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A Review of Literature on Various Techniques of COP Improvement in Vapor Compression Refrigeration System

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Abstract:** This review paper is a study on various methods of performance improvement in domestic refrigeration systems, based on the vapor compression refrigeration VCRS cycle. Here air-cooled, water-cooled, fog cooled, evaporatively cooled condensers and nano-fluid lubricant /coolant methods their working and efficiency are reviewed, compared, analyzed and presented. The paper inspects the work done by different researchers for the maximization of heat loss from condenser & compressor and bringing about necessary modifications to reduce the overall power consumption of domestic refrigerators by improving Coefficient of Performance (COP). Numerous works have been done on improving the heat dissipation capacity of condenser but using nano-fluid in lubricant base as refrigerant and in the compressor shell as coolant is a new technology. Nano-fluid increase heat transfer due the high conductivity nano particles. It has been observed that water cooled condensers and compressors with nano-lubricants/coolants give the best performance improvements but they suit better for big or large refrigeration systems like centralized air conditioning systems or cold storage warehousing, whereas air cooled and evaporative condensers are optimal for small scale or low power appliances like domestic refrigerators, water coolers or split air conditioners to reduce overall power consumption by increasing the COP.

Keywords:** Refrigeration system, COP improvement, Condenser, Water mist, Evaporative cooling, Nano-fluid coolant, VCRS cycle.

I. INTRODUCTION

The world is growing day by day and this growth is fueled by energy. 81% of the world's energy demand is fulfilled by fossil fuels [23]. Burning fossil fuels creates the global warming, climate change and deforestation [10]. This in turn creates the demand of cooling and refrigeration systems [7]. Throughout the development path of sciences various methods of cooling, refrigeration and air conditioning viz. VCRS cycle, VARS cycle, Diffusion Absorption Refrigeration Systems, Air Refrigeration Systems etcetera. They consume electricity which in turn again increases the carbon footprint.

Burning of fossil fuel to curb the growing energy demand, is creating green house gas which is causing the global warming, environment degradation and creating the demand of cooling systems. These cooling systems also consume electricity, causing more global warming. To break this vigorous cycle we can make more energy efficient systems. Among the systems and technologies that we have reviewed, each has their pros and cons but accommodating the best techniques we can achieve better performance in the systems.

Recent studies have shown that if temperatures arose as predicted, worldwide residential energy consumption for cooling will be up to 34% higher than at present in 2050 and 2100 up to 61% greater [19]. Now we need to make our systems as efficient as possible to meet the growing energy demands without creating any extra carbon foot print and climate change [7]. Various techniques to increase the COP of refrigeration cycle are air cooled; water cooled evaporatively cooled condensers and compressor shell and use of high conductivity nano materials to increase the heat transfer coefficient [1].

Above techniques of COP increment are studied and reviewed, in this review paper we have evaluated numerous works done in improving the energy efficiency of domestic refrigerators through various techniques. Now the demand of energy is growing exponentially and we must search new ways/resources to meet the energy demands, but merely searching for new resources can't meet the requirement until we make systems more energy efficient [7].

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The energy is capital and wasting it is similar to crime and hence we must take steps to improve the energy efficiency of appliances. Fridge/Refrigerator is in every household and a lot of energy is used by them and great fraction of carbon footprint is generated [19], by making them more energy efficient we can save some precious energy.

Now as we know that due to ruthless extraction of coal and other fossil fuels have made the circumstances that they are going to be depleted very soon, hence now the designing approach should be as such to utilize the energy as much as possible and make the system more efficient and productive. These efficient systems would provide better cooling with low amount of refrigeration flow rate which would in turn not only reduce the electricity bill but also reduce the total equivalent warming impact (TEWI) [16]. The refrigerants used in refrigerators are also harmful to the environment and if we can reduce its use merely by more efficient systems we will be able to live in cleaner atmosphere.

II. WORKING

Vapor compression refrigeration system (VCRS) is based on the second law of thermodynamics. It is an application part of the Clausius statement of second law which states, "It is impossible to construct a device which operates on a cycle and produces no other effect than the transfer of heat from a cooler body to a hotter body." The VCRS systems is directly based on this law where the system takes heat from a lower temperature body i.e. evaporator and releases it to the higher temperature body called condenser and also it needs the electrical power to run the system and dumps it to the surrounding through condenser, which is its effect to the surrounding. Its components and their working is described below.

