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Performance Analysis of Domestic Refrigerators Condenser Coil By Applying Lampblack / Synthetic Black Blend

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Abstract: Domestic refrigerators are usually used for cooling the bounded space by absorbing the heat through the evaporator and simultaneously rejecting the heat to the surrounding through the condenser coil. The black color coated condenser coil is the main part that rejects heat to the surrounding in the form of radiations. Herein, to increase rejection of the heat from the condenser coil, to increase its performance, a blend of lampblack/ synthetic black (various w/w ratio) was partially painted on. The three different compositions (w/w) are applied on the condenser coil and accordingly, the heat radiating coefficient and coefficient of performance are measured. Optimized composition of lampblack /synthetic black (4:6) provided maximum performance in terms of coefficient of performance 5.51% and with heat transfer coefficient 16.11%. The results show a cost-effective approaches to increase the performance as well as the life time.
Keywords: Lampblack, Coefficient of performance (COP), Heat radiating coefficient and Condenser coil, Refrigerator.

I. INTRODUCTION

Domestic refrigerators are an integral part of the human lifestyle and it is widely used in the industries, houses, medical and commercial purposes. The refrigerator (Fridge) cools the space inside the system with the help of an external source of power and it works on the principle of a vapor compression refrigeration system. The refrigerator consists of four components Compressor, Condenser, Expansion valve and Evaporator. It operates in a cyclic process starting from the heat-absorbing evaporator to the heat-rejecting condenser coil and vice-versa. Condenser coils are painted black for the heat absorption from the refrigerant through convection and dispersing the heat to the surrounding in the form of radiations. As it is known that a black body tends to attain thermal equilibrium and emits radiation in the form of electromagnetic waves. Considering the black body, lampblack is one of the amorphous form of carbon black and it is the oldest pigment used in the ancient times. Lampblack is obtained by burning the rich carbon substance in a limited air supply. The size of the lampblack particle is in the range of 50 to over 100 nm [1]. Lampblack particles are so fine that their small amount can surround a much large area which is responsible for their intense black color. It consists of a higher percentage of carbon around 97-98 % [5] which is more than carbon black. Its pure black appearance, shows properties like high thermal conductivity, and high rate of heat transfer. Lampblack is used as a pigments in inks and paints due to its properties like opacity and resistance to fading. It is also used in tire industry, electronic industry, and automobile industry for dispersing heat to the surrounding.

X. Zuo et. al. [1] used lampblack mixed with distilled water in a certain ratio as a solar radiation collecting medium. The lampblack powder (size 50 to 100 nm) is converted into the ink form. They analysed the properties like heat conductivity, photo thermal conversion, stability and thermal conductivity. It shows that lampblack fluid has good dispersion stability, higher coefficient of thermal conductivity for higher temperatures, good absorbance of heat and radiate as well, gentle rise in specific heat as the temperature increases and more importantly good heat conduction for photo thermal conversion. A. Baldelli and group [2] have reviewed the soot produced from the incomplete combustion used as a non-wettable coating on the surfaces. The soot is produced from many processes like from candles and extracted from different processes. It gives the hydrophobic characteristic of the carbon particle which is used for many purposes and also for the automotive paint industry. S. Patil and coworkers [3] have introduced the experimental set-up for the analysis of the effectiveness of condenser coil. Several ways to increase the COP of the refrigerator like geometry of the condenser coil, increase the surface area, the thermal conductivity of the tube material and fin spacing. It shows that the effectiveness of a condenser coil can be increased in several ways which ultimately increases the COP of the refrigerator. M. V. Karvinkoppa et. al. [4] conducted a numerical investigation on the heat flux dissipation from the electronic components and analysed the temperature drop of heat source components using ansys.

