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Experimental Study on Evaluating the Biogas Production Potential of Major Organic Fractions of Municipal Solid Waste

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Abstract: Increasing urbanization and Industrialization leads to the generation of huge amount of municipal solid waste (MSW), which in turn increases the transportation and disposal issues associated with it. In India, mostly MSW is transported and disposed in open dumpsites, thereby leading to environmental pollution. Disposal issues associated due to lack of proper segregation, leading to mixing of both organic and inorganic fractions of wastes altogether and being dumped in dumpsites. Due to the increased waste generation, the area demand for dumpsites also becoming a greater issue. In order to solve the issues with handling of organic fractions of MSW, anaerobic digestion is a suitable option, which not only solves the issue associated with waste management, but also produces output in the form of biogas and nutrient rich fertilizer. In the study, biogas potential of major organic fractions of MSW such as cattle and goat rumen contents, slaughterhouse waste, chicken waste, fish wastes, food wastes, raw vegetable wastes from canteen, vegetable shop wastes and household wastes were evaluated. Compared to the various substrates studied, higher biogas yield of greater than 400 ml biogas/g VS added was obtained for fish and food wastes, thereby showing its higher potency compared to other wastes.
Keywords: Anaerobic digestion, organic fractions, Municipal solid waste, biogas, dumpsite.

I. INTRODUCTION

Treatment and disposal of Municipal Solid Waste (MSW) in India is becoming a huge issue now-a-days due to the urbanization and increased population. According to the planning commission report (2014), based on the per capita waste generation of 0.45 kg/capita/day, it was estimated that the waste generation from the urban centers by 2031 will be around 165 million tons/year which will require 1175 hectares of land per year for disposal, and also by 2030 it was predicted that around 436 million tons of waste/year will be generated. This will ultimately result in increasing land requirement and hence, there is a necessity to adopt suitable treatment technologies to treat the wastes in such a way to minimize the issues associated with the disposal of MSW. In 2011, it was reported that around 1,27,486tonnes of wastes/day was generated in India which clearly shows the drastic increase in MSW generation over the years.

Only 12.45 % of the MSW collected was processed and the remaining wastes are dumped in open dumpsites (CPCB report, 2013). It was reported that around 51% of the MSW contributes to organic matter (Annepu, 2012). Generally, the organic fractions of MSW includes vegetable waste, kitchen waste, household waste, fruit and flower waste, garden sweeping, green waste and food waste etc. (Agarwal, 2015).

Improper segregation of MSW results in the dumping of major fractions of these wastes without utilizing their potential (Nandan, 2017). Bioenergy from waste is a promising and sustainable technology to meet the emerging energy needs as well as to overcome environmental pollution issues. Improper disposal of wastes not only have detrimental effect on the environment but also will affect human health (Singh, 2012).

The Tamil Nadu, Chennai city alone contributes about 4000- 4500 tonnes of waste per day. More than 6 tonnes of fish waste are being generated every day (Thirumurugan et al., 2012). Slaughterhouses in Chennai generate around 8-9 tonnes of wastes/day. A wholesale vegetable market in Chennai city generates around 150-200 tonnes of wastes/day. Also, because of the rise in urban population, poultry waste generation is also becoming increased.

Hence, there is a need for treating these wastes, thereby addressing the issue associated with its transportation and disposal. Anaerobic digestion is a potential technology which not only solve this environmental issue rather it provides output in the form of biogas and a nutrient rich fertilizer (Alvarez et al., 2008).

The current study focuses on estimating the biogas production potential of various organic fractions of MSW such as chicken waste (CW), fish waste (FW), food waste from canteen (CFW), canteen's raw (uncooked) vegetable waste (CVW), campus Vegetable shop waste (VW), Mixed Slaughter house waste (SHW), Cattle's rumen content (CRC), Goat's rumen content (GRC) and household wastes (HW).

II. MATERIALS AND METHODS

The anaerobic inoculum was collected from the nearby sewage treatment plant. Mixed Slaughterhouse wastes (SHW) and cattle rumen content (CRC) during cattle slaughtering were collected from the slaughterhouse at Perambur, Chennai. Goat's rumen content (GRC) was collected from the slaughterhouse at Saidapet, Chennai. The chicken waste (CW) was collected from a local abattoir shop and the composition was quantified.

