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Study of Coefficient of Heat Transfer of R-1234yf, R-410a as an Alternative Refrigerant to R-134a and R12

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Abstract: ***This paper deals with finding the alternative of R134a and R12 based on the existing correlation for heat transfer coefficient. Heat transfer coefficient which were obtained from the correlation for evaporation and condensation are compared for heat exchanger under the different conditions found in Refrigeration and Air Conditioning. It is shown that the heat transfer coefficient of R410a is higher than R134a and R12. Thus, it can be used as an alternative of R134a and R12.***

I. INTRODUCTION

Chlorofluorocarbons (CFCs) are used in a wide variety of applications, such as refrigerators, foam bowings, aerosol propellants and cleaning solvents and are proved to be one of the most useful classes of compounds, ever developed as refrigeration and air conditioning working fluids called refrigerants, because of their desirable thermal properties.

However, some of the properties that make CFCs desirable, such as chemical stability, had led to global environmental problems. As a result of chemical stability, CFCs have long environmental residence time and its emissions lead to accumulation in the lower atmosphere. CFCs migrate and mix with chemicals in the upper atmosphere where they dissociate, releasing chlorine atoms that catalyze the destruction of Ozone molecules. Since ozone provides a screen against solar ultraviolet radiation (UV-B) and excess UV-B has a potential of contributing to health and environmental hazard, hence significant depletion of ozone layer should be avoided.

Heat transfer evaluation of HFC134a and other alternative refrigerants have become important as reductions in CFCs. As the thermo-physical properties of the two refrigerants are similar, HFC134a is considered a potential replacement for CFC12. HFC134a is more environmentally acceptable with a zero ODP. This paper reviewed the comparison of experimental results for HFC134a and CFC 12 with predicted heat transfer coefficients obtained from the some existing correlation. The predicted heat transfer coefficient can be use for two purposes. First, as a heat transfer fluid, the effectiveness of R134a as a replacement refrigerant for system that use R12 can be assessed. Second, the heat transfer coefficient presented herein can help in the design of new systems that employ R134a as working fluid.

Unlike R-12, R-134a does not contain chlorine and does not damage the ozone layer. However, R-134a has a high GWP, which is a relative measure of how much heat a greenhouse gas traps in the atmosphere when compared to the amount of heat trapped by carbon dioxide (CO2).

There are three refrigerants that can be used to replace R-134a: R-1234yf, R-152a and R-744. More on these replacements later. An interesting fact about the phase out of R-134a is that unlike the switch from R-12 to R-134a, there will be no mandatory reduction in production or imports of the refrigerant, which means that supplies of R-134a should be stable both in availability and cost.

However, the demand will start shrinking with each passing year because no new vehicles after 2020 will be able to use it. Over the next 10 or so years, vehicles that use R-134a will inevitably end up in junk yards and the production of R-134a will be reduced, then disappear completely. Instead of a phase out, R-134a will be economically starved out of existence.

To date, most auto manufacturers are using the hydrofluoroolefin (HFO) refrigerant R-1234yf as the replacement of choice for R134a.The 2013 Cadillac XTS was the first U.S.made vehicle to use the new refrigerant. With a GWP of 4 (instead of 1,430 for R-134a) R-1234yf is more environmentally friendly.

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List of Alternatives to CFC and HCFC Refrigerants and Their Environmental Effects

Refrigerants	Boiling Point	Ozone Depletion Potential (ODP)	Global Warming Potential (GWP)
R-12	-29.79	1.0	8100
R-134a	-26.1	0	1300
R-410A	-33.0	0.037	1100
R-409A	34.3	0.048	1400

TABLE 1.1- List of Alternatives to CFC and HCFC Refrigerants and Their Environmental Effects.

II. PROPERTY CALCULATION

For being a suitable replacement for R12 and R134a, refrigerant R410a and R1234yf should have similar thermodynamic properties. Table 2 below shows the comparison between properties of R12, R134a, R410a and R1234yf.