It shows that the components painted with lampblack, which is attributed to its radiations have a big temperature drop through the natural and mixed convection processes. S. M. Singh [5] applied black paints with different absorbers on the solar plate collector surfaces. This will help to understand the absorptance of incident solar radiation on different material surfaces. Lampblack is the most appropriate for the pigmentation of black paint. It consists of 97-98% of carbon. It has the finer particles which results in greater intensity of colour. It is readily mixed with oil, varnish and lacquers and applied on the solar palate collector where it absorbs the most incident solar radiation with a high value of absorptivity and emissivity. It has an absorptance coefficient of 0.96. Meng-Jiao and Kirk-Othmer Encyclopedia of Chemical Technology [6] shows the flame interrupting method to manufacture the lampblack of definite particle size. It gives the method in which shallow pans of 0.5 – 2 m are used and it is placed 16 cm above the base of burning raw materials in a restricted air supply. The unburnt carbon deposited on the pans which later scrapped off. It shows the applications for lampblack like as a filler in tyre industries and as a pigment in the paint industry. H. H. Yoshikawa et. al. [7] analysed the lampblack-based graphite material contraction during the exposure of high-temperature radiation. It also shows the change in the properties during radiation exposure such as the coefficient of thermal expansion, thermal conductivity, electrical resistivity and elastic modulus. Analysis shows that at a certain high-temperature lampblack material thermal conductivity increases up to a certain limit and then decreases as temperature increases. P. S. Babu and coworkers [8] had analysed the optimum working condition for different lengths of condenser tubes and with different fin spacing. The condenser tube length varies causing the change in COP of the system. Various variables are also showing changes in its performance like mass flow rate, heat rejection rate and condenser temperature. H.C.R Reuter and group [9] blended the copper oxide filler in the black paint (Paint-based protective films) and then applied it to the condenser tubes. It shows very good anti-fouling efficiency. Simulation is done on the condenser tubes after applying the mixture and it gives good protection against corrosion. It also does not affect the effectiveness of the coating. L.S Frumkin and group [10] analysis of different carbon black materials in rubber mixture at the temperature of 100^0C shows that the lampblack shows higher heat conductivities than the gas black, mykop but less than yaroslav carbon blacks. A. Dubey et. al. [11] placed the setup in enclosed box which is PVC coated with the lampblack paint as it gives less than 1% reflectivity for wavelengths of the visible spectrum and it is a very good absorber of radiation**.** S. H. Al-Nesrawy and group [12] experimented on vulcanization of rubber in which mixing ratio of lampblack causes the increases in certain mechanical properties like abrasion resistance, tear resistance, fatigue and specific gravity. A. D Rayani and his partners [13], used the software ansys to analyse the temperature distribution, heat flux and thermal gradient of the condenser tubes. A. S. Sawad and group [14] used ansys for the thermal analysis of a condenser coil and it shows the heat flux and temperature distribution in the condenser tubes. G. Pfaff et. al. [15] used the lampblack properties like thermal stability, tinting strength and jets responsible for applications like coating and paint in the automotive industry and rubber industries. H. Wanga and group [16] used lampblack nanofluid made up of carbon black on the solar cell and it shows very good photo thermal conversion performance.

From the literature reviews, it is observed that the lampblack usage shows the promising nature of high rate of heat transfer as it is considered pure black. It shows high thermal conductivity as the temperature increases and it attains rapid thermal equilibrium within the room temperature which shows good thermal stability. Lampblack is considered a perfect absorber and perfect emitter of radiation with a high surface emissivity of 0.96[5]. Its small size of the particle measured in nanometers is in the form of powder which is used as a pigment in black paints for industries. As seen from the works of literature, the condenser coil is painted with synthetic black paint for heat transfer to the surrounding medium. Lampblack applications are limited to tire industries and for paint on parts of automotive and electronics industries. The powder form of lampblack is converted into nanofluid. Then it is mixed in a certain ratio with the synthetic black paint and applying on the condenser coil to increase the rate of radiative heat transfer.

II. EXPERIMENTAL SECTION

A. Material Specification

A steel plate (size 100 X100 mm) of grade 304 is used. The scriber is used for scraping off the accumulated powder. The stirrer is used to mix the lampblack nanofluid into the black paint. The spray paint machine is used to apply the mixture onto the condenser coils.

B. Synthesis of Lampblack Powder

The lampblack is manufactured by the flame interrupting method or incomplete combustion method. The incomplete combustion method is used for the creation of free carbon. In this method, the candle is burned and a stainless steel plate or spoon is held above the flame. The plate is held with the help of fixtures like brick above the flame such that the plate is interrupting the flame. Hold the plate in position for some time like 2-3 minutes in which the free carbon from the flame gets deposited on the plate.