The fish waste (FW) was collected from the fish market at Saidapet, Chennai whereas the canteen food waste (CFW) and canteen raw vegetable peelings waste (CVW) was collected from the Central Leather Research Institute (CLRI) campus, Chennai. Vegetable waste (VW) was collected from the vegetable shop located within the institute campus, CLRI.

The household waste (HW) generated from the quarters present inside CLRI campus were also monitored daily. The vegetable store inside the campus was also monitored for the waste generation for a period of month.

The slaughterhouse waste was collected from the slaughter house at Perambur, which is one of the biggest slaughter houses in the Chennai city.

Total solids, Volatile solids and Moisture content were estimated according to APHA Standard Methods (APHA, 1998). Protein, lipid and carbohydrates were estimated by Bradford method (Bradford, 1976), phosphovanillin method (Frings and Dunn, 1970) and phenol-sulphuric acid method (Dubois, 1956).

Carbon (C) and Nitrogen (N) content was estimated using elemental analyzer. Fibre analysis was carried out by following Van soestfibre analysis (Van Soest, 1991). Hemicellulose was calculated by the differences between Neutral Detergent Fibre (NDF) and Acid Detergent Fibre (ADF).

III. RESULTS AND DISCUSSION

A. Composition of different wastes

The quantity of waste generations were monitored on daily basis for CFW, VW, CVW, HW and composition of these wastes were also monitored. For other wastes like SHW, FW, CW, CRC and GRC, the quantity of waste generated and composition of these wastes were studied.

1) *Chicken Waste:* The chicken waste consists of the following compositions: 58.49% feathers, 13.68% legs, 7.73% head, 19.01% intestines, 0.45% pancreas and 0.62% liver. Initially a total of 7 chickens were taken and the live weight of these chickens was measured to be 16.3 kg. Out of this, a total weight of 5.5 kg turned up as the wastes which indicates around one-third of the live weight remains as waste. Based on this composition of the waste, the mixed chicken waste was taken and minced in a mincer with sieve size of 3mm. The minced sample was stored at -20°C in deep freezer to prevent microbial activity. Similarly, all the wastes stated above are collected and preserved for further use.
2) *Fish Waste:* The fish waste was collected from the fish market at Saidapet, Chennai. The waste collected consists of mixed varieties of fishes such as seerfish, cuttlefish, rohu fish, catla fish, king fish, anchovy, horse mackerel, catfish, pomfret etc. The fish waste mainly comprised of scales and intestine. It is reported that more than 6 tonnes of fish waste has been generated in Chennai city everyday mostly from three fish markets (Chintadripet, saidapet and vanagaram fish markets) and around 16-28% is the waste generated from the raw weight of different fishes (Thirumurugan et al., 2012).
3) *Slaughterhouse Waste:* The slaughterhouse waste was collected from the Perambur slaughterhouse, which is the biggest slaughterhouse in the Chennai city. The slaughterhouse waste from cattle mainly consisted of were rumen content, intestines and blood. It was found that out of the total slaughterhouse waste, rumen content contributed around 70-75% of the waste generated; blood ranges between 20-25% and intestines < 5%. Biogas potential of rumen content and mixed slaughterhouse waste (SHW) comprising 75% rumen content, 20% blood and 5% intestines were taken.
4) *Canteen vegetable Waste:* Table 1 represents the average composition of raw vegetable waste (uncooked) from canteen for a period of 30 days and an average of around 9 Kg/day waste was generated.

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VW	Average (%)	CVW	Average (%)	HW	Average (%)
Ash guard	18.0	Beetroot & peels	2.8	Apple	8.1
Banana	1.0	Brinjal	5.2	Beans	2.4
Brinjal	5.3	Bittergourd	2.2	Beetroot peels	3.4
Bittergourd	3.8	Cabbage	3.2	Brinjal	4.5
Cabbage	4.0	Carrot & peels	0.5	Cabbage	5.0
Capsicum	2.4	Cauliflower leaves	3.2	Carrot	5.6
Carrot	3.4	Chilly	1.7	Cauliflower leaves	5.7
Cauliflower leaves	6.1	Chayote	5.5	Chilly	2.4
Chayote	3.8	Curry Leaves	3.9	Cucumber	3.7
Cucumber	5.6	Drumstick & peels	0.3	Egg Shell	3.0
Greens	4.0	Ginger peels	0.2	Greens	10.0
Lady's Finger	4.3	Greens	1.6	Lady's Finger	3.3
Onion	4.8	Lady's Finger	1.8	Onion & peels	13.0
Papaya	2.0	Onion & peels	43.5	Potato	3.7
Potato	8.6	Potato	6.6	Radish	1.6
Pumpkin	4.5	Bottleguard	1.5	Rice	10.5
Tomato	8.0	Tomato	6.0	Tomato	5.1
Others	10.3	Others	10.2	Others	9.0

