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Energy Efficiency in Wastewater Treatment Plant

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Abstract: Municipal waste water treatment systems are one of the major energy consumer systems. Treatment of waste water is an energy intensive and costly process and also a huge source of Greenhouse gases (GHGs) emissions whether directly or indirectly. As per research and estimates, it is indicated that waste water treatment plants (WWTPs) consume about 1 to 3% of the total electric energy output of a developed country and about 0.5 to 2% of the same for developing countries. In order to treat fresh water crisis, it becomes imperative to treat and recycle waste water which requires huge amount of energy and capital investments. Moreover, increase in energy prices and continuously deteriorating quality of environment as a result of generation of energy forced the policy makers and other stakeholders to adopt suitable measures which can increase the energy efficiency of WWTPs and simultaneously achieving the desired effluent quality. Treatment of waste water requires lot of energy during various stages i.e. collection, pumping, treatment, handling, storage, disposal etc. On the other hand, waste water/sewage contains energy in different forms namely potential, chemical and thermal. The aim of this paper is to study the application of new technology, process modification techniques and management practices to achieve energy efficiency in energy intensive WWTPs. Implementation of modern and advanced technologies will help in energy savings and at the same time allows recovery of energy during waste water treatment. Adoption of optimizing techniques and better management practices promised to show better results.
Keywords: Wastewater, greenhouse gases, energy management, urban local bodies, waste activated sludge, aeration, management strategies and heat recovery.

I. INTRODUCTION

As per estimates about 382 trillion liters of waste water is being generated in the world. It is estimated that the generation will be reached up to 470 trillion liters by 2030.

As per report of Central Pollution Control Board (CPCB) 4754 MLD of domestic waste water is generated from urban centers. Currently India has capacity to treat approximately 37% of its waste water generated. Thus, there is a big gap in treatment of domestic waste water.

Based on the study per capita waste water generation in the country is about 121 liters per capital per day. Based on the projected population for the year 2051 the waste water generation is going to be about 132000 MLD.

A. Energy Consumption in WWTPs

The most common energy conversion is the use of electrical energy to provide oxygen for aerobic biological system, such as activated sludge treatment. As per estimates WWTPs consume about 1% to 3 %of the electrical energy output of a developed country and 0.5% to 2% for developed country. In India which is a developing country, the total electricity generation for the year 2019 is about 1500 TWh. On an average about Rs 3.05 is incurred for production of one unit of electricity which is also one of the cheapest in the world.

From above, it can be estimated that for generation of 1500 TWh unit of electricity the total cost incurred is given by

Cost incurred = 3.05 x1500x1000000000

=Rs. 4575 Billion

Assuming in India about 1 % of electrical energy consumed in India in WWTPs the electrical energy expended in terms of money is around 46 Billion Rupees.

With adoption of new technology, process optimization and management practices around 10 to 25 % of the energy can be solved. While considering the lower side i.e. 10% survey about 4.6 Billion Rupees can be saved which can be a great boon for developing country like India.

II. PRINCIPLE

Electrical devices and components involved in wastewater processing are discussed as below: -

1) *Electrical Motors:* Every motor consists of few basic components i.e. bearings, end cap, brushes, insulated windings, brush holder, commutator, frame, armature etc.

   Motor efficiency is the ratio of motor output to motor input.

   $$\text{Motor efficiency} = P_m/P_e * 100$$

   where,
   Pm = mechanical power output, W
   Pe = electrical power input, W

2) *Pumps:* Pumps are used in wastewater collection to raise water to high points in the system, to which the water cannot flow by gravity. Energy consumption for a pump is not only dependent on the pump, but on the hydraulics of the system in which it is installed.

   Pumps convert some form of energy into water energy. The power required is defined in terms of work as weight of water per unit time multiplied by total dynamic head.

   $$p_w = KQh$$

   where
   p_w = water power. kW
   Q = flowrate, m^3/s
   h = pump head, m
   K = unit conversion factor
   9.8 for kW

   The mechanical efficiency of pump is the ratio of water power from the pump to mechanical power input to the pump shaft.