Thermodynamic Property	R12	R134a	R410a	R1234yf
Chemical Formula	CCl_2F_2	CH_2FCF_3	CH_2F_2 (50%) CHF_2CF_3 (50%)	$C_3H_2F_4$
Molar Mass (kg/kmol)	120.913	102.03	72.58	114.04
Boiling Point at 1 atm (K)	243.40	247.08	240.15	243.7
Critical Temperature(K)	111.97	374.21	70.45	367.85
Critical Pressure(MPa)	4.13	4.06	4.81	3.38

TABLE 2.1- PROPERTY CALCULATION OF REFRIGERANT R12, R134a, R410a and R1234yf

Calculation of the heat transfer coefficient requires knowledge of thermodynamic and transport properties of a refrigerants. The thermodynamic and transport properties of R12, R134a, R410a and R1234yf are determined from the temperature based correlation. A Comparison of those thermodynamic and transport properties of R12, R134a, R410a and R1234yf that affect heat transfer at typical condenser temperature can be seen in Table 1, Table 2 and Table 3. Of those properties that affect heat transfer, the greatest difference between the three refrigerants is in there thermal conductivity. The liquid thermal conductivity of R-134a is about 20.23% higher than that of R-12 and 3.71% higher than that of R-409a, the liquid thermal conductivity of R409a is about 15.92% higher than that of R-12 at 45˚C, a typical condenser temperature.

For many correlations the heat transfer coefficient is defined in terms of thermal conductivity so that an increase in thermal conductivity causes a direct increase in heat transfer coefficient.

Another major property that affect heat transfer coefficient is liquid specific heat. The liquid specific heat of R-134a is about 45.45% higher than that of R-12 and 16.98% higher than that of R-409a, the liquid specific heat of R409a is about 24.33% higher than that of R-12 at 45˚C. Liquid specific heat affect heat transfer coefficient by altering the Prandtl number. Prandtl number is also affected by increases in the liquid thermal conductivity and liquid dynamic viscosity. The liquid Prandtl number of R-134a is about 4.42% higher than that of R-12 and 21.19% higher than that of R-409a, the liquid Prandtl number of R409a is about 13.83% lower than that of R-12 at 45˚C.

III. NOMENCLATURE

A. Nomenclature Of Terms

CFC	Chlorofluorocarbon
GWP	Global Warming Potential
HC	Hydrocarbon
HCFC	Hydro chlorofluorocarbon
HFC	Hydrofluorocarbon
HFO	Hydrofluoroolefin
ODP	Ozone depletion potential
TEWI	Total equivalent warming impact

B. Nomenclature Of Symbols

h_{TP} (W/ m^2s)	Local heat transfer coefficient
μ_l (Pa-s)	Dynamic viscosity of saturated liquid
μ_v (Pa-s)	Dynamic viscosity of saturated vapour
ρ_l (kg/m3)	Density of saturated liquid
ρ_v (kg/m3)	Density of saturated vapour
k_l (W/mK)	Thermal conductivity of saturated liquid
CP_l (J / kg-K)	Specific heat of saturated liquid
D (m)	Diameter of tube
G (kg/m^2s)	Mass flux
x	Quality
P_{crit} (Pa)	Critical pressure of saturated liquid
$P_R = P/P_{crit}$	Pressure ratio

