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Characteristics and Treatment of Effluent from a Ceramic Fiber Products Manufacturing Factory

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Abstract: Wastewater generated from Ceramic Fiber industry poses serious environmental pollution due to its high chemical load and complex composition. This study investigates the wastewater generated from the production of various ceramic fiber products, such as ceramic fiber paper, board, and vacuum formed shapes. As ceramic fiber products provide excellent thermal insulation and are helpful in energy savings, growth of this industry in future is obvious. Though ceramic fiber production uses water in a considerable amount, comprehensive wastewater treatment is a necessity to reduce environmental footprint of this industry. The primary objective of this study was to analyze and characterize wastewater parameters such as Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and Total Dissolved Solids (TDS). In this study, the chemical treatment utilizes poly aluminum chloride as a coagulant and poly electrolyte as a flocculant. Chemical treatment yields BOD and COD removal by 70.12% and 73.9% respectively. Further, the aerobic biological treatment provides a reduction of BOD by 77.1% and COD by 63.21%. An advanced oxidation process, ozonation trial was also employed for the evaluation of further reduction of pollutants to bring them within regulatory limits. The ozonation trail yields BOD and COD reduction by 75.2% and 55.8% respectively.

Keywords: Ceramic fibre wastewater, BOD, COD, coagulation, biological treatment, ozonation.

I. INTRODUCTION

1) *Overview of Ceramic Fiber Industry:* Ceramic fibers are a type of refractory material, made primarily from alumina (Al_2O_5) and silica (SiO_2). They are known for their exceptional thermal insulation properties, making them ideal for high-temperature applications (Yalamaç et al., 2017). Ceramic fibers typically have an alumina-silica composition of 47% alumina and 53% silica. The development of ceramic fibers began in the 1960s. Their key applications include industrial insulation, where they are extensively used in furnaces, kilns, and other high-temperature processing equipment. In Automotives, they are employed in catalytic converters and exhaust systems for thermal insulation. In Aerospace, they are used in heat shield and in power generation, they are applied in boilers, turbines, and other equipment requiring high thermal efficiency. Ceramic fiber products are lightweight, easy to handle and highly resistive to chemical attack. Ceramic fibers are produced using various methods, including melt spinning, blowing, and sol-gel processes (S.M. Imtiazuddin et al., 2012). Ceramic fibers are typically produced in the range of 1 to 5 micron. Finer the fiber greater their thermal insulation properties.

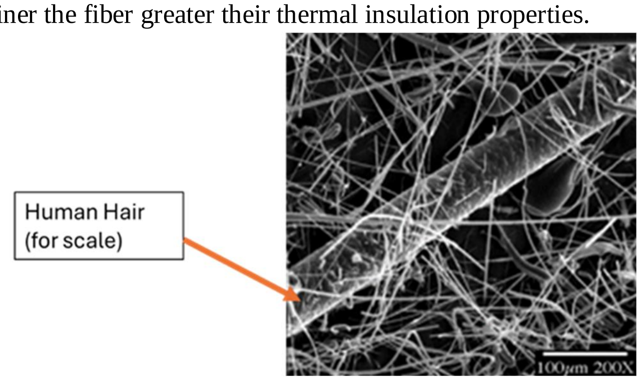

Fig 1. Wool-like matrix of ceramic fibers

Density of ceramic fiber is relatively low, and it ranges from 64 to 190 kg/m3 which also depends on the fiber forms, blanket or bulk. Low density provides excellent thermal insulation with minimal weight of the ceramic fiber modules which is critical in various industries.

The tensile strength of ceramic fiber is moderate, generally ranging from 0.5 to 1.0 MPa for bulk fiber. When handling and installing them, this provides a certain level of mechanical integrity, but they are more brittle than metallic fibers. Ceramic fibers have high porosity because of their fibrous structure, which also helps to explain their low bulk density and excellent thermal insulation properties. Ceramic fiber boards, paper, vacuum-formed shapes etc. are produced in wet processes involving water and chemicals additives. The fibers are mixed with water to create fiber slurry or pulp. This slurry forms the basis of ceramic fiber paper. This pulp or slurry is further mixed with binders, retention aid, and defoamer. This complete mixture is then passed through conveyor to form desired size. Similarly, vacuum-formed shapes are produced using water but instead of forming a sheet, the slurry is cast into mold. Effluent treatment is crucial in the ceramic fiber industry due to the significant water usage in processes that generate highly turbid wastewater containing harmful chemicals, suspended solids, and altered pH levels. This wastewater, if discharged untreated can severely impact water bodies and ecosystems.

