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Performance Enhancement of Domestic Refrigerator Using Hydrocarbon Mixture R-436A as Refrigerant

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Abstract: Domestic refrigerators use R-12 and R-134a as refrigerants because these gases have excellent thermodynamic properties. According to MONTREAL and KYOTO protocols, R-12 should have been phased out by 2010 and the consumption of R-134a must be reduced. The reason for R-12 phase out is its Ozone Depletion Potential (ODP) effect, and for R-134a reduction is its high Global Warming Potential (GWP) effect of 1300. From the environmental, ecological and health point of view, it is urgent to find some better substitute for HFC refrigerants. Many researchers have reported that hydrocarbon mixtures are found to be environment friendly alternative refrigerants.

In the present work, a hydrocarbon mixture refrigerant R-436a (a mixture of R-290 and R-600a with a mass ratio of 56/44) is used as an alternative to R-134a in domestic refrigerator of 165 L capacity without any modification in refrigeration cycle. Results showed that in comparison to refrigerant R-134a the refrigerator working with refrigerant R-436a has improvement in COP and energy consumption is reduced with no load and load performances.

I. INTODUCTION

Vapor compression-based systems are generally employed in refrigeration, air-conditioning and heat pump units. During the last century, the halogenated refrigerants have dominated the vapor compression based systems due to its good thermodynamic and thermo-physical properties. But, the halogenated refrigerants are having poor environmental properties with respect to ozone depletion potential (ODP) and global warming potential (GWP). The international protocols (Montreal and Kyoto) restrict the use of the halogenated refrigerants in the vapor compression based refrigeration systems.

In this paper, a hydrocarbon mixture refrigerant R-436a (a mixture of R-290 and R-600a with a mass ratio of 56/44) is used as an alternative to R-134a in domestic refrigerator of 165 L capacity without any modification in refrigeration cycle. Results showed that in comparison to refrigerant R-134a the refrigerator working with refrigerant R-436a has improvement in COP and energy consumption is reduced with no load and load performances.

1.R-290- PROPANE - C_3H_8 2.R-600a - ISOBUTANE (2-Methylpropane) – C_4H_{10}

II. EXPERIMENTAL PROCEDURE

The vapor compression system is initially cleaned and the evacuation of the system is carried out with the help of a vacuum pump for nearly 30 min and then the refrigerant is charged into the system.

Initially the system is charged with refrigerant **R-134a** and then the following tests were carried out.

A. For Pull-Down Characteristics

The pull-down period is the time required to reduce the air temperature inside the refrigerator from ambient condition to the desired cabin air temperature (i.e., $+7^0$C average cabinet temperature) after switching on the unit.

1) *Procedure:* Initially the refrigerator door is kept open until the evaporator cabin attains the environment temperature and then it is closed and system is switched ON to run. System is kept for running condition until required temperature is attained. After attaining required temperature the system is switched OFF. Time taken by the system to get to required temperature is noted. Energy meter readings also noted from starting to off conditions.

B. No Load Performance

In no load performance the refrigerator is switched on and kept in running condition without placing any type of load inside the cabin until the steady state conditions are attained and then the readings are noted for calculating the COP of the system and system is switched off.

1) *Procedure:* Initially the system is switched ON. The system is kept in running condition continuously to obtain steady state conditions. After attaining steady state conditions the pressure gauge and temperature readings are noted as shown in tables. Energy meter readings also noted down and then system is switched OFF. COP calculations are made from the obtained values using p-h chart of the refrigerants as shown in figures**.**

C. Load Performance

In load performance the refrigerator is loaded by arranging a bulb having capacity of 60 watts inside the evaporator cabin and the system is switched on and kept in running condition until the steady state conditions are attained and then the readings are noted for calculating the COP of the system and system is switched off.

1) *Procedure:* Initially the system is switched ON. After some time a 60W capacity incandescent bulb is placed inside the evaporator cabin and switched on for loading the system. The system is kept in running condition continuously for obtaining steady state conditions. After attaining steady state conditions the pressure gauge and temperature readings are noted as shown and bulb is switched off. Energy meter readings also noted down and then system is switched OFF. COP calculations are made from the obtained values using p-h chart of the refrigerants .