IV. DIFFERENT CORRELATION FOR COFFICIENCT OF HEAT TRANSFER

A. Local Heat Transfer Cofficient

1) *Cavallini Zecchin Correlation (1974):* This equation is based on 460 data points for all refrigerants with 41% of these points being for R-12. The accuracy of the correlation varies for each refrigerant, for R-12, a standard deviation of 36% was found. This correlation is applicable for Re_l between 7000 to 53000 and, for liquid to vapour viscosity ratios (μ_l / μ_v), from 11 to 314.
$h_{TP} = 0.05\ Re_{eq}^{0.8}\ Pr_l^{0.33} \left(\frac{k}{d}\right)$
2) *Bohdal et al Correlation (2011):* Bohdal have developed their own experimental correlation with the use of mathematical statics principals and with a selection of the model's parameters with Quasi-Newton and simplex methods. The developed experimental correlation was verified for the refrigerants R-134a, R-404a and R-407c and a range of parameters, d = 0.31 mm to 3.30 mm, x = 1 to 0, T_s= 20˚C to 50˚C, and G = 100 to 1300 kg / m^2.
$h_{TP} = 25.084\ Re_l^{\ 0.258}\ Pr_l^{-0.495}\ P_R^{-0.288}\left(\frac{x}{1-x}\right)^{0.266}\left(\frac{k}{d}\right)$
3) *Park et al Correlation (2011):* Park et al. (2011) studied the experimental condensation heat transfer data for the new Refrigerant R1234ze(E), trans-1,3,3,3-tetraflu oropropene, and compared with refrigerants R134a and R236fa for a vertically aligned, aluminum multi port tube of 1.45 mm hydraulic diameter and 260 mm length. The experimental data ranges are vapor quality of 0 to 1, mass fluxes of 50– 260 kg/m2s, saturation temperature of 25–70˚C, and heat fluxes of 1–62 kW/m^2. D-K. W. Moser (1998)- Reynolds number model, based on the heat momentum analogy, is developed in this study. This model is then shown to predict the experimental Nusselt number of 1197 data points from 18 sources with an average deviation of 13.64 percent. The data are for tube internal diameters between 3.14 and 20 mm.

$$h_{TP} = \frac{0.0994^{C1} \times Rel^{C2} \times Reeq^{(1+(0.875*C1))} \times Prl^{0.815} \times K}{((1.58*lnReeq)-3.28)\left((2.58\times lnReeq)+13.78Prl^{\frac{2}{3}}-19.1\right)\times D}$$

4) *Akers and Rosson (1960):* In 1959, Akers et al. developed an in-tube condensation model, which defines the all-liquid flow rate that provides the same heat transfer coefficient as an annular condensing flow. This liquid flow rate was expressed by an "equivalent" Reynolds number and used in a single-phase, turbulent flow equation to predict the condensation coefficient.

$$\frac{h_{tp}\ D_h}{k_f} = 0.026 Pr_f^{1/3}\left\{G\left[(1-x)+x\left(\frac{\rho_f}{\rho_g}\right)^{0.5}\right]\frac{D_h}{\mu_f}\right\}^{0.8}$$

B. Average Heat Transfer Cofficient

1) *Cavallini Zecchin Correlation (1974)*: $h_{TPavg}=\frac{0.5}{1.8} \times Prl^{0.33} \times \frac{k}{D} \times \frac{b^{1.8}-a^{1.8}}{b-a}$
2) *Bohdal et al correlation (2011):* Bohdal have developed their own experimental correlation with the use of mathematical statics principals and with a selection of the model's parameters with Quasi-Newton and simplex methods. $h_{TPavg}= 19.092 \times \left(\frac{G\times D}{\mu l}\right)^{0.258} \times Prl^{-0.495} \times Pr^{-0.288} \times \frac{k}{D}$
3) *Park et al Correlation (2011):* Average heat transfer coefficient of Park et al correlation is obtained by Trapezoidal rule, $h_{TPavg} = \frac{L}{2}\ [(h_{TP1} + h_{TPn}) + 2\ (h_{TP1} + h_{TP2} + \cdots + h_{TP(n-1)})$

Where,
Average heat transfer coefficient = hTPavg (W/m^{2}K).
Interval = L
h_{TP1} , h_{TP2},…, h_{TP}(n-1) , h_{TP}(n) = values of hTP for a range of x from 0 to1 with interval of 0.01.

