iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 5 **Issue:** VI **Month of publication:** June 2017

DOI:

Volume 5 Issue VI, June 2017
ISSN: 2321-9653
International Journal for Research in Applied Science & Engineering Technology (IJRASET)

Generation of Biogas and Enhancing its Methane Content by Chemical Absorption Technique

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Abstract**: In this paper we will discuss India's existing biogas potential as a substitute to fossil fuels for domestic purpose. In the second part of the paper we will discuss the technique of upgrading the biogas using a chemical absorption technique for use in S.I engines as a substitute to compressed natural gas. A huge quantity of bio waste is generated in housing societies in metropolitan cities. Conversion of bio waste into biogas would result in localized municipal solid waste (MSW) management reducing the cost of transportation, eliminating the need of empty spaces for dumping grounds and also presenting an alternative source of fossil fuels. For experimentation, biogas was produced in a floating drum digester tank from daily produced kitchen waste and then with the chemical absorption technique using sodium carbonate (Na_2CO_3) as the scrubbing liquid, biogas was upgraded to bio-methane. The outcomes of the experiment was a combustible biogas consisting of 44.14% CO_2, 53.19% CH_4 and traces of other gases with a calorific value of 21180.25kJ/kg which when upgraded had around 88.39% methane and 8.05% carbon dioxide with a calorific value of 35196.89kJ/kg.
***Keywords**: Bio-waste, Biogas, Municipal solid waste, fossil fuels, Upgrading, Sodium carbonate, bio-methane.*

I. INTRODUCTION

Rapid urbanization and industrial growth puts the limited energy resources of developing countries under pressure resulting in the augmentation of new and existing renewable energy options. Dependency on thermal power plants for energy requirements causes depletion of fossil fuel reserves of the country and associated emissions of greenhouse gases into the atmosphere. A greenhouse emission further causes global warming, climatic changes and damage to human and animals respiratory systems[1]. Specifically in India, the current energy scenario reveals a wide gap between the supply and demand of energy. Three-quarters of India energy demand is met by fossil fuels[2]. It becomes extremely essential to explore the unearthed and untouched renewable energy reserves of the country in an organized way. This will decrease the dependency on fossil fuel imports and improve the energy economy of the country. In India, there is tremendous potential of renewable energy like solar, wind, biomass, biogas, tidal energy etc. As of 30 April 2017, the country's solar grid had a cumulative capacity of 12.50 GW, wind power grid had a cumulative capacity of 32.28 GW, small hydro plants had a cumulative grid capacity of 4.38 GW, biomass had a cumulative grid power capacity of 8.18 MW and biogas had a cumulative off grid capacity of 49.56 MW [3]. There is huge potential of waste to energy conversion in India. Around 30 million tons of solid waste and 4400 cubic meters of liquid waste is produced in India every year. The municipal solid waste (MSW) generation range is from 0.25 to 0.66 kg/person/day with an average of 0.45 kg/person /day [4]. With proper segregation and organized channelling, all these waste can be converted to useful biogas which is a potential substitute to LPG useful for cooking and water heating. In this paper we will discuss the biogas generation process in a floating type digester tank installed at Rajiv Gandhi Institute of technology and in the second part we will discuss the methodology of upgrading the biogas using chemical absorption technique. Upgraded biogas is an alternate for CNG and when compressed to a pressure of 200bar can be directly used to propel IC engines [5].

Paper is organized as follows. Section II describes biogas generation process in a floating drum digester tank using food waste. Biogas generated can be used directly in cooking stove and for water heating purpose. Raw biogas has a low calorific value for its use in engines. Section III describes the process of biogas scrubbing using solution of sodium carbonate. The complete setup will be discussed in this section. Biogas obtained after scrubbing is enhanced in methane content. Section IV presents experimental results showing graphs for raw and upgraded biogas obtained by gas chromatography technique. Finally, Section V presents conclusion.

