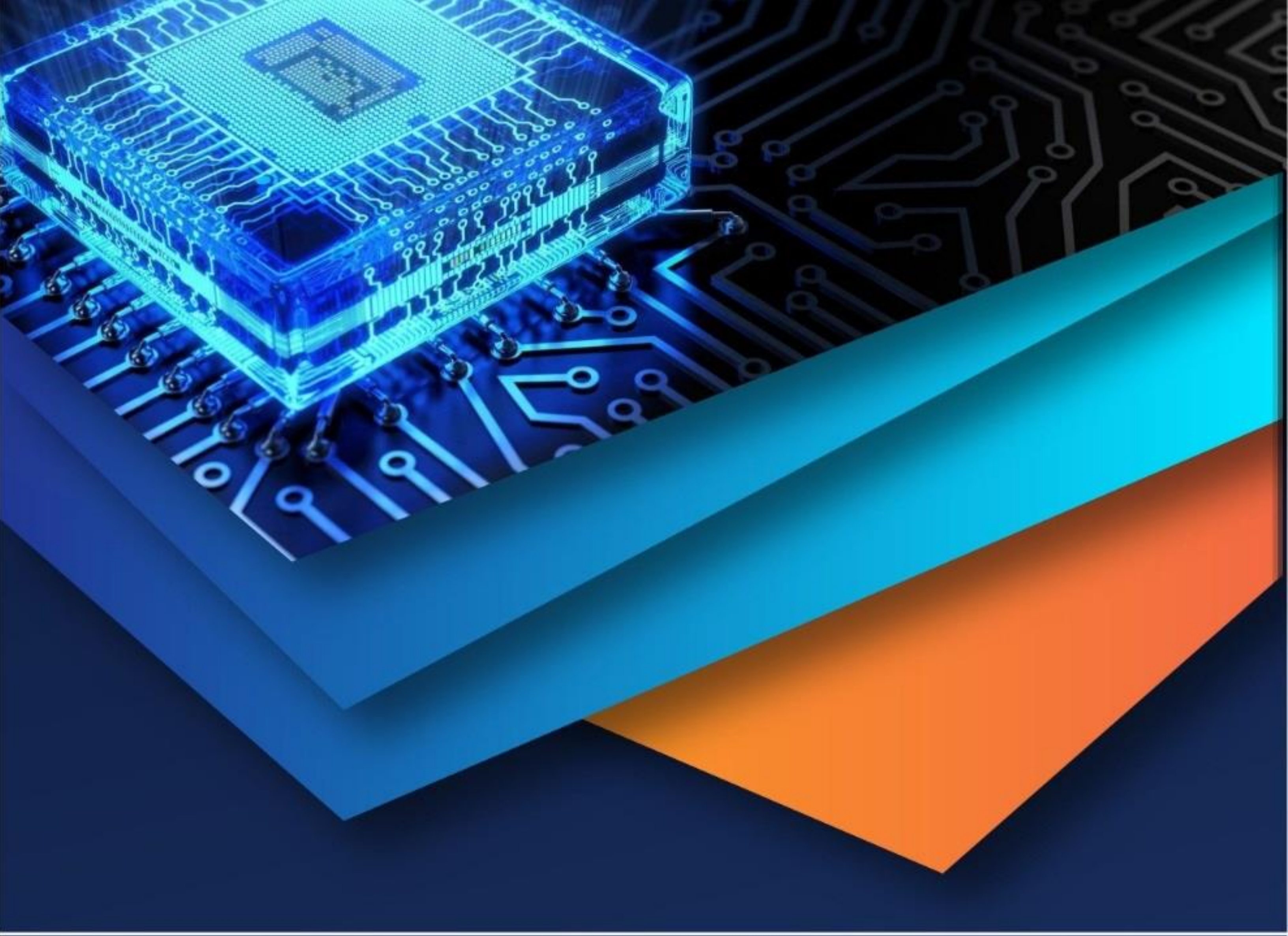

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