D. FROSTING AND DEFROSTING

For occurrence of frosting the system is switched on with a load of water in open trough is placed in the evaporator cabin and kept in continuous running condition for 72 hours and then the system is switched off. The system is allowed to defrost for certain period and the quantity of water is collected.

1) *Procedure:* Initially the load of 3litres of water is placed inside the cabin and then the system is switched ON. The system is kept in continuous running condition for 72 hours to allow for frosting of freezer.Then the system is switched OFF and allowed to defrost for some period. The defrosted water is collected and measured the quantity of water collected . After that the vapor compression test rig is evacuated and retrofitted with refrigerant **R-436a** and the above tests were carried out following the same procedure. Tabular columns from experimental procedure

Base line performance of domestic refrigerator using refrigerant **R-134a** with no load and with load:

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

Table.1

	With no load							With load						
	Pressure in bar		Temperature in (^{0}C)					pressure (in bar)		Temperature in (^{0}C				
	P_s	P_d	T_1	T_2	T_3	T_4	T_5	P_s	P_d	T_1	T_2	T_3	T_4	T_5
0	4.2	3.9	35.2	35.4	35.2	31.6	21.3	3.0	2.9	33.4	32.6	33.3	33.6	29.0
15	1.8	16.1	28.6	51.3	41.2	25.3	-9.7	1.2	15.2	28.2	50.3	40.3	33.4	-11.0
30	1.3	15.9	24.8	53.7	40.3	19.7	-13.6	1.25	15.9	24.5	53.7	40.9	31.9	-12.7
45	1.25	15.9	19.8	55.1	40.9	16.3	-14.6	1.25	15.9	23.4	55.4	40.7	30.9	-13.0
60	1.25	15.9	18.6	56.1	41.2	13.3	-15.1	1.20	16.0	23.1	56.4	41.3	30.2	-13.1
75	1.25	15.9	18.2	56.4	41.0	11.3	-15.5	1.20	16.0	23.1	56.9	41.5	30.0	-13.1
90	1.25	15.9	17.8	56.8	41.2	9.9	-15.6	1.20	16.0	22.8	57.3	41.5	30.1	-13.1
105	1.25	15.9	17.4	57.5	41.4	9.0	-15.8	1.20	16.2	22.5	57.7	41.4	30.2	-13.1
120	1.25	15.9	17.3	57.8	41.3	8.4	-16.0	1.20	16.2	22.4	55.4	41.4	30.1	-13.2
135								1.20	16.2	22.3	54.9	41.4	30.2	-13.2
150								1.20	16.2	22.4	54.7	41.3	30.1	-13.2

Performance of domestic refrigerator using refrigerant **R-436a** with no load and with load: TABLE 2

	With no load							With load						
	Pressure in bar		Temperature in (^{0}C)					pressure (in bar)		Temperature in (^{0}C				
	P_s	P_d	T_1	T_2	T_3	T_4	T_5	P_s	P_d	T_1	T_2	T_3	T_4	T_5
0	4.2	3.9	35.2	35.4	35.2	31.6	21.3	3.0	2.9	33.4	32.6	33.3	33.6	29.0
15	1.8	16.1	28.6	51.3	41.2	25.3	-9.7	1.2	15.2	28.2	50.3	40.3	33.4	-11.0
30	1.3	15.9	24.8	53.7	40.3	19.7	-13.6	1.25	15.9	24.5	53.7	40.9	31.9	-12.7
45	1.25	15.9	19.8	55.1	40.9	16.3	-14.6	1.25	15.6	23.4	55.4	40.7	30.9	-13.0
60	1.25	15.9	18.6	56.1	41.2	13.3	-15.1	1.20	16.0	23.1	56.4	41.3	30.2	-13.1
75	1.25	15.9	18.2	56.4	41.0	11.3	-15.5	1.20	16.0	23.1	56.9	41.5	30.0	-13.1
90	1.25	15.9	17.8	56.8	41.2	9.9	-15.6	1.20	16.0	22.8	57.3	41.5	30.1	-13.1
105	1.25	15.9	17.4	57.5	41.4	9.0	-15.8	1.20	16.2	22.5	57.7	41.4	30.2	-13.1
120	1.25	15.9	17.3	57.8	41.3	8.4	-16.0	1.20	16.2	22.4	55.4	41.4	30.1	-13.2
135								1.20	16.2	22.3	54.9	41.4	30.2	-13.2
150								1.20	16.2	22.4	54.7	41.3	30.1	-13.2