4) *K. W. Moser (1998):* The average Nusselt number can be denned as the average of the local values with respect to the length of the condenser tube:

$Nu_{avg} = \frac{1}{L}\int_0^l Nu\ dz$

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V. RESULT AND DISCUSSION

A. Local Heat Transfer Coefficient

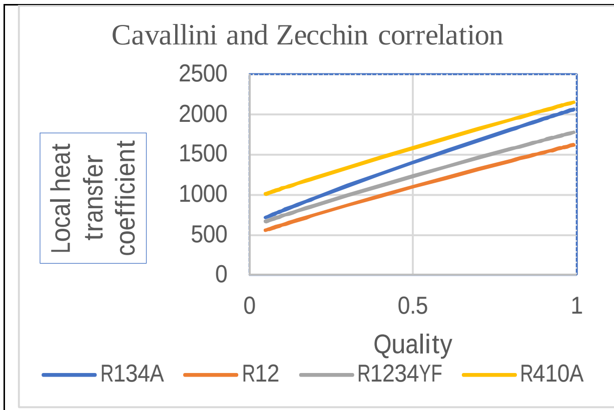

FIGURE 5.1- Local heat transfer coefficient of R12, R134a, R410a and R1234yf from Cavallini and Zecchin correlation at condensing temperature 45˚C

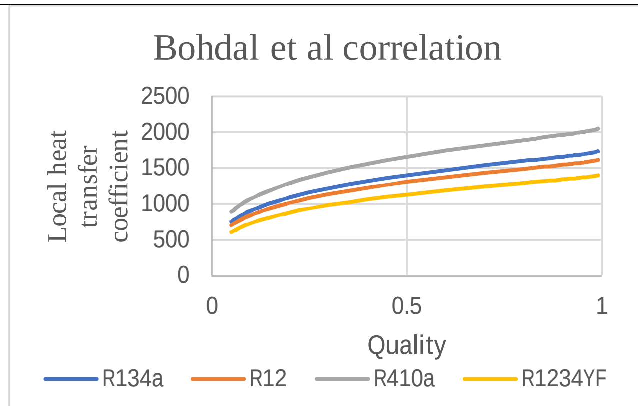

FIGURE 5.2- Local heat transfer coefficient of R12, R134a, R410a and R1234yf from Bohdal et al correlation at condensing temperature 45˚C

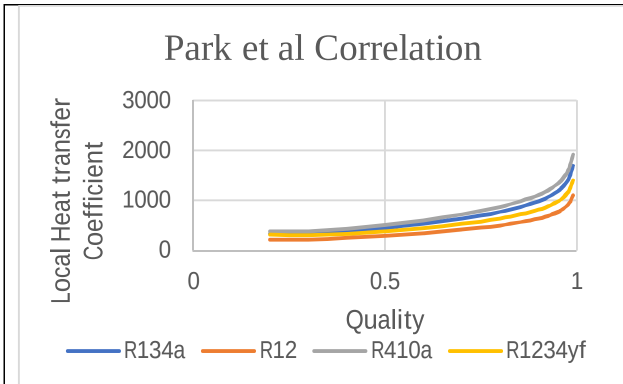

FIGURE 5.3- Local heat transfer coefficient of R12, R134a, R410a and R1234YF from Park et al Correlation at condensing temperature 45˚C

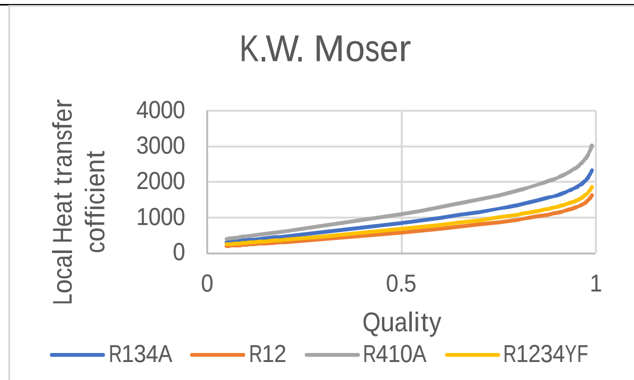

FIGURE 5.4- Local heat transfer coefficient of R12, R134a, R410a and R1234YF from K. W. Moser at condensing temperature 45˚C