   Pump efficiency can be expressed as

   $$e_p = KQh/p_m$$

   where
   e_p = pump efficiency
   Q = flowrate
   h = pump head
   p_m = output of the motor

   The energy consumption over a period of time is the water power multiplied by the length of time and divided by the wire to water efficiency;

   $$E = hp\ (water) * 0.746\ kW/hp*t/e_{ww}$$

   Where
   E = Energy, kWh
   t = time over which energy is consumed

3) *Aeration Systems:* Electricity for aeration systems represents a substantial portion of the total energy use for most secondary and advanced WWTPs. It is therefore logical to focus initial efforts to achieve energy conservation on the aeration system. An aeration system is a collection of devices when combined, deliver oxygen to water. A common aeration system consists of a blower, piping, valves, diffusers and controls.

   The aeration blowers typically consume 50% of the total energy in diffused aeration activated sludge secondary treatment plants. The power required for compressing air is a function of flowrate and pressure ratio from inlet to discharge of the blower, as follows:

   $$bhp = 0.01542*QpX/n$$

   where
   bhp = brake horsepower at blower
   Q = blower inlet volumetric flowrate, ICFM
   p = blower inlet pressure
   n = blower efficiency
   X = blower adiabatic factor

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III. METHODOLOGY

During the course of study different types of WWTPS/STPs in the state of Chhattisgarh has been visited to study their operation, design, energy consumption pattern etc. Following WWTPs have been visited during the course of study: -

1) Municipal Corporation Bilaspur STP- 54 MLD at Domuhani, Bilaspur
2) Municipal Corporation Bilaspur STP- 17 MLD at Chilhati, Bilaspur
3) NRDA STP- 20 MLD at Sector-28, Nava Raipur Atal Nagar
4) Prakash Industries Limited, Champa Residential Colony STP- 500 KLD, Hathnevra, Champa
5) Ambuja Cements Limited, Bhatapara Cement Works STP- 500 KLD at Bhatapara

The above mentioned first three WWTPs are designed and operated to treat wastewater generated from towns of Bilaspur and Nava Raipur Atal Nagar whereas the latter two are catering the need of residential colonies of industrial establishments. Electric energy consumption in WWTPs is summarized as follows: -

S.No.	STP Location	Avg. daily electricity consumption (Current scenario)	Avg. daily electricity consumption (Projected scenario)
1.	Domuhani	750 Kwh	18000 kwh
2.	Chilhati	750 Kwh	7000 Kwh
3.	Nava Raipur	735 Kwh	7500 Kwh
4.	PIL Champa	100 Kwh	800 Kwh
5.	Bhatapara Cement works	30 Kwh	400 Kwh

A. Methodology Proposed to be Adopted for Achieving energy Efficiency in WWTPs:

The energy saving strategies can be proposed in the following two aspects:

1) *Technical Strategies:* The technical strategies can be implemented in different processes involved in wastewater treatment and with their application energy efficiency can be achieved either by application of energy efficient equipment or by energy recovery. The implementation of technical strategies at different stages in wastewater treatment is discussed as follows:

a) Enhancing Motor Efficiency

Following are the ways by which the energy efficiency of motors can be enhanced: -