A. Evaporator

The evaporator is a small cabin used for cold storage. All that cooling effect is noticed here. The cooling coil is wrapped around this chamber and the cold refrigerant flows at low pressure and temperature through it around evaporator and produces the cooling effect. In the vapor compression cycle this refrigerant is sucked by an inline compressor. The refrigerant coming from the capillary tube is in wet condition and the liquid refrigerant absorbs its latent heat of evaporation and gets vaporized and enters compressor in saturated vapor condition. Here the latent heat of vaporization is taken by the liquid refrigerant to get converted into saturated vapor. A sensor is also present in upstream direction to detect any infiltration of liquid particles to compressor inlet. Any liquid particle in the compressor inlet can cause severe damage to the compressor hence the state of refrigerant is either saturated or super heated vapor.

B. Compressor

The job of compressor is to increase the pressure of the dry saturated vapor coming off of evaporator. While increasing the pressure of the refrigerant it gets heated up as a side effect and it reaches to the super heated state and its temperature increases considerably higher than the atmosphere. Here hermetically or semi-hermetically sealed reciprocating compressors are generally used in vapor compression refrigeration systems for increasing the pressure of refrigerant vapor. In VCRS cycle high pressure increment is required with relatively lower flow rates; reciprocating type positive displacement compressors are best suited for this kind of application.

C. Condenser

The refrigerant coming out of the compressor has become considerably hot and the job of condenser is to cool it down to atmospheric temperature and condense it to saturated liquid state. Condenser is designed in such a way that the hot refrigerant coming out of the compressor gets sufficient surface area to cooled down here and condense to saturated liquid state. Here the condenser coil helps refrigerant to lose the excess amount of heat it has gained to the atmosphere. Even after losing excess heat to the atmosphere the pressure of saturated liquid refrigerant is still high.

D. Capillary tube/Expansion Valve

This is a thin tube of very small diameter which creates hindrance to the flow of liquid refrigerant and due to this frictional resistance the pressure of the liquid refrigerant gets down when refrigerant flows through it. But here in this tube very peculiar phenomena called Joule-Thomson effect occurs, where the temperature of the liquid refrigerant also decreases with decrease in the pressure while flowing through it. This creates the refrigeration effect. Now the refrigerant is ready to cool the substance kept in the evaporator and hence the low temperature and low pressure liquid refrigerant is sent to the evaporator where it will absorbs the heat from evaporator chamber and gets vaporized where it is sucked in by the compressor, and this cycle continues. Compressor is the main driving part of the VCRS cycle.