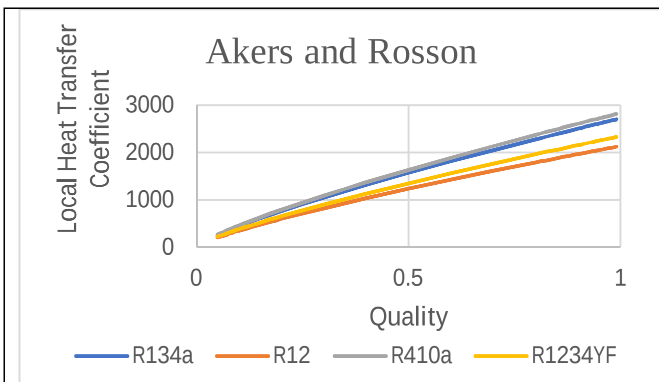

FIGURE 5.5- Local heat transfer coefficient of R12, R134a, R410a and R1234yf from Akers and Rosson at condensing temperature 45˚C.

Figure 5.1, Figure 5.2, Figure 5.3, Figure 5.4, Figure 5.5 shows the local heat transfer coefficient of R12, R134a, R1234YF and R410a using Cavallini and Zecchin, Bohdal, Park and Huang correlation,K.W. Moser and Akers and Rosson at condensing temperature 45˚C. Cavallini and Zecchin.

As the quality increases, local heat transfer coefficient also increases upto 0.95. After 0.95 quality behaviour of local heat transfer coefficient change for the four refrigerants. Cavallini and Zecchin and Akers and Rosson correlation shows the linear increment. While Bohdal, Park and Huang and K.W. Moser correlation shows sudden increament in local heat transfer coefficient for three refrigerant after 0.95 quality.

B. Average Heat Transfer Cofficient

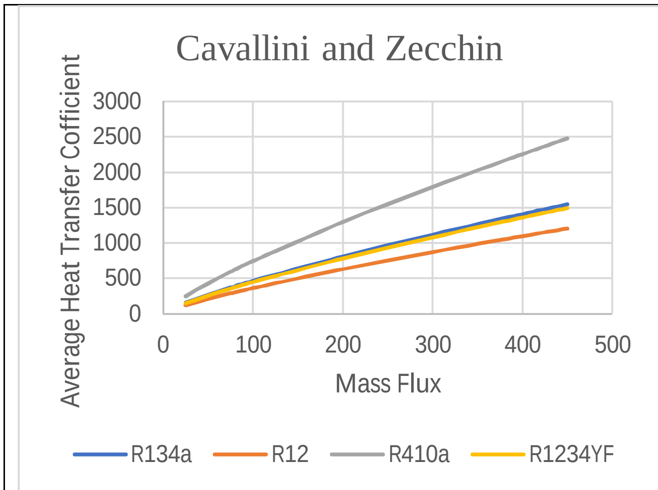

FIGURE 5.6- Average heat transfer coefficient of R12, R134a, R410a and R1234yf from Cavallini and Zecchin correlation at condensing temperature 45˚C

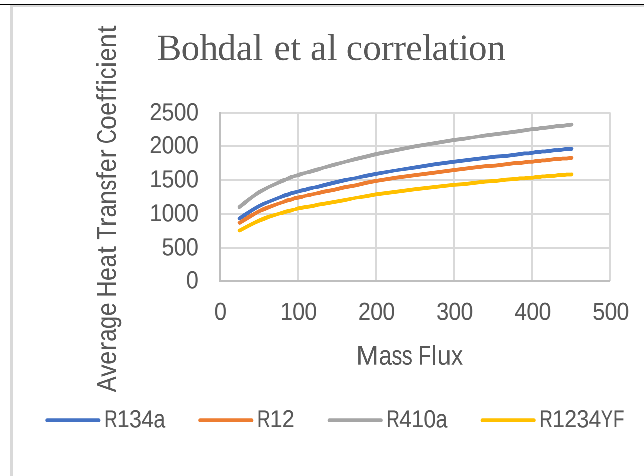

FIGURE 5.7- Average heat transfer coefficient of R12, R134a, R410a and R1234yf from Bohdal et al correlation at condensing temperature 45˚C