II. GENERATION OF BIOGAS

Biogas consists of 50-70% methane, 30-45% carbon dioxide, traces of water vapor and hydrogen sulfide [6]. The process of anaerobic digestion converts food waste to biogas as shown in fig 1.Anaerobic digestion of organic waste in a digester tank takes place in four key stages biogas namely hydrolysis, acidogenesis, acetogenesis and methanogenesis. The overall process can be

Volume 5 Issue VI, June 2017
ISSN: 2321-9653
International Journal for Research in Applied Science & Engineering Technology (IJRASET)

described by the chemical reaction, where organic material such as glucose ($C_6H_{12}O_6$) is biochemically digested into carbon dioxide (CO_2) and methane (CH_4) by the anaerobic microorganisms.

$$C_6H_{12}O_6 \rightarrow 3CO_2 + 3CH_4$$

A. Hydrolysis

In most cases, biomass is made up of large organic polymers. For the bacteria in anaerobic digesters to access the energy potential of the material, these chains must first be broken down into their smaller constituent parts. These constituent parts, or monomers, such as sugars, are readily available to other bacteria. The process of breaking these chains and dissolving the smaller molecules into solution is called hydrolysis.

B. Acidogenesi

The biological process of acidogenesis results in further breakdown of the remaining components by acidogenic bacteria. Here, VFAs are created, along with ammonia, carbon dioxide, and hydrogen sulphide, as well as other byproducts.

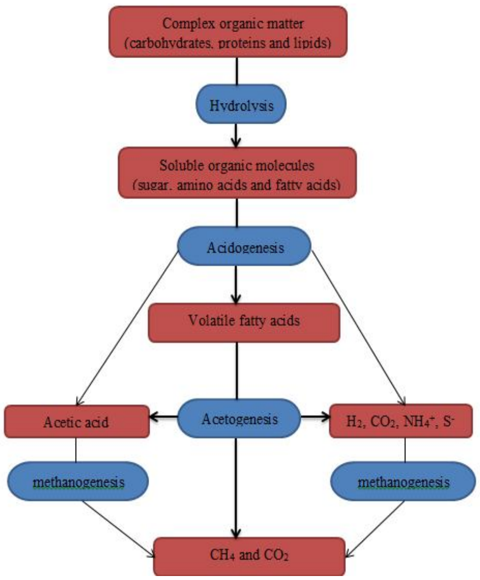

Fig.1 Stages of anaerobic digestion [7]

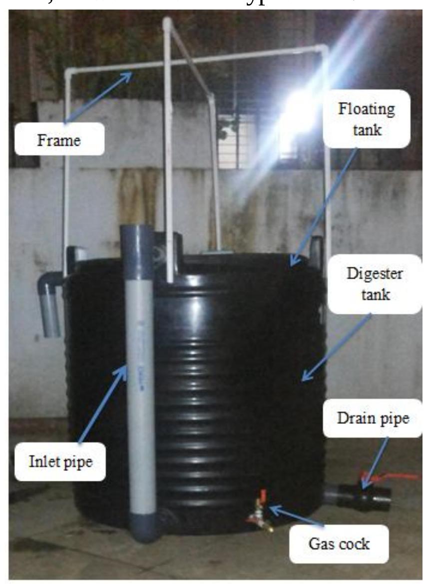

Fig.2 Biogas digester tank setup

C. Acetogenesis

The third stage of anaerobic digestion is acetogenesis. Here, simple molecules created through the acidogenesis phase are further digested by acetogens to produce largely acetic acid, as well as carbon dioxide and hydrogen.