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III. LITERATURE REVIEW

1) *Surendra H. Shah et al.* The author have used 1-ton vapor compression refrigeration with a fog-based condenser cooling system, where they made tiny fog droplets spread onto the hot surface of condenser which evaporate quickly and provide better heat dissipation to the condenser. These droplets are then recovered further in a water recovery heat exchanger resulting in least or no water loss at all. This trend of water conservation is expected to continue for large-scale cooling because water is recovered in a closed system. As a result they got up to 50% improvement in COP.
2) *D.S. Adelekan et al.* The author has used slightly modified domestic refrigerator as a test rig and used various concentrations of nano-lubricant/refrigerant mixtures to investigate the effect of varying test conditions including ambient temperature (19, 22, and 25°C), mass charges of R600a refrigerant (40, 50, 60, and 70 g), and concentrations of TiO2 nano-lubricant (0, 0.2 and 0.4 g/L) on the performance of the refrigeration system. At optimum conditions, they achieved the evaporator air temperature within the range 5.26 to 26.32 %, and energy consumption reduced as 0.13 to 14.09 %, while the coefficient of performance and second law efficiency increased within the range 0.05 to 16.32 %, and 2.8 to 16 %, respectively.
3) *Huijun Mao et al.* The author from China has used Ethylene tetrafluoroethylene (ETFE) cushion roof to improve indoor natural lighting. But, their poor thermal insulation compelled them to use a water mist based roof cooling system. The author has suggested that exterior surface temperatures of ETFE cushion roofs should not go beyond 33.7°C to establish a thermally tolerable indoor environment. They have even achieved a decreases in exterior and interior surface temperatures by the spraying system respectively ranged from 4.8◦C to 19.5◦C and from 0.2◦C to 4.9◦C respectively. They even suggested, the decreases in exterior surface temperatures were most affected by environment temperature, followed by solar radiation, wind speed, and lastly the wet-bulb temperature, whereas decreases in interior surface temperatures were most affected by solar radiation.
4) *Suraj Kumar et al.* They have used nano-fluid in refrigerant base as a nano refrigerant. The nano particles in the colloidal mixture are supposed to improve the heat transfer coefficient in condenser and evaporator in VCRS cycle. Here small particles (size 100nm or less) having high thermal conductivity are mixed with refrigerant or base fluid and a colloidal solution is made. These nano particles increase the rate of heat transfer. As refrigerant base fluid R 600a and (Aluminum oxide) as nano-material was used. As a result 3.68% – 11.05% improvement in coefficient of performance was observed during the investigations with different concentrations of nano-material.
5) *Bahadır Do˘gan et al.* Here they have used two mini-channel flat wire-on-tube novel condensers with different offset strip fin configurations instead of a conventional condenser. The tests are conducted with different amount of refrigerant charges (48–64 g) and three different capillary lengths (2800, 3300, and 3800 mm). In the experiment the author achieved 5.7% of energy-saving when one of the novel condensers is coupled with a 3300 mm length capillary tube and 50 g of refrigerant. The other achievement they got was reducing 10.7% of the refrigerant amount with the application of the novel condenser with offset strip fins on a mini channel flat tube.
6) *Chunkyraj Khangembam et al.* The author has done experimental and numerical study of air-water mist jet impingement cooling over a heated cylinder in the non-boiling region at different mist loading fractions and Reynolds numbers. They have observed that increasing the mist loading fraction increases the heat transfer while decreasing Reynolds number gave better heat transfer. They achieved high enhancement in heat transfer for low surface-to-nozzle spacing (H/d) near the point of stagnation till a certain extent, beyond which the curve reverses as high enhancement is observed at high H/d.
7) *MCarmen Guerrero Delgado et al.* Here the authors have done a comparative analysis of evaporative cooling power of sprayed water mist with the evaporative cooling power of water filled simple pond. Two identical ponds were made and mist fan blower gave good air flow over the other pond. Total cooling power achieved was 500Wh and 6 °C drop in temperature was observed compared to 2 °C drop in the other pond. Here author used to evaporative cooling capacity of water through mist sprayed system with least amount of energy consumed as pomp work and achieved the cooling effect.
8) *P. Saji Raveendran et al.* The author has used brazed plate water-cooled condenser in a refrigeration system connected to the prevailing water distribution system of a house with necessary modifications required in the existing arrangements. The experimental findings indicated that the brazed plate condenser refrigeration systems decreased 21 to 27% of daily energy consumption. The total equivalent warming impact was lowered by 26.8% to that of conventional systems. The refrigerants, R290/R600a (45.2:54.8 - mass fraction) mixture showed 5.9% lower per day energy consumption. They achieved 8.9% increase in the COP with R290/R600a than that of R134a.