Where, T_1, T_2 = Compressor inlet and outlet temperature

T_3 = Condenser outlet temperature

T_4 = Evaporator cabin temperature

T_5 = Evaporator freezer temperature

Operating pressures (absolute) of refrigerants **R-134a** and **R-436a**:

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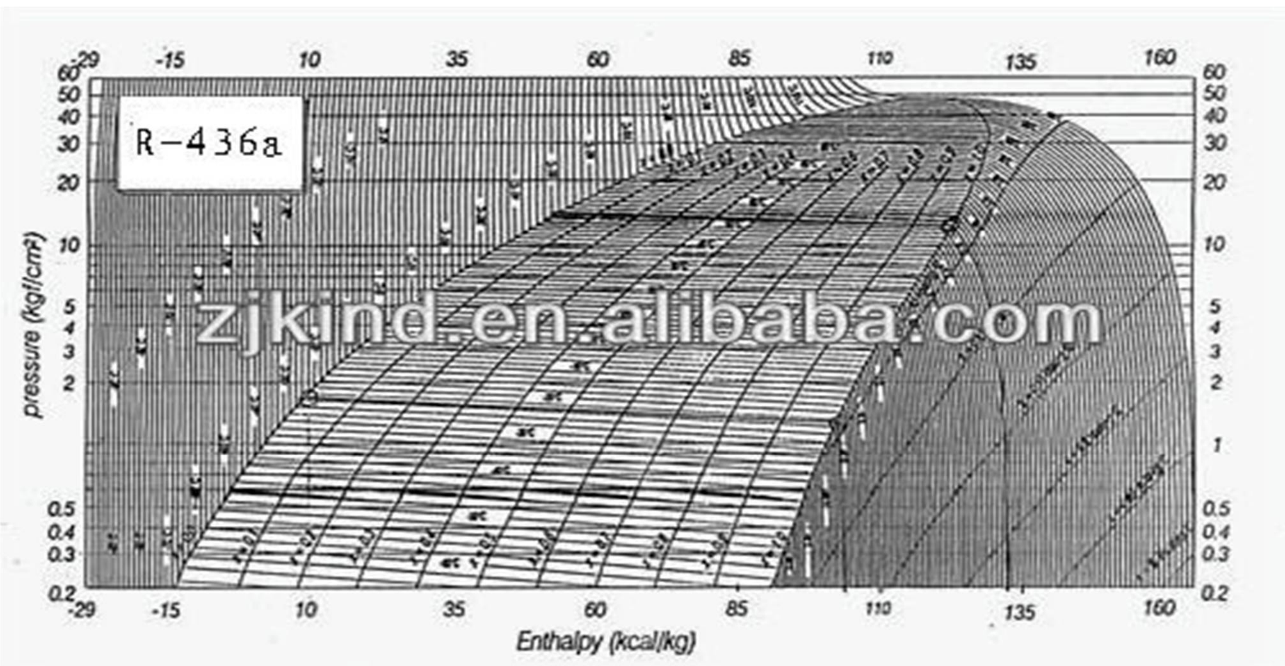
Table.3

Refrigerant	Compressor inlet pressure (in bar)		Compressor outlet pressure (in bar)		Pressure ratio	
	With no load	With load	With no load	With load	With no load	With load
R-134a	1.6635	1.5635	14.8135	14.2135	8.9050	9.0908
R-436a	2.2635	2.2135	16.9135	17.2135	7.4723	7.7766

III. RESULTS, DISCUSSIONS & GRAPHS

From **p-h** chart of refrigerant **R-436a** as shown in figure, we find the enthalpy values at state points 1, 2, 3&4

P-h chart of refrigerant R-436a



Where,

h_1, h_2 = Enthalpy value of refrigerant at compressor inlet and outlet.

h_3 = Enthalpy value of refrigerant at condenser outlet.

h_4 = Enthalpy value of refrigerant at evaporator inlet.