The free carbon accumulated on the plate making the black spot. So the plate is taken away and the carbon deposit on the plate is chipped off from the plate with the help of a scraper or knife. The chipped-off carbon from the plate in the form of powder is called soot or lampblack.

C. Preparation of Paint

Now to prepare the paint, lampblack powder is mixed with deionized water and thoroughly stirred for some minutes [1]. The mixture formed is filtered and lampblack nanofluid is prepared. Adding lampblack nanofluid by the proportion of 20%, 30% and 40% in the synthetic black paint. Stir the mixture for 5-10 minutes to complete the blending. A mixture of lampblack nanofluid in the black paint is thoroughly blended to avoid any paste formation. Adding thinner to the mixture of paint by the proportion of 3-4% helps us to avoid the formation of dry and thick paint. Now fill the paint mixture in the spray paint machine and spray the black paint mixture on the condenser coil. Place the condenser coil in open surrounding for time to dry the painted condenser coil.

D. Designing of Experiment set up

Lampblack is blended in a ratio of 20, 30 and 40% by weight in the synthetic black colour. Apply the lampblack blended mixture on the horizontal condenser coil and let it dry for 1-2 days. Calculations and analysis of the vapour compression refrigeration test rig are done after each ratio of the mixture is applied. The readings are taken at room temperature in a closed room with the help of calibrated digital thermometer. The outside and inside parameters of the vapour compression refrigeration test rig are kept constant. The VCR system is kept running for around 1-1.30 hr to attain the equilibrium conditions or steady state conditions and then the readings are measured. The summarized system is presented in the following table (**Table 1**). The temperatures measured with the help of digital thermometer. The temperature of condenser and evaporator is varying as the blend percentage is increasing.

Table 1: Data measured from VCR Test Rig for Condenser and Evaporator Temperature at different mixture ratios

Case No.	Lampblack Blending	Condenser temperature (K)	Evaporator temperature(K)
I	No blending	318.0172	268.925
II	20% blending	316.9125	268.2125
III	30% blending	314.7125	267.2
IV	40% blending	312.7125	266.6125

III. RESULTS AND DISCUSSION

Table 2: Summarization of the calculated values of condenser surface temperature, heat radiating coefficient and coefficient of performance.

Blend %(w/w)	Condenser surface temperature (K)	Heat radiating coefficient (Wm^2/K)	Coefficient of performance
0%	318.8376	5.99	5.47
20%	320.2239	6.46	5.51
30%	321.5239	6.50	5.62
40%	323.4376	6.57	5.78

The condenser surface temperature (T_S) is basically the mean addition of the temperature of each condenser tubes and fins after attaining steady-state conditions.

It is important in domestic refrigerators as it is used to disperse heat to the surrounding through the convection and radiations. This can be determined by the following equation (**Equation 1**)

$$T_s = \frac{A_t T_{ot} + A_w T_w}{A_o} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (\boldsymbol{Equation\ 1})$$

Where A_t – Area of condenser tube
A_w – Area of fin wire
T_{ot} – Temperature of condenser tubes
T_w – Temperature of fine wire
A_o – Overall area of condenser tubes and fine wire

Figure 3 shows the variation in condenser surface temperature as the lampblack in the blend ratio in increasing. Without the lampblack, the condenser surface temperature is 318.8376, the value 323.4376 obtained using the 40% lampblack with remaining mixture. This indicates the temperature of condenser tubes goes beyond the 50^0C, which causes the phenomenon of overheating.

Another important parameter is heat radiating coefficient (h_r) in which the rate of heat transferred by the radiations to the surrounding is calculated.
It is important function of temperature as it is used to determine the rate of heat transfer through the medium.
This can be determined by the following equation (**Equation 2**)

$$h_r = \varepsilon\, \boldsymbol{\sigma} \frac{T_s^4 - T_{atm}^4}{T_s - T_{atm}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (\boldsymbol{Equation}\ \mathbf{2})$$

Where ε – surface emissivity
$\boldsymbol{\sigma}$ – Stefan Boltzmann constant ($5.67 * 10^{-8}$ W/m^2 k^4)
T_s – Condenser surface Temperature
T_{atm} – atmospheric Temperature

Figure 4 shows the variation in condenser surface temperature as the lampblack in the blend ratio in increasing. Without the lampblack, the condenser surface temperature is 318.8376, the value 323.4376 obtained using the 40% lampblack with remaining mixture. This indicates the temperature of condenser tubes goes beyond the 50^0C, which causes the phenomenon of overheating.