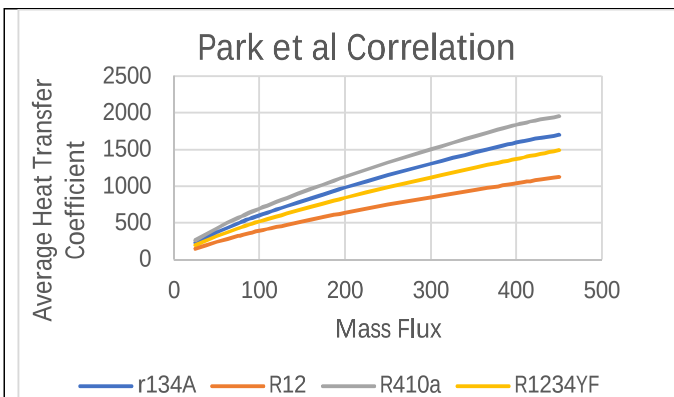

FIGURE 5.8- Average heat transfer coefficient of R12, R134a, R410a and R1234yf from Park et al Correlation at condensing temperature 45˚C

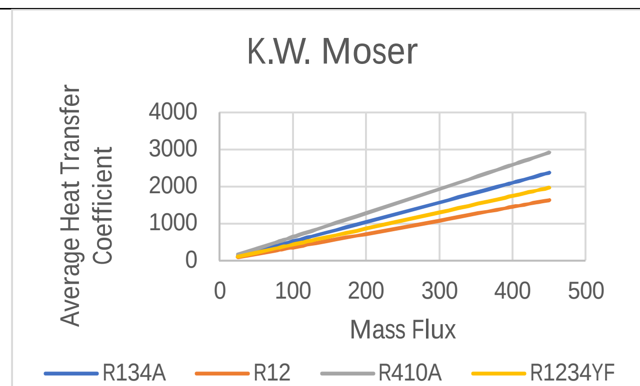

FIGURE 5.9- Average heat transfer coefficient of R12, R134a, R410a and R1234yf from K. W. Moser at condensing temperature 45˚C

Figure 5.6, Figure 5.7, Figure 5.8, Figure 5.9 shows the average heat transfer coefficient of R12, R134a, R1234YF and using Cavallini and Zecchin, Bohdal, Park and Huang correlation, K.W. Moser and Akers and Rosson correlation at condensing temperature 45˚C.

As the mass flux increases average heat transfer coefficient also increases for the all the four refrigerants. for all correlations. Cavallini and Zecchin correlation shows the average heat transfer coefficient of R410a is higher than R134a,R1234yf and R12 while Park et al shows the average heat transfer coefficient of R134a is higher than R410a,R1234yf and R12.

VI. CONCLUSION

A. Average heat transfer coefficient for R-12, R-134a, R410a and R-1234yf increases as the mass flux increases for all the correlations.

B. Cavallini & Zecchin, Bohdal correlation,Park Correlation, K.W. Moser and Akers and Rosson predicts local and average heat transfer coefficient for R-410a is higher than R-134a and R-12.

C. Cavallini & Zecchin, Bohdal correlation,Park Correlation, K.W. Moser and Akers and Rosson predicts local and average heat transfer coefficient for R-1234yf is higher than R-12 but lower than R134a.

D. Local heat transfer coefficient shows different behaviour for three refrigerants after 0.95 dryness fraction-
-Cavallini and Zecchin, Bohdal and Akers and Rosson correlation shows linear increment.
-Park and Moser correlation shows sudden increment.