D. Methanogenesis

The terminal stage of anaerobic digestion is the biological process of methanogenesis. Here, methanogens use the intermediate products of the preceding stages and convert them into methane, carbon dioxide, and water. These components make up the majority of the biogas emitted from the system. Methanogenesis is sensitive to both high and low pHs and occurs between pH 6.5 and pH 8. The remaining, indigestible material the microbes cannot use and any dead bacterial remains constitute the digestate [7].
We use to feed 1 cubic meter biogas digester tank with 4 kg of food waste on daily basis which used to produce about 400gms of biogas with a burning time of approximately 90 min sufficient for cooking meals 2 times a day. This offsets the requirement of LPG for domestic purpose and also treats the kitchen waste locally.

III. BIOGAS UPGRADING

Carbon dioxide is second largest constituent in biogas after methane. Presence of carbon dioxide in the biogas reduces its thermal efficiency. So, removal of biogas is a must to make biogas a competitive renewable fuel by increasing its efficiency [8]. Different biogas scrubbing techniques such as pressure swing adsorption, temperature swing adsorption, water scrubbing, air separation units and many other absorption techniques using amines and alcohols for absorption have been studied and reviewed subject to various operating parameters. On comparison water scrubbing proved to be a potential competitor for CO_2 scrubbing but the problem was the regeneration of scrubbed water which carried dissolved CO_2 and also the system had high pressure requirements. This shortcoming was given due consideration and use of aqueous solution of Na_2CO_3 was considered as a potential solution to the problem of regeneration. The different parameters for design consideration of the scrubbing unit are working pressure, tower packing, height and diameter of the packed bed. The experimental setup for scrubbing of biogas generated in the biogas digester is shown in Fig.3 The technique is based on the principle of adsorption of CO_2 by counter current flow of biogas in a packed bed column with the scrubbing sodium carbonate (Na_2CO_3) liquid travelling downward which is then collected in a separate tank.

Fig 3Setup for biogas scrubbing

Upgraded biogas had increased content of methane and reduced content of carbon dioxide, hydrogen sulfide and traces of other gases. With the use of sodium carbonate for scrubbing, affinity of CO_2 to water increases even at low pressure. The setup was completed in the premises of Rajiv Gandhi Institute of technology and the test results for biogas composition before and after upgrading were obtained by conducting a test on a gas chromatography machine. The test results are discussed in section IV.

IV. RESULTS AND DISCUSSIONS

First the raw biogas sample was tested for its composition and after knowing the composition the calorific value of the gas was computed. Similarly the values for composition and calorific value were computed for upgraded biogas. The peak height versus time plot for the calibrated gas, raw biogas and upgraded biogas is shown in fig.4, fig.5 and fig.6 respectively. After obtaining the area under the graph for the three samples we were able to calculate the composition of methane and carbon dioxide in the biogas by the method of normalizing and thus able to find its calorific value.