Another important parameter is coefficient of performance (COP) which measures the energy efficiency of the refrigerator unit's cooling performance.
It is the main property of refrigerator in the terms of temperatures of evaporator in the chiller part and the temperature of condenser coil.

This can be determined by the following equation (**Equation 3**)

$$COP = \frac{T_{eva}}{T_{con} - T_{eva}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .(\boldsymbol{Equation}\ \mathbf{3})$$

Where T_{eva} – Evaporator temperature
T_{con} – Condenser coil temperature

Figure 5 shows the variation in coefficient of performance as the lampblack in the blend ratio varies. Without the lampblack, the coefficient of performance is 5.47, the value 5.78 obtained using the 40% lampblack with remaining mixture. This indicates the coefficient of performance is increasing for optimized blend ratio (LB/SB).
The graphs are plotted for the various blend ratios (w/w) that gives the different values of the properties. Figure 1 shows the reduction in the condenser temperature as the percentage of blend ratios increasing. It gives maximum heat at the time of sub cooling or at the end of condenser coil. Figure 2 shows the chiller temperature goes down for various blend ratios. It collects more heat from the bounded space compared to the no blend ratios. Figure 3 shows the increased surface temperature of the condenser coil for maximum blend ratio. It causes the overheating of the coil which is undesirable. Figure 4 shows the increasing value of heat radiating coefficient as the blend ratio is optimized. Figure 5 indicates the values of coefficient of performance increasing as the lampblack in blend ratio is increasing to maximum.

Figure 1 the variation of condenser temperature with the increase in blending ratio.

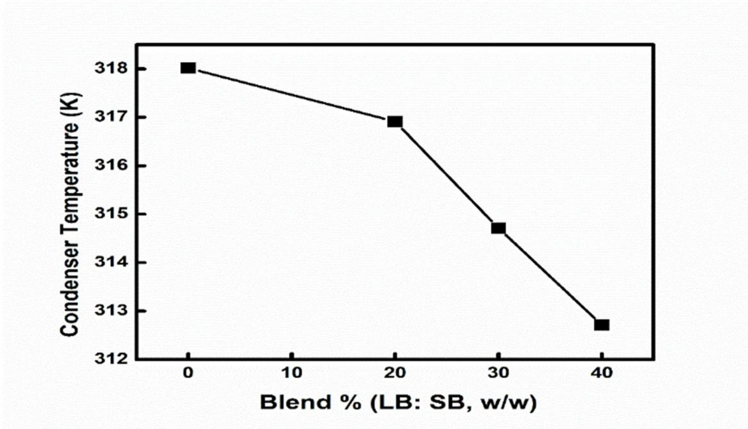

Figure 1

Figure 2 the variation of evaporator temperature with the increase in blending ratio.

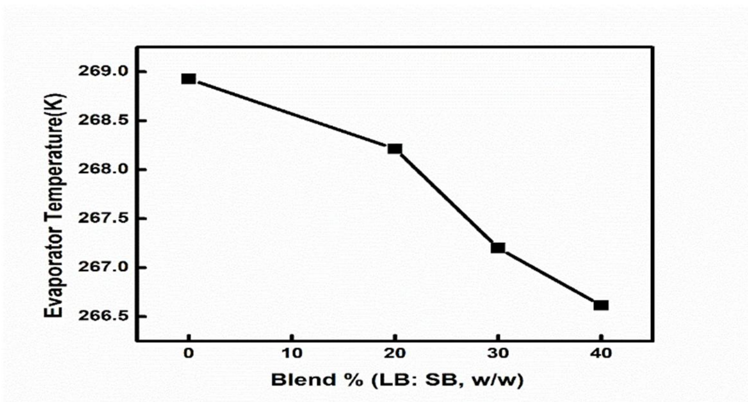

Figure 2

Figure 3 the variation of surface condenser temperature with the increase in blending ratio.