Table 1: Average of daily vegetable and fruit waste (VW), Raw canteen Vegetable waste (CVW), Household waste (HW) composition for December Month

During sampling, it was observed that the daily composition remained almost same as that of the monthly average data. The highest weight share among the raw canteen vegetable waste was found to be for onion and peels of around 43.5%. Mixture of different peels such as carrot peels, beetroot peels, etc., which has been categorized under 'others' contributed to around 10.2% of the total waste generated. Potato, tomato, Brinjal and chayote each contributed more than 5% in the waste generated.

5) *Stores vegetable Waste:* The vegetable and fruit waste generated from the institute campus from the shop within the institute premises was monitored for a period of 1 month during December. The quantity and composition of the waste was monitored daily. An average of around 12 Kg/day of waste was generated. It was found from the overall average composition that the Ash guard contributed highest weight share of around 18% of the total waste generated. Also the following Vegetables/fruits contributes more than 5% of the total waste: Brinjal, cauliflower leaves, cucumber, potato and tomato. The category 'others' consists of mixture of turnip, lemon, chilly, corn, Radish, beetroot and beans.
6) *Household Waste:* The household organic fractions of waste generated from the selected 5 houses containing 3 members each, from the staff quarters located inside CLRI campus were also monitored daily and the daily waste generation was found to be around 250-350 g per day. The waste such as rice and vegetables were turned to be the major waste according to the data collected from entire one month. It also had few quantities of fruit waste as well. Sumon et al., (2016) reported that the solid waste generation from household waste containing 1-3 persons ranged between 0.5 Kg/d and he reported that vegetable and food waste contributed 90% of the waste generated, which is comparable with the results of current study. In household wastes, from the average composition observed for a month, it was found that onion and peels found to be the highest in terms of weight basis (13%). Whereas rice contributed around 10.5% and greens to about 10%.The category 'others' consists of watermelon, lemon, corn, banana, capsicum, ginger peels, pumpkin skin and bitterguard. Since each of these fractions were less than 1%, it has been together expressed as 'others'.
7) *Canteen food Waste:* The food waste from CLRI campus canteen were monitored on daily basis for 1 month and was found that the average food waste coming out was found to be varying in the range of 8-9 kg/day whereas the average vegetable waste was around 9kg/day.

B. Characterization of Waste

Sample	Moisture (%)	TS (%)	VS (%)	VS (% TS)	Carbohydrates (%)	Protein (%)	Lipid (%)	NDF (% DM)	Hemi-cellulose (% DM)	LCM (% DM)	C/N ratio
CRC	69.1	30.9	25.5	82.7	10.1	6.7	3.8	32.1	11.1	20.9	28.4
FW	81.7	18.4	16.0	87.1	1.8	9.4	4.1	7.1	1.3	5.7	5.6
GR	82.9	17.1	15.0	88.0	7.6	3.0	2.6	42.7	14.4	28.3	12.6
SHW	72.8	27.2	19.5	71.6	8.6	6.8	3.6	30.4	7.6	22.7	21.5
CFW	71.9	28.1	27.0	96.0	15.3	5.3	1.1	44.2	21.2	22.9	18.9
HW	90.5	9.5	8.7	90.7	6.2	1.2	0.3	46.8	20.6	26.2	16.5
VW	89.3	10.7	9.6	89.6	6.3	1.7	0.4	39.5	13.9	25.6	18.8
CVW	89.5	10.5	8.9	84.6	6.1	1.3	0.3	40.4	15.3	25.1	13.9
CW	65.4	34.6	32.9	95.0	4.9	16.0	7.6	13.8	5.7	8.1	6.8

Table 2: Characteristics of the waste

From the characteristics of the waste, it can be found that most of the substrates has moisture content greater than 70% except for CRC and CW, for which it exceeds 65%. It can be noted that, more than 70% of the total solids contributes to volatile solids thereby indicating the presence of high organic matter content compared to inorganic fractions. Kafle et al (2012) reported the C/N ratio of fish waste as 4.1 and 88% of TS contributes to VS, which is comparable with the results obtained in the current study.