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9) *G. Ulpiani et al.* The author of this paper investigated the effect of local meteorological trends in the cooling efficiency of a dry mist system. An experimental set up of 24 overhead nozzles operating at 0.7 MPa, were installed and monitored for a week in summertime. The temperature and relative humidity underneath the water spray mist were mapped in five locations with a time step of 10s. The meteorological parameters were also measured at an undisturbed location for reference. It was demonstrated that the cooling capacity of the tested system was largely a function of the local wet bulb depression, as instantaneous reading as well as short-term trend. During testing, the temperature in the undisturbed location peaked at 36.3 °C, while the relative humidity reached 87.1%. In the misted area, the temperature could be reduced by up to 7.4 °C by injecting pulverized water droplets, while maintaining the humidity gain below 13 %.
10) *T.O Babarindea et al.* The authors investigated R600a refrigerant in (Multiwall carbon nanotube) MWCNT-nanolubricant (0.4g/L and 0.6g/L concentrations) as a replacement for R134a refrigerant in a household refrigerator system. They tested with varied mass charge of R600a (50, 60 and 70 g). They compared the results with the result obtained through R134a refrigerant in the system, that showed R600a perform better in terms of COP, power consumption and cooling capacity. They achieved a lower evaporator temperature of −11 °C and power consumption of 0.0639 kW and highest COP in the system.
11) *Ghassem Heidarinejad et al.* The authors used the water mist cooling system to condenser of air-cooled chiller for better heat dissipation. Here they have studied the effect of a water mist cooling system attached to the condenser; on chiller COP in various orientations of the spray nozzle. As a result the outcome shows the improvement in the system performance is considerable as 5.9 to 10.6% improvement in the COP is noted corresponding to different nozzle angle orientations. In the channel spray nozzles were kept in different orientations to mix with air and provide the cooling effect to the passing air and with altering their orientation, changes in COP was recorded. At 22.5° elevation the least 5.9% while at 90° elevation the best 10.6% improvement in the COP was observed.
12) *Shennan Yang et al.* Graphene nanosheet has an ultra-thin sheet like structure that can fill the contact friction surface and reduce frictional losses between flowing fluid and solid surface and enhance its thermal conductivity to 5,300W/mK. Hence, a nanofluid was prepared by the author adding graphene nanosheets to base liquid. Mixing 10mg/L, 20mg/L and 30mg/L grapheme nanosheets with refrigerant oil they compared their effect on system performance as cooling rate, freezing capacity, and energy consumption of the refrigerator. The 30mg/L graphene nanosheets refrigerant oil increased the freezing capacity of the refrigeration system by 11.1%, and the coefficient of friction (COF) was reduced by 17.5% compared with the pure oil. Also 10mg/L, 20mg/L and 30mg/L concentration dropped the energy consumption by 15.4%, 19.2% and 20.3% respectively.
13) *Amrat Kumar Dhamneya et al.* Here the author and team used a vapor compression refrigeration system coupled with evaporatively cooled pad, and nano-refrigerant, for improving the performance of the system in hot & dry weather. They used TiO2 0.2 g/L to 0.6 g/L nanoparticles mixture with R-134a refrigerant in the ice test rig. The experimental investigations revealed that the performance characteristics of the evaporatively-cooled condenser significantly enhanced and the team was able to achieve a maximum C.O.P. increases by about 51% in the hot and dry climate condition than the normal system. Results also revealed that the direct evaporative cooling system is the most suitable option for performance enhancement of VCRS cycle than the use of nano refrigerant in warm and dry weather which was crucial information for the project work.
14) *P. Saji Raveendran et al.* The author studied the performance of domestic refrigeration system retrofitted with building integrated water-cooled condenser and used brazed plate heat exchanger (BPHE) for heat transfer. Here domestic water used for general purposes in a residential building has been considered as the cooling water for the condenser. The quantity of circulation water per day has been varied, and the variation of COP has been studied. The results obtained from the experiments showed that the COP of the system with brazed plate heat exchanger in the water cooled condenser is 57% to 75% higher than that of air cooled condenser. Also, they successfully reduced the per day energy consumption of the system from 21% to 27% with the help of water cooled brazed plate heat exchanger (BPHE). The total equivalent warming impact (TEWI) of the system was also 5% to 43% lower than that of the system with air-cooled condenser.
15) *Z. Liu, F. Zhao et al.* To save the energy from electric heater defrosting (EHD) in domestic refrigerator the author has developed a bypass cycle defrosting system using 50W compressor casing thermal storage (BCD-CCTS). In the experiments author revealed that in the BCD-CCTS method, defrosting time decreased by 65%–77% and the defrost energy consumption decreased by 89%–92%. After 60 h of normal operation, the temperature of the compressor casing exposed to air was approximately 60 °C, whereas that of the compressor casing exposed to the heat storage phase change material (PCM) was maintained at about 54 °C. Although author did not do anything to imporove the COP still it gave an insight to the use of phase change material PCM that can be used effectively in cooling down the condenser and the compressor casing as well which will in turn defiantly improve the COP of the system.

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16) *N. Nethaji et al.* The author has used the defrost drips as an energy saving measure for cooling of compressor shell in the vapor compression refrigeration system. The defrost water was made to drip on the hermetically sealed compressor enclosed in a shell. The water on the surface slowly evaporated and cooled the compressor, which reduced the energy consumption of the compressor. The experiment revealed that around 8–10% energy savings can be achieved in the given operating conditions.
17) *Chung-Neng Huang et al.* Authors developed a supersonic water-mist cooling system with a fuzzy control system to ad and optimize existing air conditioning system and reduce its energy consumption. Operating water mist system with AC, energy saving of 25% was observed. The condenser temperature was approximately 45.6°C without additional system and was approximately 40.2°C with supersonic atomization the difference being 5.4°C. The chiller with mist-cooled system had COP value of 4.34 which is 33% higher than that of the old condenser set up without misting system, which is significant and encouraging.
18) *H. Barrow et al.* The author has made a test set up for evaluating the evaporation capacity of droplets sized from 25 to 200 µm and their evaporation with respective trailing distance in the air during evaporation and recorded the temperature of droplets. The recorded terminal temperature of droplets was 291.1 K when environment temperature was 301 K and environment relative humidity was 40%. The author noticed the droplet of size 25 µm was evaporated in 0.66 seconds travelling a distance of 0.006 m in the air of relative humidity was 40%. Whereas the droplets of diameter 200 µm took 28 seconds to evaporate travelling a distance of 15.70 m. This drop of 10 degrees in temperature is sufficient to make the misting system to be used as cooling systems in various applications.
19) *Ibrahim Atmaca et al.* In this study the author examined the performance of a split-type air conditioner with evaporatively-cooled condenser. The effects of outdoor temperature and relative humidity on total power consumption and on COP were studied with the evaporative cooling of the condenser of the split-type air conditioner, the increase in COP noticed was 10.2%–35.3%. The cooling capacity increased by 5.8%–18.6%, whereas the total power consumption decreased by 4%–12.4%. The results presented show that the outdoor conditions play a significant role on the performance and COP. The cooling capacity and total power input is also affected by environmental conditions. The optimal condition for maximizing the COP of the system was estimated as higher outdoor temperature and lower relative humidity.