- Oversized motors are sometimes less efficient than correctly sized motors: motors are at their most effective working point when operating between 30% and 100% of rated load and are built to sustain short periods at 120% of their rated load. Replacement of oversized motors with an appropriate high efficiency motor can result in savings.
- Improving active energy efficiency by simply stopping motors when they no longer need to be running. This method may require improvements to be made in terms of automation, training or monitoring, and operator incentives may have to be offered. If an operator is not accountable for energy consumption, he/she may well forget to stop a motor at times when it is not required.
- Monitoring and correcting all the components in drive chains, starting with those on the larger motors, which may affect the overall efficiency. This may involve, for example, aligning shafts or couplings as required. An angular offset of 0.6 mm in a coupling can result in a power loss of as much as 8%.
- When the application requires varying the speed, a Variable Speed Drive (VSD) provides a very efficient active solution as it adapts the speed of the motor to limit energy consumption.
- Periodical lubrication by trained technicians preferable to lifetime lubrication.
- All motor bearing casings should be fitted with a grease relief to permit exit of excess grease.
- The following items should be checked periodically to ensure long bearing life: external or internal grease accumulations, dirt build up, excessive motor temperature, shaft alignment, bearing play and excessive noise or vibration.
- The motor should be checked for proper voltage, amperage and resistance to ground.

From the above, it can be observed that high efficiency motors not only enhance the energy efficiency of the system but also requires lesser maintenance cost, low heat dissipation etc.

b) Enhancing the Pumping Efficiency in WWTPs

Variable Frequency Drives (VFDs) are used to vary the speed of pump to match the variable flow conditions. They control the speed of motors by varying the frequency of the power delivery to the motors which results in close match of the electrical power input to the pump with the hydraulic power needed to pump the water. VFDs are proven technologies that are more efficient than control methods and are suited in situations where the flow rate is highly variable. Following are the ways by which the energy efficiency in pumping can be achieved:

- *Maintenance:* Inadequate/improper maintenance lowers pump system efficiency, causes pumps to wear out more quickly and increases costs. Proper maintenance includes the following:
- Replacement of worn impellers
- Inspection and repair of bearing.
- Bearing lubrication replacement
- Replacement/inspection of packing seals.
- Replacement/inspection of mechanical seals.
- Wear ring and impeller replacement.
- Checking of pump/motor alignment.
- Avoid throttling losses.

- *Monitoring:* Monitoring can determine clearances that need be adjusted, indicate blockage, impeller damage, inadequate suction, operation outside preferences, clogged or gas-filled pumps or pipes, or worn out pumps.
- *Controls:* The objective of any control strategy is to shut off unneeded pumps or to reduce the load of individual pumps. Remote controls enable pumping systems to be started and stopped relatively quickly and accurately, and reduce the required labor with respect to traditional control systems.
- *Reduction of Demand:* Holding tanks can be used to equalize the flow over the production cycle, enhancing energy efficiency and potentially reducing the need to add pump capacity. In addition, bypass loops and other unnecessary flows should be eliminated.
- *More Efficient Pumps:* Pump efficiency may degrade 10% to 25% in its lifetime. Industry experts however point out that this degrading performance is not necessarily due to the age of the pump but can also be caused by changes in the process which may have caused a mismatch between the pump capacity and its operation. Nevertheless, it can sometimes be more efficient to buy a need pump, also because newer models are more efficient.
- *Multiple Pumps for Varying Load:* The use of multiple pumps is often the most cost-effective and most energy-efficient solution for varying loads, particularly in a static head-dominated system. Alternatively, adjustable speed drives could be considered for dynamic systems. Parallel pumps offer redundancy and increased reliability.
- *Proper Pipe Sizing:* The use of multiple pumps is often the most cost-effective and most energy-efficient solution for varying loads, particularly in a static head-dominated system. Alternatively, adjustable speed drives could be considered for dynamic systems. Parallel pumps offer redundancy and increased reliability.
- *Replacement of Belt Drives:* The use of multiple pumps is often the most cost-effective and most energy-efficient solution for varying loads, particularly in a static head-dominated system. Alternatively, adjustable speed drives could be considered for dynamic systems. Parallel pumps offer redundancy and increased reliability. It is even better to replace the pump by a direct driven system, resulting in increased savings of up to 8% of pumping systems energy use with payback periods as short as 6 months.
- *Precision Castings, Surface Coatings or Polishing:* The use of castings, coatings or polishing reduces surface roughness that in turn, increases energy-efficiency. It may also help maintain efficiency over time. This measure is more effective on smaller pumps.
- *Improvement of Sealing:* Seal failure accounts for up to 70% of pump failures in many applications. The sealing arrangements on pumps will contribute to the power absorbed. Often the use of gas barrier seals, balanced seals, and no-contacting labyrinth seals can help to optimize pump efficiency.