The ideal C/N ratio for anaerobic digestion is 20-30. Higher C/N ratio will results in low gas production because of rapid acidification and lower C/N ratio will cause ammonia inhibition in the reactor in the form of NH_4 which will increase reactor pH and cause toxicity to methanogens. (Mane et al., 2015). It can be found that CRC, SHW was found to be within the optimum limit, whereas the C/N ratio of all other wastes remained less than the optimum thereby indicating the possibility of process inhibitions.

It can be observed that carbohydrate content was higher when compared to protein and lipid content for most of the wastes except for fish waste and chicken waste for which the protein content is higher. It can also be observed that hemicellulose content is lower than the ligno-cellulosic content of all the wastes, thereby indicating the possibility of process inhibitions/delay in the hydrolysis. In SHW, out of the total solids, 13.2%, 25.0% and 31.6% is occupied towards lipid, protein and carbohydrates respectively. Aidan and Niamh (2016) reported that out of total solids present in the slaughterhouse waste, 28.4%, 27.3% and 41% of TS is contributed towards fat, protein and carbohydrates respectively. Comparatively high variations in the lipid content than the current study may be due to the addition of fat trimmings in the composition of mixed slaughterhouse waste reported.

C. Specific Biogas Yield

The specific biogas yields of different wastes are expressed in figure 1.From the batch anaerobic digestion study, the biogas produced is expressed in terms of ml Biogas/g VS of substrate added, which in turn expressed as specific biogas yield (SBY).

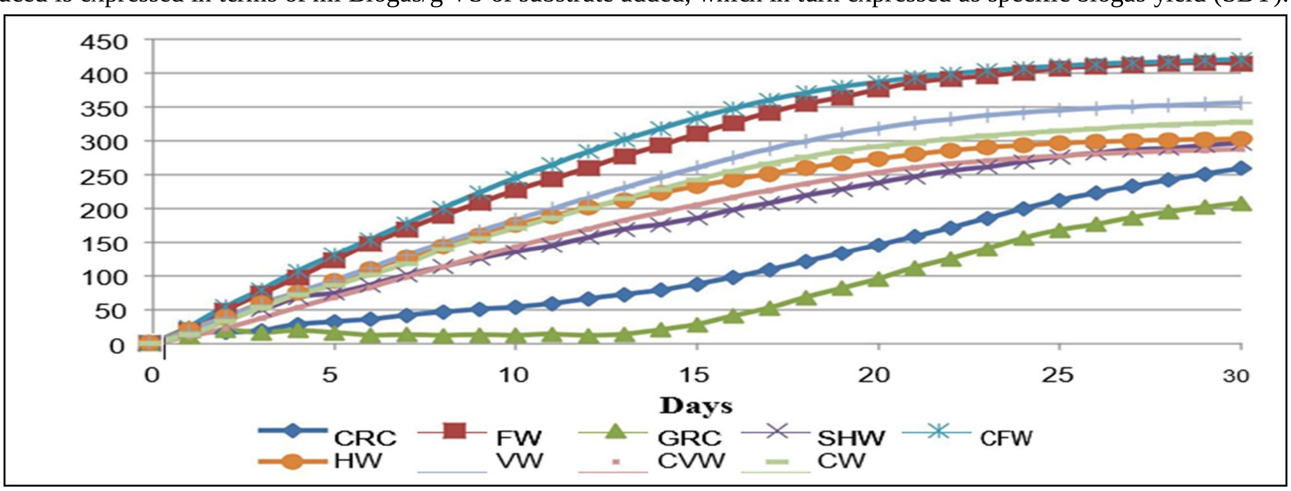

Figure 1: Specific Biogas Yield of different substrates

The SBY of cattle's rumen content was found to be around 259.7 ml Biogas/g VS added, whereas for fish waste the yield was found to be 414.1 ml Biogas/g VS added. Kafle et al., (2012) reported the higher biogas yield when compared to the current study for fish waste as 757 mL/g VS added in a time period of 60 days with VS reduction of 77.3%.