IV. SUMMARY

So much research work has been done in the field of vapor compression refrigeration systems and on its COP improvement through various methods viz. defrost water drip system, water mist jet impingement, air water evaporative cooling, nozzle orientation for mist cooling system attached to the chiller, fog-based condenser cooling system, nano-fluid in refrigerant to maximize the heat transfer coefficient within the evaporator and condenser tube. nano fluids, (Multiwall carbon nanotube) MWCNT-nanolubricant and Graphene nanosheet was made the research article. Considerable improvement in the heat transfer rate and the COP was reported through this technology. Still preparing the nano fluid by mixing the base fluid and nano materials and making the colloidal solution is a hectic task. One need to add some stabilizer along with the nano particles in the base fluid and the lumps created must be break down to nano level through ultra sonic vibrations in a machine for at least 3 hours or so, which discourages one to use this process for the article. The author showed that a considerable amount of increment in the COP of domestic refrigerator operated through vapor compression refrigeration system can also be achieved through cooling down the compressor shell which reduces the winding temperature thereby reducing the work required by compressor. It is also evident that a considerable amount of cooling effect can be generated by evaporative cooling in water spray mist cooling system, which can attain 6 °C drop in temperature. The author achieved up to 50% improvement in coefficient. The author with split-type air conditioner with evaporatively-cooled condenser proved that the mist cooling system can be used in the modified condenser of a component running on VCRS cycle and gave a great improvement in COP as well. The colloidal solution of nano particles suspended in the refrigerant base has its own limitations whereas the evaporative cooling system attached to the condenser through water spray mist fan looks very good and has shown appreciating results in large systems, but they can also be used to small applications with some necessary modifications like in domestic refrigerators.

V. OBJECTIVES

The objectives to be achieved with experiments in the modified domestic refrigeration with water mist cooling system are:

1) To increase the coefficient of performance (COP) in modified domestic refrigeration with the help of water mist cooling system.
2) To compare the exit temperature of refrigerant from condenser in conventional and modified domestic refrigeration with water mist cooling system.

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3) To assess change in various parameters in modified domestic refrigeration system and the effect of water mist cooling on condenser performance.

VI. METHODOLOGY

Condenser is one of the main components that releases the heat energy of refrigerant acquired during compression and condenses it. It makes the refrigerant to cool down after throttling to provide the cooling effect. We are investigating that is it possible to improve the coefficient of performance of domestic refrigeration system by providing the condenser better heat dissipation through water mist cooling system.

1) *Experimental Set up:* A 150-litre domestic refrigerator coupled with hermetically sealed reciprocating compressor, air-cooled condenser, evaporator coil and capillary tube is to be used as a conventional cooling system. Condenser of this system is modified and coupled with a water mist fan for providing better heat dissipation. To create a water mist fan a 12 volt reciprocating water pump of 150 psi pressure rating is connected with 4 mist nozzles and adequate size of piping to complete the circuit. And this system is attached to the rim of a fan so that the combination of misting system and the fan will make evaporative cooling better and efficient.

2) *Collection of Data:* In the experimental setup, two pressure gauges one at the inlet and one at the outlet of the compressor will be placed. The operating pressure of evaporator and condenser will be recorded with these gauges. Temperature sensors will be placed at each step of the refrigeration cycle, as at the compressor inlet, compressor outlet, condenser outlet, compressor dome, evaporator inlet, and at various other positions like inside the freezer and food compartments. An energy meter will be installed to evaluate the power consumption of the system.