c) Enhancing the Aeration Efficiency

Strategies to enhance energy efficiency in aeration system are discussed as below: -

- Because of the variability of the influent wastewater, the oxygen added to the aeration process should be controlled and adjusted by on-line measurements. According to Energy Sector Management Assistance Program (ESMAP, 2012), the introduction of such control measures or strategy will not only show energy savings, but also deliver a better oxygen distribution. Thus, an improved environment for the micro-organisms will lead to higher sludge quality. The total costs of the proposed energy saving will include investment cost of the new aeration control system, maintenance, service, spare parts, and repairs.
- A common approach is to use tapered aeration to reduce the rate of oxygen supply along the length of a basin. It can be accomplished by placing more diffusers at the inlet to the basin where the organic loading is highest and decreasing the number of the diffusers along the basin's length. Tapered aeration better matches the oxygen demand across the basin by providing more air to the head of the basin where it is needed and less air near the end of the basin where the food-to-microorganisms (F/M) ratio is lower, thereby saving energy.
- Intermittent aeration saves energy by reducing the number of hours that an aeration system operates or the aeration system capacity. The methodology involves momentarily stopping air flow to an aeration zone or cycling air flow from zone to zone.
- Automated dissolved oxygen control can achieve significant energy saving.
- Replacement of coarse bubble diffusers with fine bubble diffuser also provides a good opportunity to reduce the energy consumption in blowers of aerators. The higher transfer rates reduce the need to compress air, thereby reducing the cost of operating aeration blowers.

d) Energy Efficiency in Solids/sludge Processing

Technical strategies to enhance energy efficiency in sludge processing are discussed as follows: -

- As far as possible coagulation and flocculation should be avoided in wastewater treatment process. Coagulation and flocculation lead to generation of huge quantity of sludge which is not only difficult to handle but also, requires greater energy for its handling and disposal. Moreover, coagulation and flocculation employed the use of mixers and propellors for mixing which also requires electrical energy for their operation. If the process is avoided there will not at all any energy consumption in such equipment.
- Adopt anaerobic digestion of sludge in place of aerobic digestion. As a result of anaerobic digestion in digestor gases are released which can be used for energy recovery. Digestor gas contains 40 to 75 % methane, with 60% being a common percentage. Because methane has a higher heating value of 37000 kJ/cub. meter, the higher heating value of digestor gas is commonly taken to be 22000 kJ/cub. meter. Biogas/digestor gas is a natural complement to operations at many STP's that use anaerobic digestion to stabilize waste water solids. An effective way to use biogas is in a combined heat and power application. All of the biogas is directed to and burned in an engine or turbine that in turn powers an electrical generator. The electricity can be used on STP site. The waste heat is recovered and used to heat the anaerobic digestor to provide heat to the other uses in the plant site.
- Aerobic-anoxic operation would be preferred to aerobic digestion. In aerobic digestion the nitrogenous matter in the digesting sludge is transformed to nitrates. In aerobic-anoxic operation, the aeration to the digestor is turned on and off alternatively. During the anoxic periods, denitrification takes place, converting the nitrates that accumulated during the aerobic period into Nitrogen gas. A 20% reduction in oxygen is obtained. In addition, there is a recovery of alkalinity by removing nitrates that acidify the digestor contents. There is no need to mix during the anoxic period, further reducing energy use if a high enough concentration of MLSS is maintained in the digestor.
- Operation at low dissolved concentration (0.1 to 0.5 mg/l) induces simultaneous nitrification-denitrification, obtaining a similar effect as presented previously with no need for alternating aeration cycles. A further advantage of this operation is reducing the aeration expenditure by running at lower dissolved oxygen concentration.
- Co-digestion of wastewater sludge with other biowastes, especially food waste and fat, grease and oil (FOG) becomes in practice. According to the literature review, co-digestion will enhance the biogas production by 50-185% (sewage sludge co-digested with food waste) and, 100-410% (sewage sludge co-digested with FOG).