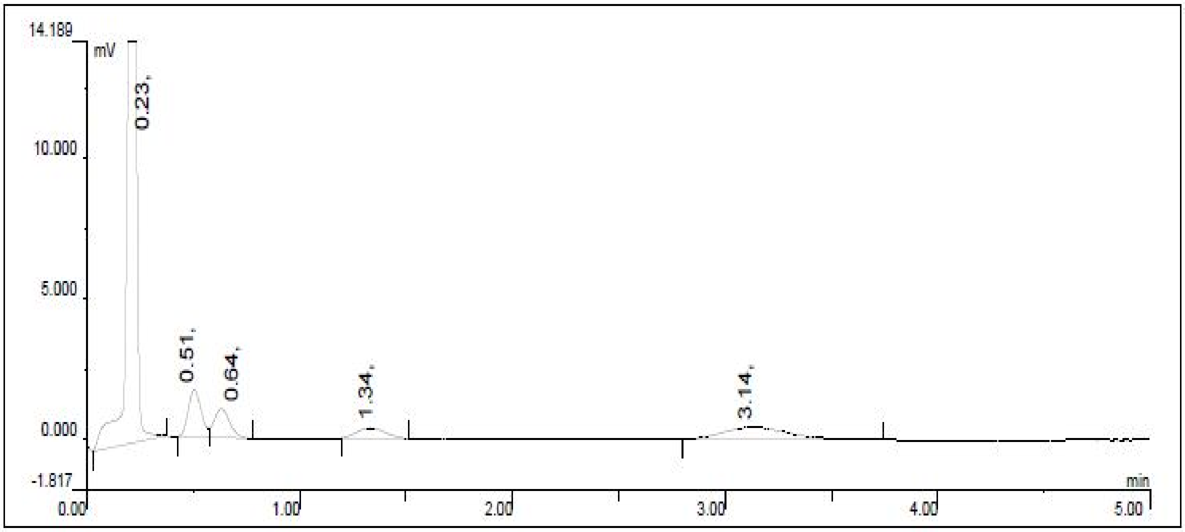

Fig.4 Peak Diagram of different constituent gases of calibration mixture.

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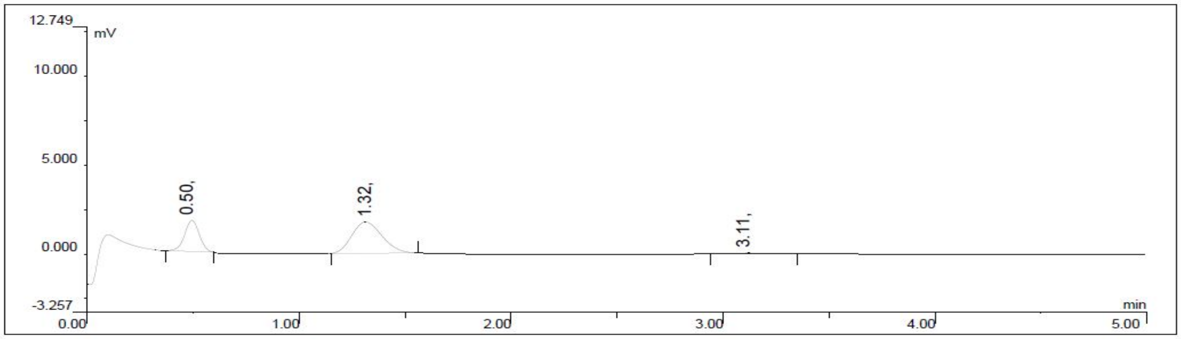

Fig.5 Peak Diagram of different constituent gases of raw biogas

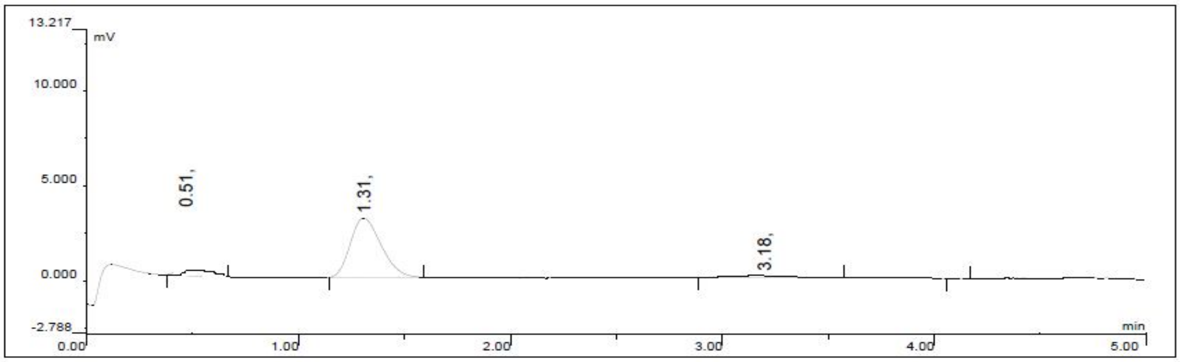

Fig.6 Peak Diagram of different constituent gases of upgraded biogas

Table I shows the result of percent area for each constituent gas present in the calibrated mixture.. The readings thus obtained can be used as a reference for the actual sample of the gas to be tested. Table II shows the area under the curve for different gases and it is clearly evident that the maximum area is for CH_4 followed by CO_2 and N_2. This data can be used to determine the percentage of each constituent gas present in raw biogas by comparing it with the area of the same constituent gas in the calibrated mixture and then normalizing the values to get the required values. Table III clearly shows variation in areas for raw and upgraded biogas. The peak height of CO_2 is almost negligible meaning very less percentage of CO_2 presence in this sample of biogas which subsequently means a higher calorific value of the fuel.