The SBY was found to be 208.1, 296.8, 420.3, 302.9, 356.0, 287.4 and 327.6 ml Biogas/g VS added for Goat's rumen content, Mixed Slaughterhouse Waste, Canteen's Food Waste, Household organic Waste, Stores' Vegetable Waste, Canteen's Vegetable Waste and Chicken Waste respectively. Abubakar and Ismail (2012) studied the biogas potential of cow dung andreported to be around 150ml/g VS added with 47% VS removal. The lesser biogas yield of CVW compared to VW, is that the canteen wastes contains mainly of onion and peels which contributed around 43%, as well as raw peelings from vegetables, which is comparatively complex substrate for hydrolysis compared to other vegetables.

Aidan and Niamh (2016) studied the anaerobic digestion feasibility of cattle rumen content and reported that the methane yield from paunch would be limited because of the complexity in the hydrolysis process due to the presence of ligno-cellulosic matter thereby showing the presence of complex nature of carbohydrates. Also, it can be observed from the current study that around 65%, 66% and 75% of the NDF contributes to ligno-cellulosic matter for CRC, GRC and SHW respectively, which could be the reason for the lesser biogas yield from ruminal contents (CRC, GRC) and mixed slaughterhouse waste (SHW). Selina and Joseph (2008) reported the biogas potential of vegetable waste as 391 mL/g VS added which is comparable with the results of current study as 356 ml/g VS added for vegetable wastes.

D. Volatile Solids Reduction Profile

The volatile solids reduction before and after batch reactor study was calculated and expressed in terms of % reduction obtained in table 3.

Substrate	VS Reduction (%)
CRC	53.96
FW	51.25
GRC	46.25
SHW	42.42
CFW	62.49
HHW	58.18
VW	63.21
CVW	54.82
CW	43.23

Table 3: VS reduction (%) of different substrates

From the volatile solids reduction (%), it can be observed that higher VS reductions (%) were observed for canteen food waste (62.5%) and vegetable market waste (63.2%) in concurrence with their higher biogas yields when compared to other wastes except fish waste for which highest biogas yield was obtained comparatively (table 3). Though fish waste has obtained higher biogas yield when compared to all other substrates, it can be observed that only 51% of the volatile solids added were degraded.

E. Comparison Of Estimated And Experimental Biogas Yield

The experimentally obtained biogas yields were compared with estimated biogas yields using different approaches used in literatures (Baserga, 1998; Weiland, 2001; ATV-DVWK-M 363, 2002) in table 4. The estimation of biogas yield was carried out based on the digestibility values for protein, lipids, raw fibres and nitrogen free extract substances using the fodder analysis data base (DLG, 1997), by utilizing the samples' proteins, lipids, fibres and carbohydrates content. The experimental and estimated biogas yields by these three methods are given in table 4.

Sample	Experimental Biogas Yield	Estimated Biogas yield		
		Baserga 1998	Weiland 2001	ATV-DVWK-M 363 2002
CRC	259.72	463.85	438.15	506.26
FW	414.11	607.44	532.10	625.52
GR	208.11	506.87	488.12	565.20
SHW	296.75	562.69	527.18	609.63
CFW	420.26	410.24	407.37	456.61
HW	302.87	453.90	461.84	516.21
VW	356.03	448.98	451.38	505.00
CVW	287.40	447.84	454.33	508.23
CW	327.65	547.02	484.57	569.48

Table 4: Experimental and Estimated Biogas yields

It is evident from table 3 that the experimental biogas yield of canteen food waste is comparable with that of the estimated biogas yields using calculation approaches. It can be observed that when compared to the estimated biogas yields CRC reached only 51-55% of the estimated yield, whereas FW reached only 66-78%; GRC - 37-43%; SHW-49-56%; HW – 59-67%; VW-71-79%; RVW-56-64%; CW-58-68 %. Overall from the estimation approaches, it can be observed that other than food wastes, the experimental biogas yield obtained for all other waste samples were significantly lower than the estimated biogas yields which is due to less digestibility of volatile matter obtained during the current study than stated in the three estimation approaches. Considering the biogas production potential of different organic fractions of MSW studied, it can be stated that instead of dumping these wastes in the dumpsites without utilizing the potential of the wastes, it can be utilized for biogas production.