3) *Analysis:* The collected data will be analyzed and the assessment will be done that what was the effect of the water mist cooling system attached to the condenser on the condenser outlet temperature and the COP of the system.

$$COP = \frac{\text{Desired effect}}{\text{Work Input}}$$

$$COP = \frac{H1 - H3}{H2 - H1}$$

H1= Enthalpy of refrigerant at compressor inlet
H2= Enthalpy of refrigerant at compressor outlet
H3= Enthalpy of refrigerant at condenser outlet
H4= Enthalpy of refrigerant after throttling, but as throttling is an adiabatic process hence H3=H4.

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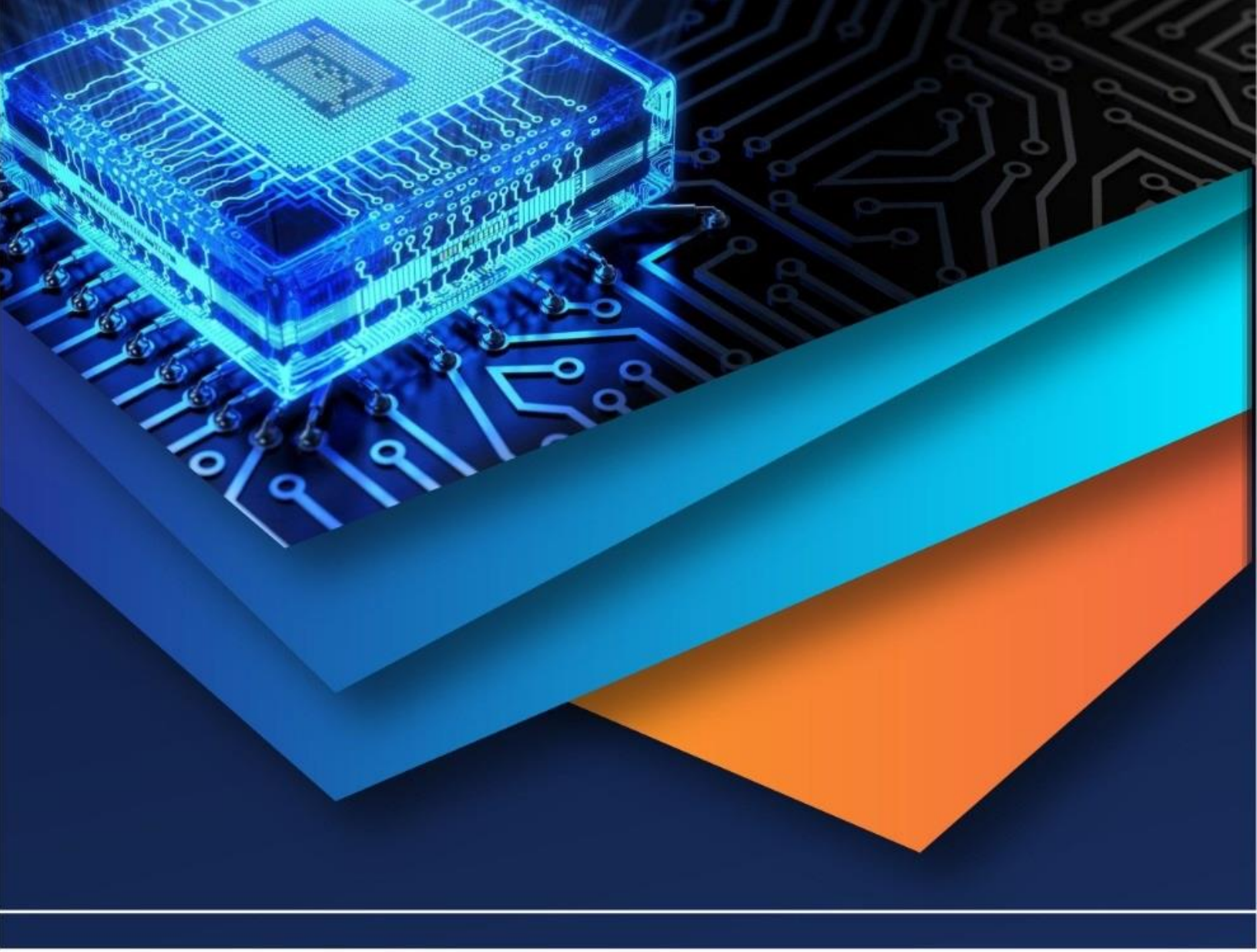

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