Table I
area%, height % for calibrated mixture containing h_2, co_2, co, ch_4 and n_2

Sr No.	Component Name	Ret. Time.	Area µ Volt Sec	Area %	Height µ Volt	Height %
1	Hydrogen	0.23	86608.7429	77.15	38280	91.58
2	Carbon Dioxide	0.51	7237.7649	6.45	1680	4.02
3	Carbon Monoxide	0.64	5293.3850	4.72	1022	2.45
4	Methane	1.34	3492.3429	3.11	377	0.90
5	Nitrogen	3.14	9627.5429	8.58	440	1.05
			112259.7785	100.00	41800	100.00

Table ii

area%, height % for raw biogas containing co_2 and ch_4

Sr. No.	Component Name	Ret. Time.	Area µ Volt Sec	Area %	Height µ Volt	Height %
1	Carbon-dioxide	0.50	6377.915	24.07	1754	49.36
2	Methane	1.32	19564.085	73.86	1760	49.52
3	Nitrogen	3.11	544.3429	2.06	40	1.13
			26486.8000	100.00	3554	100.00

Table iii

Area%, height % for upgraded biogas containing co_2 and ch_4

Sr. No.	Component Name	Ret. Time.	Area µ Volt Sec	Area %	Height µ Volt	Height %
1	Carbon-dioxide	0.51	1670.4685	3.38	112	1.70
2	Methane	1.31	46709.0744	94.51	3137	47.45
3	Nitrogen	3.18	1042.77	2.11	108	1.64
			49422.3129	100.00	6611	100.00

MASS COMPOSITION AND CALORIFIC VALUE OF RAW AND UPGRADED BIOGAS

Normalizing method to determine percentage composition of constituent gases of raw biogas as the calibrated mixture consists of hydrogen and carbon monoxide which are not present in the raw biogas. The terminology used and normalizing method adopted is explained as follows.

A. Terminology

$X_{\text{carbon-dioxide}}$ » Percentage composition of CO_2 in raw biogas
X_{methane} » Percentage composition of CH_4 in raw biogas
X_{nitrogen} » Percentage composition of N_2 in raw biogas
$Y_{\text{carbon-dioxide}}$ » Percentage composition of CO_2 in upgraded biogas
Y_{methane} » Percentage composition of CH_4 in upgraded biogas
Y_{nitrogen} » Percentage composition of N_2 in upgraded biogas
A » Percentage area of CO_2 in raw biogas
B » Percentage area of CH_4 in raw biogas
C » Percentage area of N_2 in raw biogas
A_u » Percentage area of CO_2 in upgraded biogas
B_u » Percentage area of CH_4 in upgraded biogas
C_u » Percentage area of N_2 in upgraded biogas
$C_{\text{carbon dioxide}}$ » Calibration cylinder constant for CO_2
C_{methane} » Calibration cylinder constant for CH_4
C_{nitrogen} » Calibration constant for N_2

B. Normalizing

Percentage of CO_2 in raw biogas ($X_{\text{carbon-dioxide}}$)

$$A = \frac{6377.915}{7237.7649} \times (C_{\text{carbon dioxide}})$$

$A = \frac{6377.915}{7237.7649} \times (26.01)$

$A = 22.92$

$X_{\text{carbon-dioxide}} = \frac{A}{A+B+C}$

$X_{\text{carbon-dioxide}} = 44.14\%$

Percentage of CH_4 in raw biogas (X_{methane})