The following are calculated,

IV. CALCULATIONS

A. Refrigerating effect of a domestic refrigerator is calculated by using formula, R.E = h_1-h_4 in kJ/kg

B. Work done by the compressor of a domestic refrigerator is calculated by using formula, W.D = h_2-h_1 in kJ/kg The calculated values of R.E and W.D are shown in **tables**.

C. Coefficient of Performance of a domestic refrigerator is calculated by using formula, COP = RE / WD = h_1-h_4 / h_2-h_1

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Calculated performance parameters of new proposed refrigerant with no load and with load:

Table 4

Refrigerant	Compressor inlet temperature (^{0}C)		Actual compressor outlet temperature (^{0}C)		Isentropic compressor outlet temperature (^{0}C)		Compressor work (kJ/kg)		Refrigerating effect (kJ/kg)	
	With no Load	with load	With no Load	with load	With no Load	with load	With no Load	with load	With no Load	with load
R-134a	20.9	20.6	62.4	69.8	107	132	78	93	165	167
R-436a	17.3	22.4	57.8	54.7	86	94	100.46	104.6	257.43	292.25

Energy consumption values: TABLES 5

Refrigerant	Energy consumption in kWh			
	For pull down time	For no load performance	For load performance	For frosting
R-134a	0.55	0.3	0.35	6.5
R-436a	0.48	0.25	0.28	9.6

A. Summary of results

1) Pull-down time of domestic refrigerator using refrigerant R-134a is 132 minutes and R-436a is 165 minutes.
2) COP of a domestic refrigerator with no load using refrigerant R-134a is 2.115 and R-436a is 2.563
3) COP of a domestic refrigerator with load using refrigerant R-134a is 1.795 and R-436a is 2.793
4) Defrosting water collected using R-134a is 220 ml and R-436a is 230 ml.
5) Energy consumed by domestic refrigerator for pull-down period using
6) R-134a is 0.55 kWh and R-436a is 0.42 kWh.
7) Energy consumed by domestic refrigerator for no load performance using
8) R-134a is 0.3 kWh and R-436a is 0.25 kWh.
9) Energy consumed by domestic refrigerator for load performance using
10) R-134a is 0.35 kWh and R-436a is 0.28 kWh.
11) Energy consumed for frosting of domestic refrigerator using R-134a is 6.5 kWh and R-436a is 9.6 kWh.

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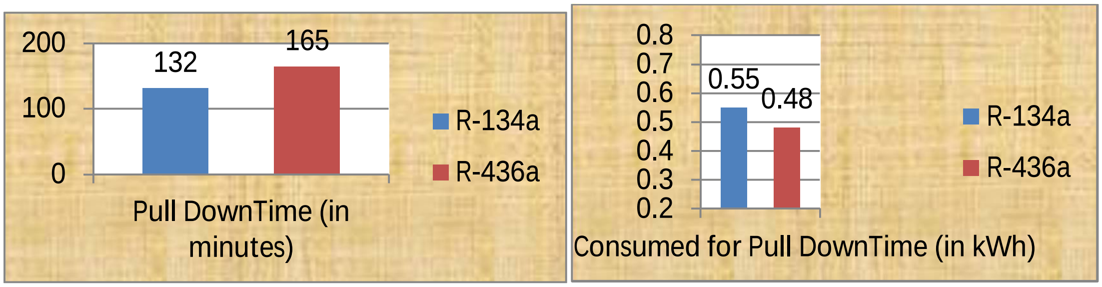
V. GRAPHS

The following graphs have been plotted for various performance parameters of vapor compression domestic refrigerator by using refrigerant **R-436a** in comparison to refrigerant **R-134a**