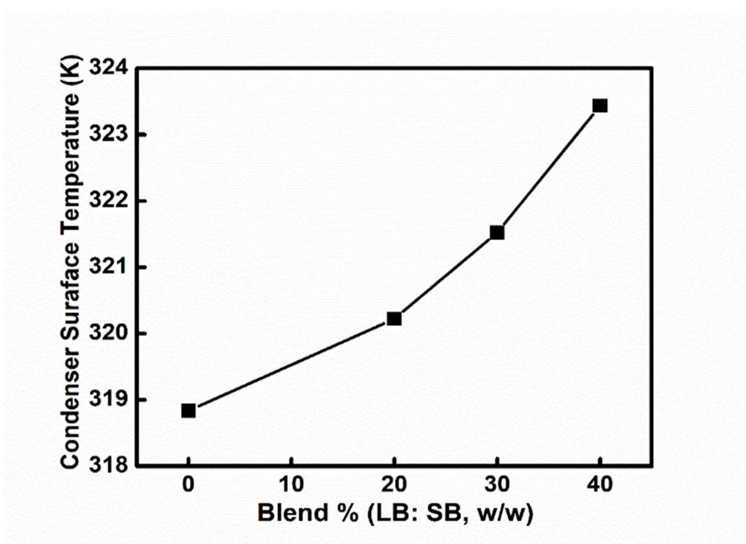

Figure 3

Figure 4 the variation of heat radiative coefficient with the increase in blending ratio.

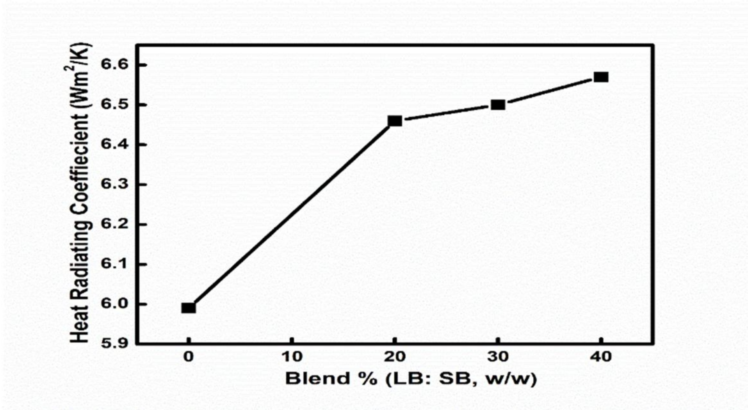

Figure 4

Figure 5 the variation of overall coefficient of performance with the increase in blending ratio.

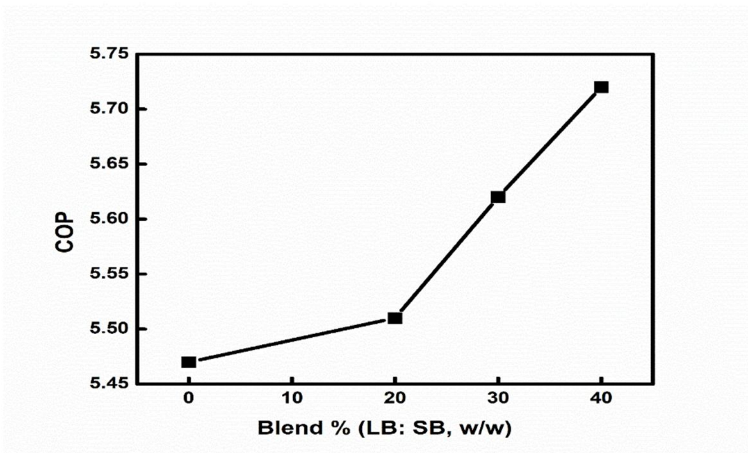

Figure 5

IV. CONCLUSION

The overall performance of the vapour compression refrigeration system by applying the blend (LB/SB) gives a significant change in the coefficient of performance and radiative heat radiating coefficient. The heat radiating coefficient is increased by 0.58 W/m^2K at the maximum lampblack ratio (40%) in the mixture. The coefficient of performance rises by the 0.31 at the maximum lampblack ratio (40%) in the mixture. As the blending ratio increases we can observe that the surface temperature of the condenser tubes is increasing beyond 50^0C, which shows the phenomenon of overheating which is undesirable. So, analysis shows the coefficient of performance of domestic refrigerators can be increased by improving the performance of condenser coil by cost effective method of applying lampblack and synthetic black mixture.