2) *Management Strategies:* Many actions could be considered to achieve a better management towards energy efficiency in the plant. Following are the management strategies by which energy efficiency can be achieved:-

- Creation of energy sustainability team. This team can involve determining their present baselines; conducting energy audit; identifying priorities; setting improvement goals, and benchmark with other WWTPs elsewhere and set target to implement the action plans, like Energy Conservation Measures (ECMs).
- Monitoring the electrical usage in the plant.
- Introduction of modern lightening systems to reduce the electricity consumption of the plant.

a) *Emerging Technologies Foe Enhancing Energy Efficiency In WWTPS:* Persistent investigations and researches have led to the development of non-conventional approaches in the field of energy efficiency. Some of the emerging technologies that can be implemented for energy recovery and in turn enhancing the efficiency of WWTPs are discussed as below: -

- *Heat Energy Recovery from Wastewater:* Apart from the thermal energy recovery from biosolids, thermal energy can be recovered from raw wastewater or effluent by exploiting the often-significant temperature differential between wastewater and the ambient conditions. This temperature difference (at least 3-5˚C) can be recovered for use in heating and cooling systems, which is generally used for buildings at the plant, and sometimes in the buildings of areas surrounding the plant. Heat pump uses electricity to recover low-temperature heat from the wastewater, and to make this heat available at suitable temperatures for both heating and cooling. The thermal energy reserves in wastewater after treatment are dependent on the temperature, flow rate, heat transfer efficiency, and specific heat capacity of the water. This can be expressed theoretically:

$$E=\rho \times Q \times Cp \times \Delta T$$

Where, E is the thermal energy reserve (kcal), ρ is the density of the wastewater (kg/m^3), Q is the effluent flow rate (m^3), Cp is the specific heat of the wastewater (kcal/kg˚C), ΔT is the temperature that can be extracted (˚C).

- *Advancement in Sludge Treatment Process:* Some of the emerging technologies for energy recovery in sludge processing is briefed as follows: -

- *Phosphorus Recovery:* From sewage sludge that can be sold to farmers as fertilizers.
- *The Omni Processor:* A process that can treat sewage sludge and can generate a surplus of electrical energy if the input materials have the right level of dryness.
- *Thermal Depolymerisation:* Produces light hydrocarbons from sludge.

b) *Miscellaneous measures that can be adopted to increase the energy efficiency or to reduce the energy consumption in WWTPs: -*

The measures are summarized as follows: -

- As far as possible WWTPs should be designed preferably with gravity flow which requires lesser pumping and in turn reduces the energy consumption for pumping. Although, topography is constraint while considering this criterion.
- Energy audit of the WWTPs should be regularly carried out to assess the performance of energy management system.
- Use of renewable sources of energy such as solar energy, wind energy etc. for lightening and other purposes in the WWTPs.
- Instead of discharging the treated water into natural water bodies, provisions should be made to utilize the treated water in irrigation, landscaping, industrial purposes etc. This can lead to reduction of load on water treatment facilities which are entrusted to provide fresh water for such purposes which results not only in conservation of water but also reduces the consumption of energy in water treatment facilities. Thus, achieving energy efficiency indirectly.

IV. RESULTS AND DISCUSSIONS

The study focused on the ways by which energy efficiency measures can be implemented in the operation of WWTPs. From the study it can be observed that if all the energy efficiency strategies would be adopted then the extensive energy consuming WWTPs can be turned into energy neutral systems and ever further generate surplus energy which can be utilized in the treatment plant itself and elsewhere required. It can be noted that energy efficiency measures are costlier at initial stage. However, they have shorter payback period in comparison to the life of WWTPs. But the funds are always limited with the government and other operating agencies hence all the measures cannot be adopted as it is. For current scenario if some basic measures as already discussed adopted, it would result in 10-25% reduction in energy conservation of conventional WWTPs.