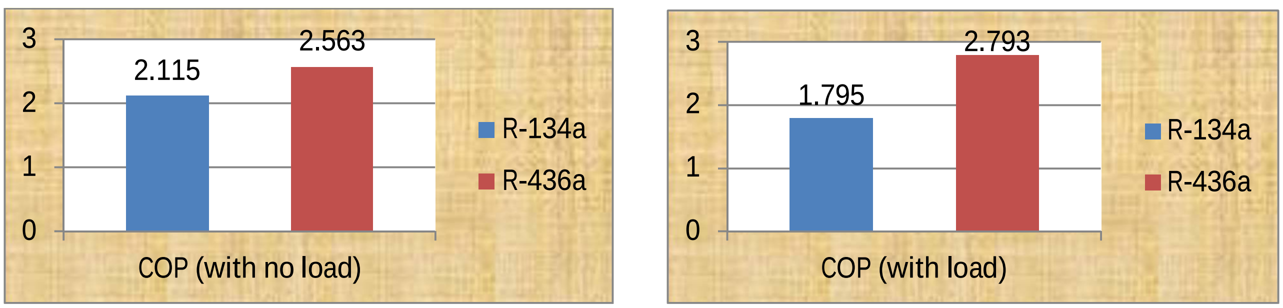
GRAPH -1



Graph 1: Pull down time of R-134a and R-436a

From Graph 1, it is observed that pull-down time of domestic refrigerator by using refrigerant R-436a is higher as compared to that of refrigerant R-134a by about 25%. From Graph 5, it is observed that energy consumed for pull-down period of domestic refrigerator by using refrigerant R-436a is lower as compared to that of refrigerant R-134a by about 23.6% which is reflected by better COP.

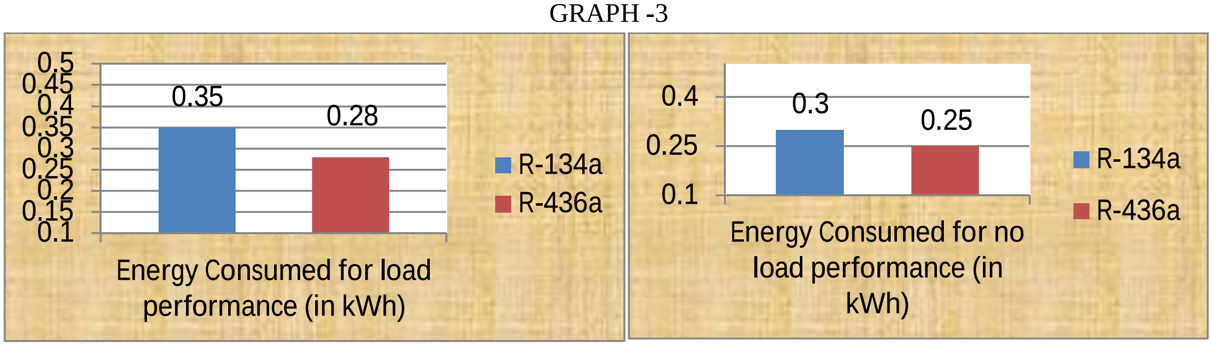
GRAPH -2



Graph2: COP of R-134a and R-436a with no load and with load

From Graph 2, it is observed that COP of domestic refrigerator by using refrigerant R-436a is higher as compared to that of refrigerant R-134a with no load is about 21.2% and with load is about 55.6% because as load is increased the refrigerating effect of the system also increases.

GRAPH -3



Energy consumed for no load and load performance of R-134a and R-436a

From Graph 3, it is observed that energy consumed by domestic refrigerator for no load and with load performance by using refrigerant R-436a is lower as compared to that of refrigerant R-134a by with no load is about 16.7% and with load is about 20%.

VI. CONCLUSIONS

Experiments have been devised and conducted to ascertain the suitability of retrofitting of a domestic refrigerator by changing the refrigerant **R-134a** by **R-436a**.

The following conclusions are drawn:

A. The pull-down characteristics show that R-436a system is higher than R-134a system by 25% and the energy consumed is lowered by 23.6% compared with R-134a.

B. At no load conditions the COP of R-436a system is higher than R-134a system by 21.2% and energy consumption has got reduced by 16.7%.

C. With load the performance of R-436a system is found to increase of COP higher than R-134a by 55.6% subsequently the energy is also consumed lower by 20%.

D. The frost collection is found to be higher by 4.5% for R-436a system since it has shown better cooling characteristics. As such the energy consumption also is higher by 47.7%. Showing that frosting is adverse to the performance of R-436a system.