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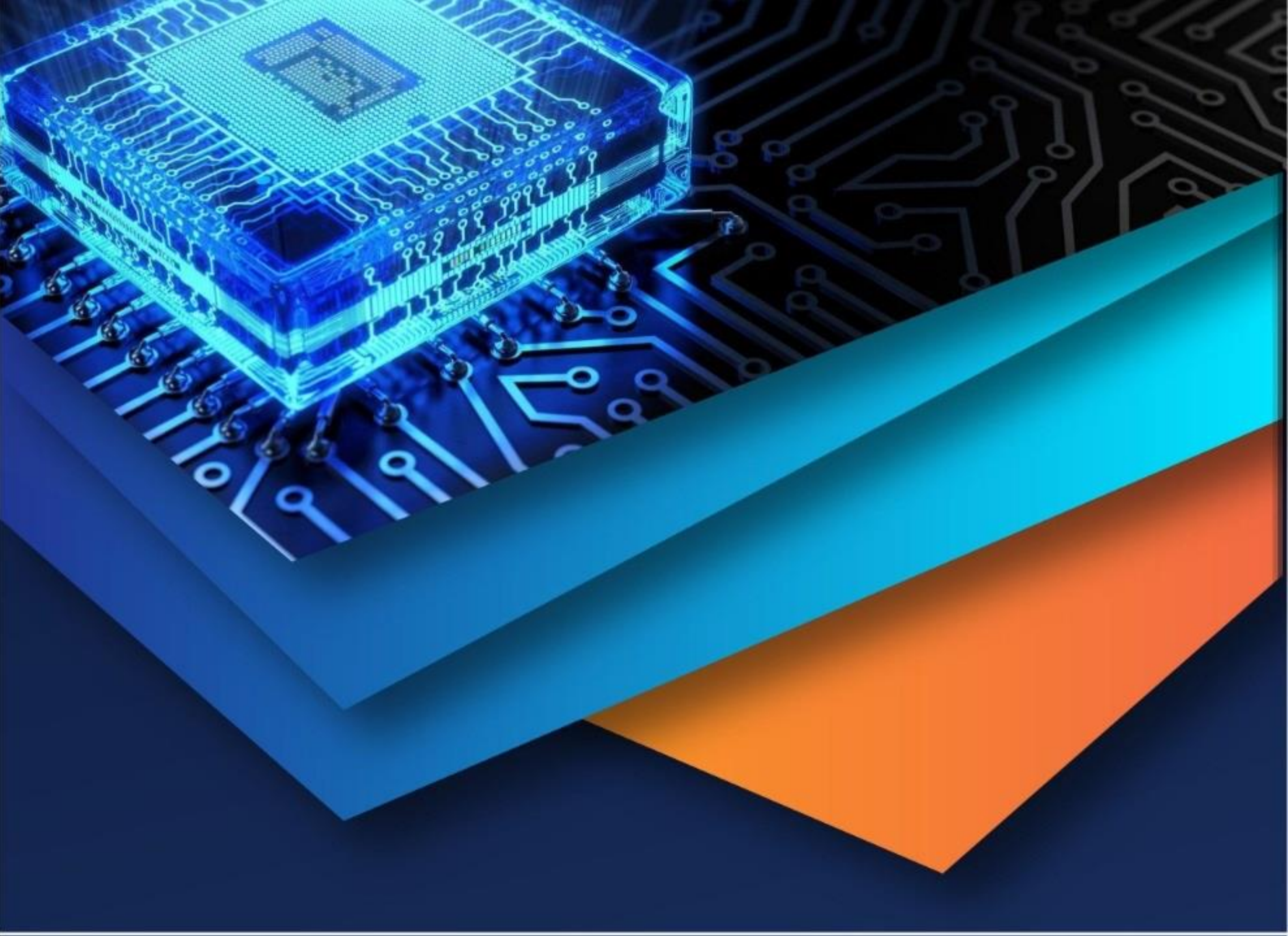

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