$B = \frac{19564.085}{3492.3429} \times (4.93)$

$B = 27.6178$

$X_{\text{methane}} = \frac{B}{A+B+C}$

$X_{\text{methane}} = 53.19\%$

Percentage of N_2 in raw biogas (X_{nitrogen})

$C = \frac{544.3429}{9627.5429} \times (C_{\text{nitrogen}})$

$C = \frac{544.3429}{9627.5429} \times (24.5)$

$C = 1.38$

$X_{\text{nitrogen}} = \frac{C}{A+B+C}$

$X_{\text{nitrogen}} = 2.67\%$

Calorific Value of Raw biogas:

$C.V_{\text{raw biogas}} = X_{\text{methane}} \times C.V \text{ of } CH_4$

$= 0.5319 \times 39820$

$C.V_{\text{raw biogas}} = 21180.258$ kJ/kg

Percentage of CO_2 in upgraded biogas ($Y_{\text{carbon-dioxide}}$):

$A_u = \frac{1670.4685}{7237.7649} \times (C_{\text{carbon dioxide}})$

$A_u = \frac{1670.4685}{7237.7649} \times (26.01)$

$A_u = 6.004$

$Y_{\text{carbon-dioxide}} = \frac{A}{A+B+C}$

$Y_{\text{carbon-dioxide}} = 8.05\%$

Percentage of CH_4 in Upgraded biogas (Y_{methane}):

$B_u = \frac{46709.0744}{3492.3429} \times (C_{\text{methane}})$

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ISSN: 2321-9653
International Journal for Research in Applied Science & Engineering Technology (IJRASET)

$B_u = \frac{46709.0744}{3492.3429} \times (4.93)$

$B_u = 65.93$

$Y_{\text{methane}} =$

$Y_{\text{methane}} = 8\frac{A}{A+B+C}8.39\%$

Percentage of N_2 in Upgraded biogas ($Y_{nitrogen}$):

$C_u = \frac{1042.77}{9627.5429} \times (C_{\text{nitrogen}})$

$C_u = \frac{1042.77}{9627.5429} \times (24.5)$

$C_u = 2.6536$

$Y_{\text{nitrogen}} = \frac{A}{A+B+C}$

$Y_{\text{nitrogen}} = 3.56\%$

Calorific Value of Upgraded biogas

$C.V_{\text{Upgraded biogas}} = Y_{\text{methane}} \times C.V \text{ of } CH_4$

$= 0.8839 \times 39820$

$C.V_{\text{Upgraded biogas}} = 35196.898$ kJ/kg

The percentage of CO_2, CH_4 and N_2 content in raw biogas was found to be 44.14%, 53.19% and 2.67% respectively. The calorific value of raw biogas obtained from biogas plant is determined to be 21180.25kJ/kg due to presence of excess CO_2. The concentration of CO_2 is reduced by upgrading the biogas and also its calorific value is increased. On upgrading the percentage composition of CH_4 increased to 88.39% and that of CO_2 was reduced to 8.05%. The calorific value of upgraded biogas was determined to be 35196.89kJ/kg which is approximately same as that of CNG.

V. CONCLUSIONS

With huge quantities of organic waste available, significant conversion of waste to energy is possible resulting in localized disposal of waste. With organized waste collection practices, municipalities can produce biogas in ample quantities with effective disposal of waste. The kitchen waste can be directly feed in to the digester tank and the biogas generated can be used for cooking meals. A small size kitchen waste digester can partially offset the LPG requirement of a household for cooking meals. Upgrading of biogas by sodium carbonate scrubbing reduces the CO_2 content of biogas by 81.70% and increases the CH_4 content by 66.20% thus making bio-methane a feasible fuel for use in automobile and static engines.