E. The compressor of the system is compatible with refrigerant R-436a which is primarily designed to work with refrigerant R-134a. The operating pressure ratios of R-436a system are lower than R-134a system. It is recommended that R-436a can be retrofitted for domestic refrigerator with R-134a by proper defrosting methods.

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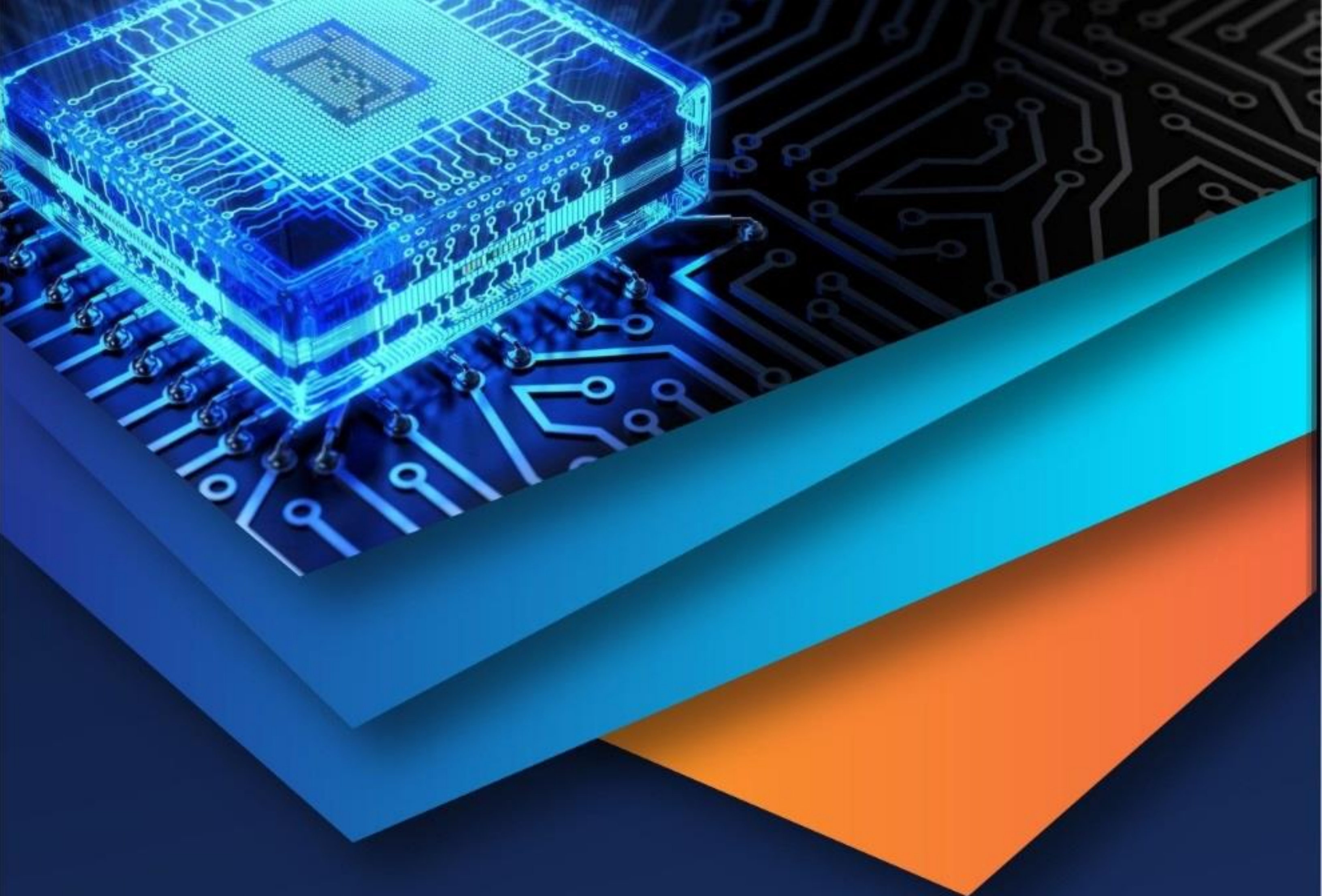

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