IV. CONCLUSION

The current study emphasis a treatment solution for utilization of various organic wastes generated from urban cities. The characterization of wastes shows its suitability for biological treatment. The batch results revealed that, the biogas production potential of different organic fractions of urban wastes. The biogas yield of fish and food waste was greater than 400 ml/g VS added, thereby showing its higher potency when compared to all other wastes studied. The biogas from wastes could be an optimal solution for treating more than 6 tonnes of fish wastes generated in Chennai city and around 8% of MSW generated in Chennai city contribute to food waste, which could be treated through anaerobic digestion. Also, 32% of MSW generated in Chennai city is green waste which includes vegetable market wastes, garden trimmings, litters, fish wastes, poultry wastes, etc., which could be treated through anaerobic digestion. Vegetable wastes also shows biogas potential of 356 ml/g VS added, thereby providing a solution for the wastes generated from wholesale vegetable markets like Koyembedu vegetable market, which generates nearly 150-200 tonnes of wastes per day.

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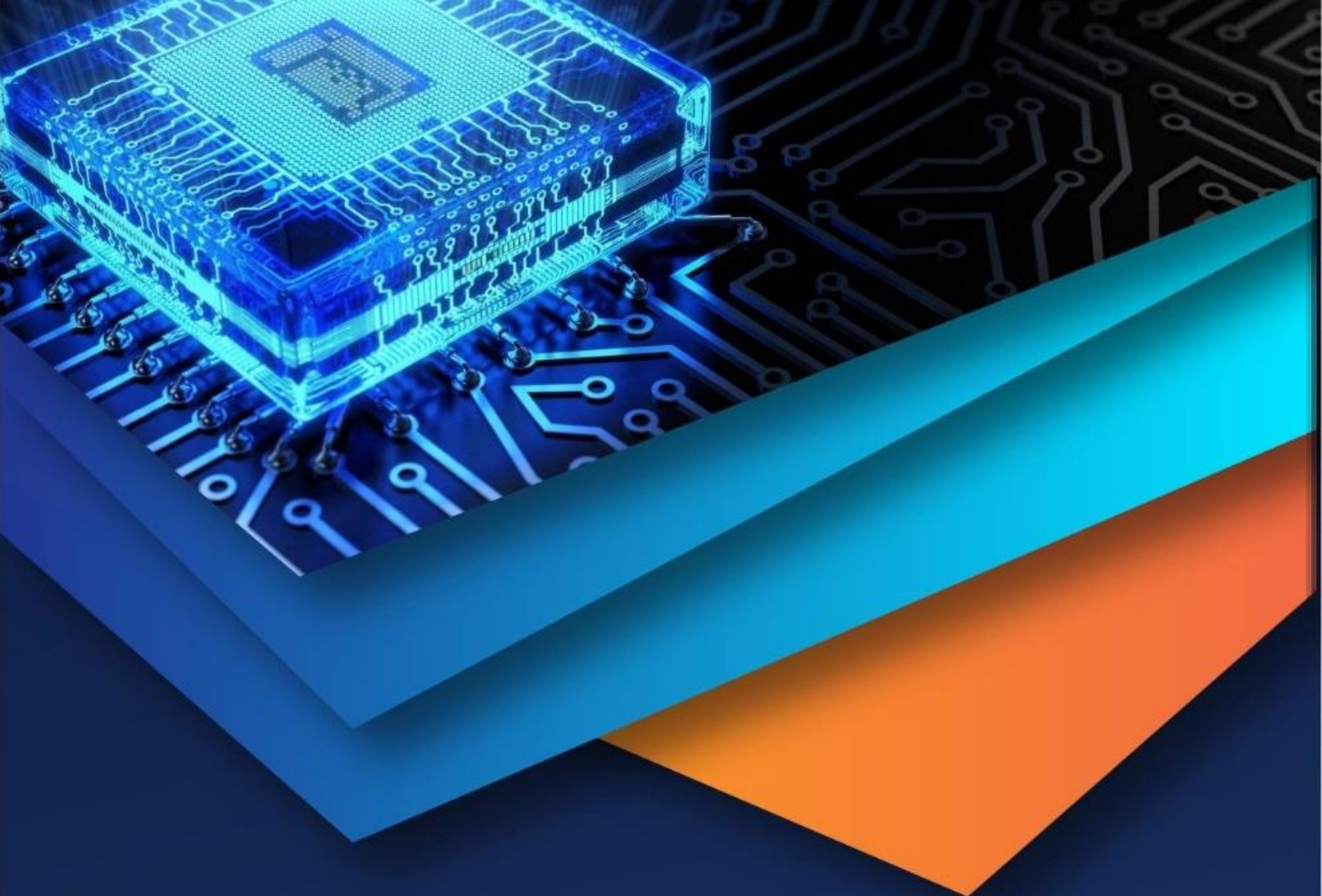

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