With the proposed implementation of energy efficiency measures such as use of high efficiency motors, pumps, blowers etc. their regular maintenance and operation at optimum range can yield 10-25% savings in electrical energy. The expected result in the WWTPs studied during the course of the project is summarized as below:

S.No.	WWTPs	Avg. daily electricity consumption (Projected scenario)	Reduction in electric energy consumption with adoption of measures (10% reduction is assumed)	Money which can be saved per year as a result of implementation*
1.	Domuhani STP	18000 kwh	1800 kwh	Rs. 4434750
2.	Chilhati STP	7000 Kwh	700 kwh	Rs. 1724625
3.	NRDA STP	7500 Kwh	750 kwh	Rs. 1847813
4.	PIL Residential Colony STP	800 Kwh	80 kwh	Rs.197100
5.	Bhatapara Cement Works STP	400 Kwh	40 kwh	Rs. 98550

*Commercial electricity tariff in C.G. state is considered as Rs. 6.75/-

A. Prospects of Thermal Energy Recovery in WWTPs

The amount of gas produced and the fuel value projected to be obtained is summarized as follows:

S.No.	WWTPs	Design capacity (MLD)	Total amount of gases produced (cubic metre)	Amount of methane gas produced (65% of total gas produced) (cubic metre)	Fuel value obtained (@36000 kJ/cu. m.)
1.	Domuhani STP	54	3980.34	2587	93.13 MkJ
2.	Chilhati STP	17	1253	814	29,3 MkJ
3.	NRDA STP	20	1474	958	34.5 MkJ

From the above it can be realized that if harnessed significant amount of thermal energy can be recovered. This energy can be used for heating, production of electricity through heat turbines which can be used within the WWTP premises and also transmitted to the grids if required.

V. CONCLUSION

The intended purpose of WWTPs/STPs is to treat the wastewater to achieve desired quality of effluent fit for disposal. Energy consumption is a significant operating cost at a treatment plant, consuming 15 to 30% of the O&M budgets at large WWTPs and 30 to 40% at small WWTPs. Energy costs of these facilities continue to rise because of the trend in the cost of fuels, inflation and increasing wastewater discharge requirements that result in application of energy-intensive treatment processes.

Advancing technologies offers new opportunities for improving energy efficiency and the application of new energy conservation measures at a treatment facility. Aeration and pumping are the major energy consumers in wastewater treatment process. Disposal of solids in the wastewater/sludge also requires significant amount of energy. With the application of new and emerging technologies energy efficiency of WWTPs can be enhanced and improves the energy footprint of WWTPs.

Wastewater itself consists of different forms of energy as earlier discussed. There should be approach towards harnessing the energy embedded in wastewater and develop energy self-sufficient WWTPs leading towards sustainable development fulfilling the sustainable development goals (SDGs) of United Nations. The energy efficiency can be achieved with the adoption and implementation of technical and management strategies discussed in details earlier. Application of high energy motors and pumps, optimum aeration of wastewater, energy recovery from sludge and implementation of energy management system will be the best to realize the aim of energy efficient wastewater treatment system.

In Chhattisgarh state per capita annual consumption of electricity is around 1724 kwh. In the current situation, the WWTPS which have been studied during the research have found to be consuming about 0.002 % of the total electric energy consumed in the state and the projected consumption of the above WWTPs when operating at their designed capacity will be about 0.03 % of the electric energy consumption of the state.

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Although, the energy consumption seems to be insignificant in comparison to the total energy consumed in the state but with the implementation of energy efficient measures significant amount of energy can be saved as several WWTPs projects are in the planning state and will be implemented very soon. Application of energy efficient measures in the design and operational stage of proposed STPs and at operational stages of existing WWTPs will result in significant conservation of energy which not only leads to reduction of financial burden on the state but also helps in the conservation of environment.