V. ACKNOWLEDGMENTS

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Conflict of interest
The authors declare no competing financial interest.

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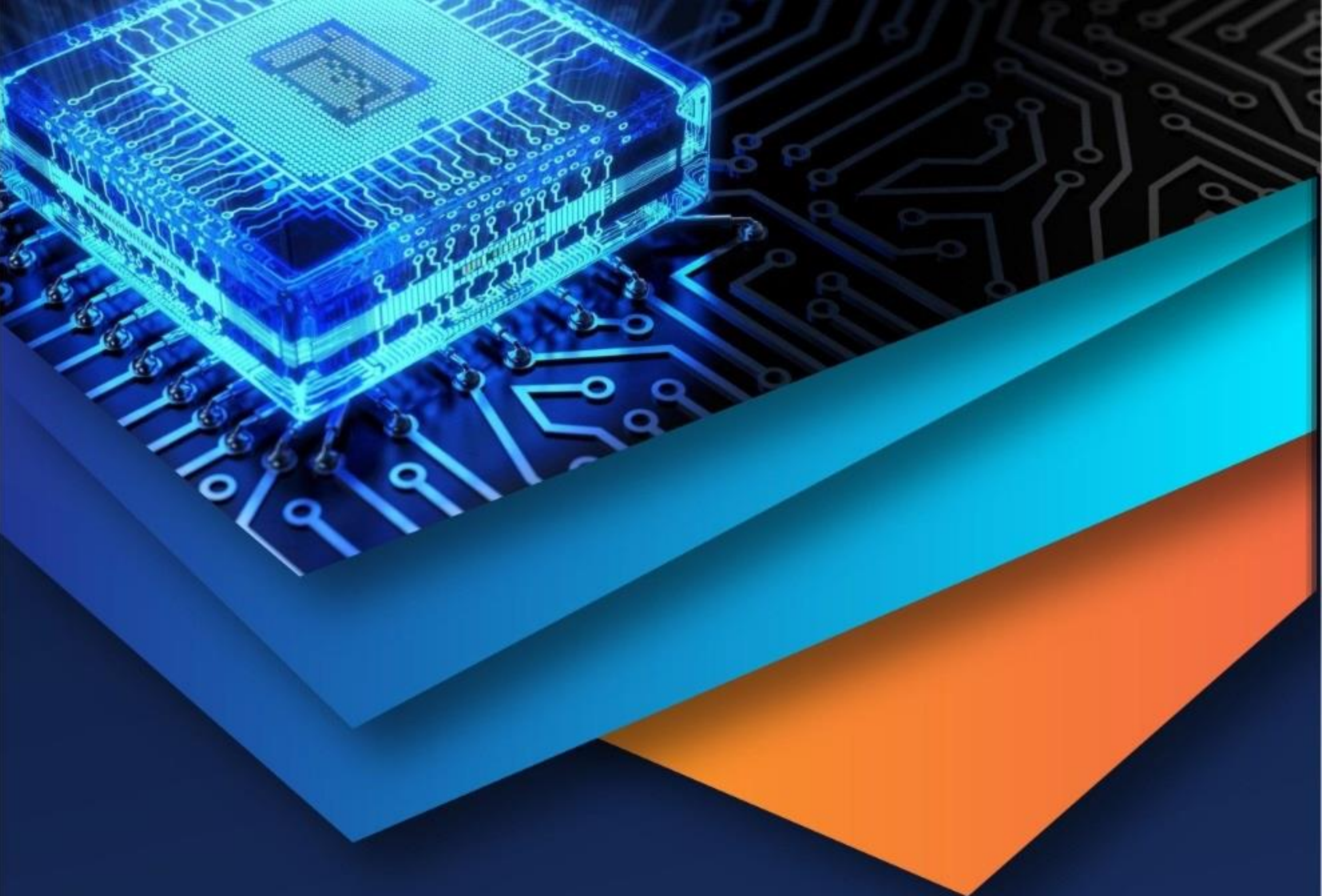

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