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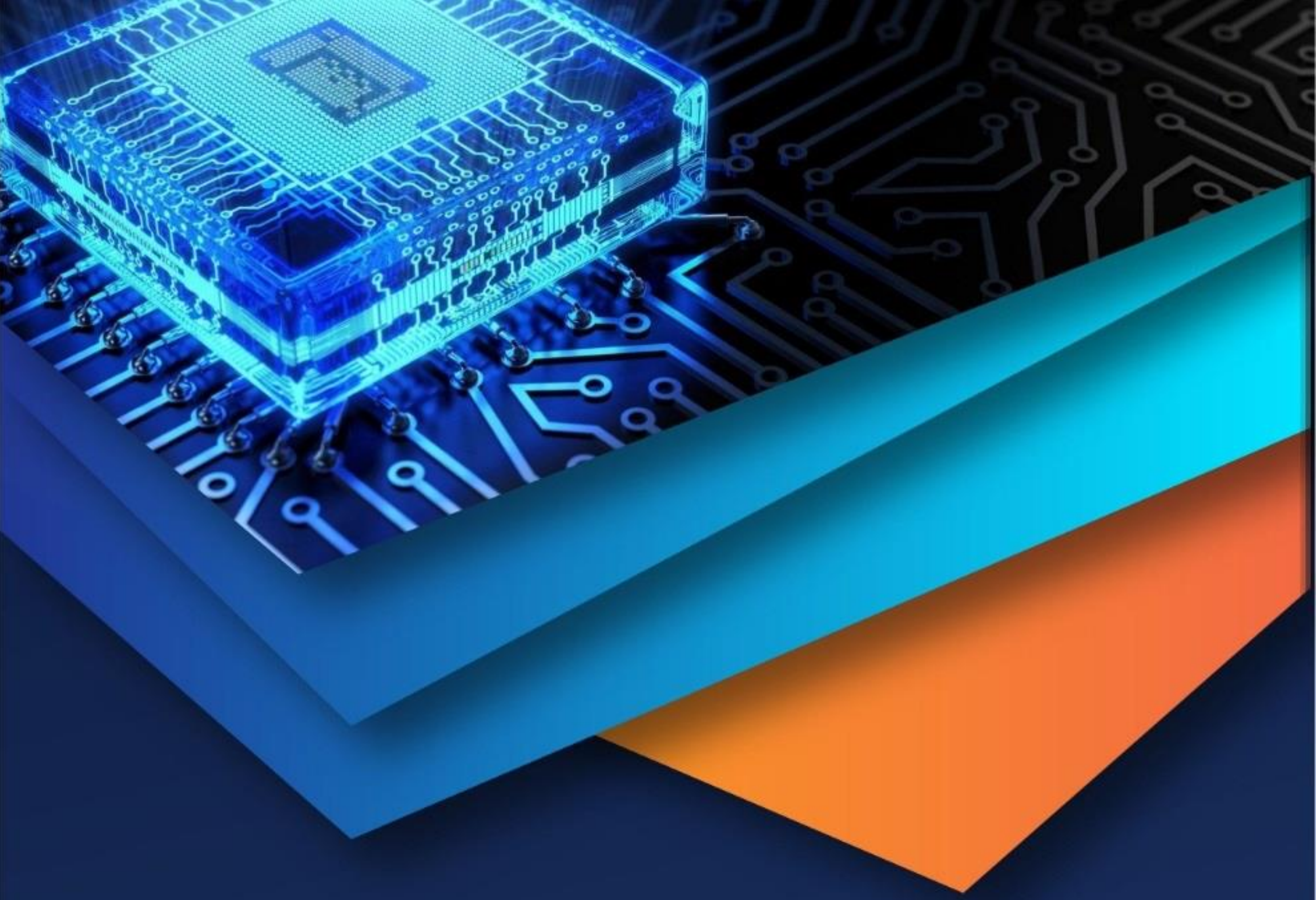

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