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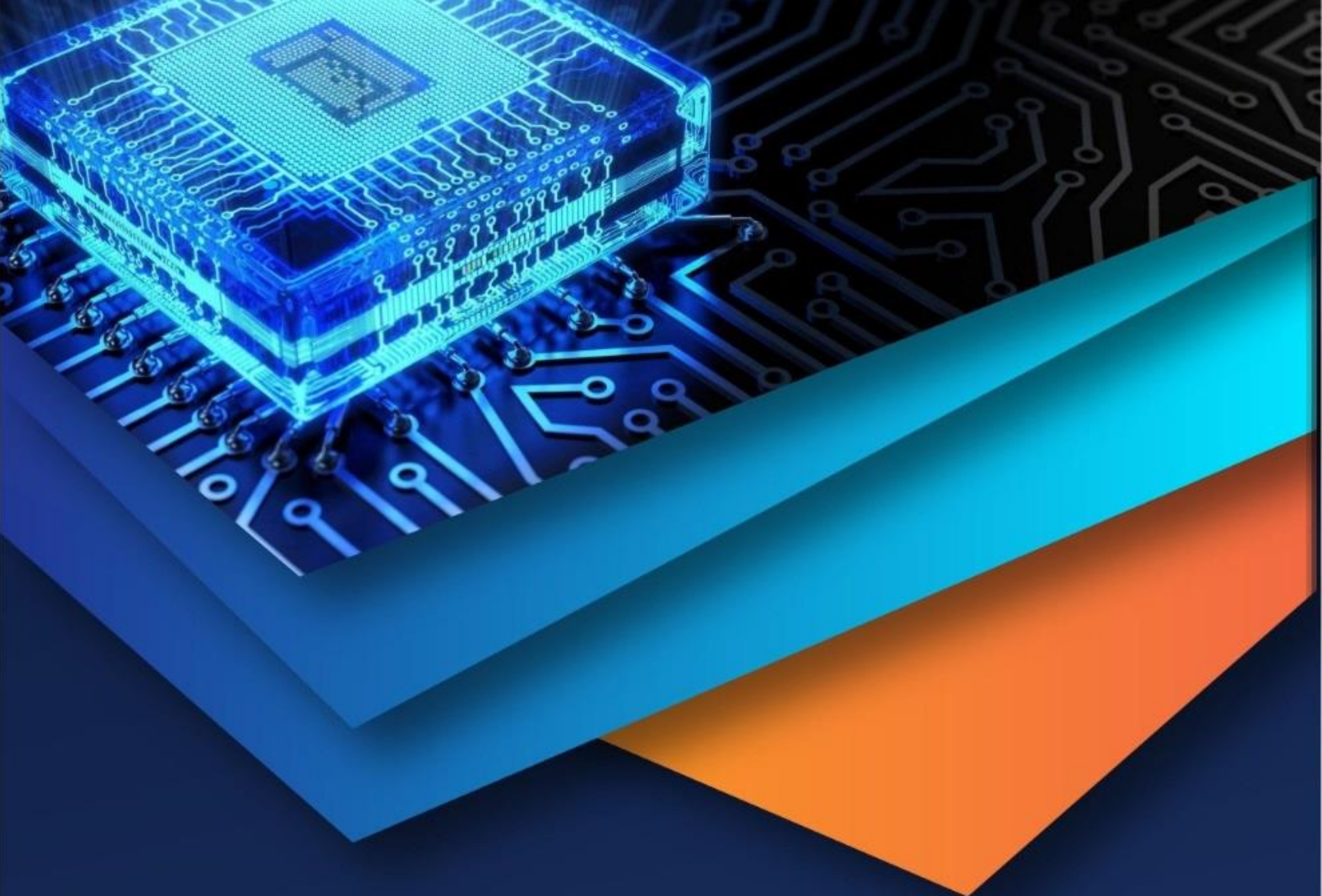

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