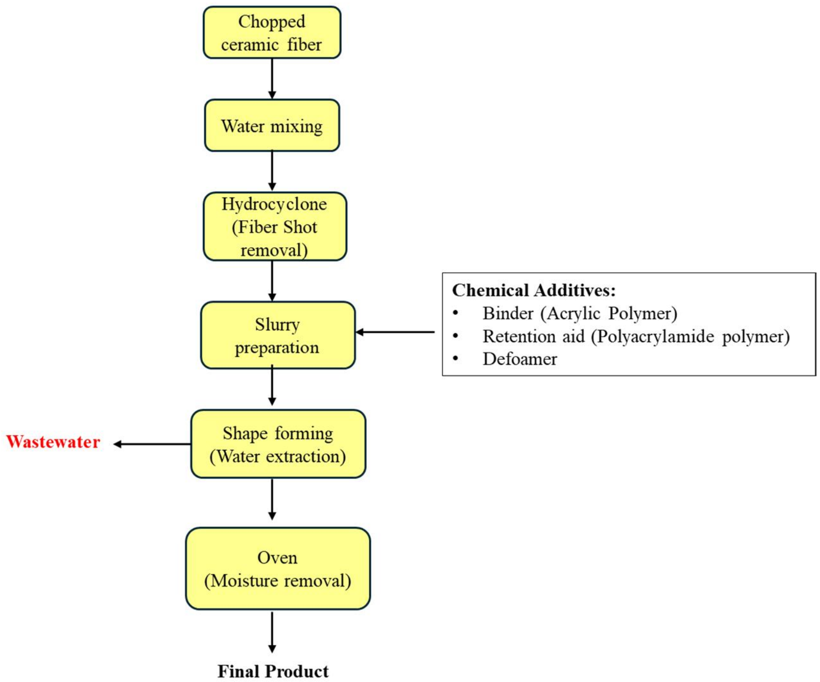

Fig 2. Manufacturing Process of ceramic fiber products

2) *Background and Context of the problem:* The ceramic fibre manufacturing industry is essential for producing high-temperature insulation materials used in sectors like metallurgy, petrochemicals, power generation, automobile etc. These products, such as ceramic fibre paper and vacuum-formed shapes, have exceptional thermal insulation properties and resistance to heat. However, the production process generates significant amounts of wastewater, estimated at 4000-5000 litres per ton of production. Different chemicals are used in the production of various ceramic fibre products such as, acrylic binders, paraffin oil based defoamers, and retention aid (polyacrylamide-based polymer). These chemicals streamline the process, improve product quality, and optimize mechanical properties of the final products. The wastewater generated from the production process contains traces of these chemicals which contribute to organic and inorganic load in the wastewater. Fine ceramic fiber particles in the wastewater contribute significantly to its solid load and turbidity. These particles are small, lightweight, and can remain suspended in water, leading to increased total suspended solids and potentially clogging filtration systems. They can also hinder biological treatment processes by interfering with microbial activity and settling. The wastewater from ceramic fibre production is characterized by high levels of chemical oxygen demand (COD), biochemical oxygen demand (BOD), total suspended solids (TSS), and total dissolved solids (TDS).
3) *Objective of the study:* The objective of this study is to investigate the wastewater generated by a ceramic fibre products manufacturing plant and to develop a practical and sustainable treatment solution. This study begins by analysing the wastewater to identify its key pollutants, focusing on parameters such as pH, total dissolved solids (TDS), chemical oxygen demand (COD), biological oxygen demand (BOD).

This analysis will provide a comprehensive understanding of the pollutant load and composition of the wastewater. Following this, a treatment process will be developed, aiming to reduce pollutant levels in line with environmental regulations.

4) *Industrial effluent treatment:* Wastewater treatment is a critical component of environmental management in manufacturing industries, as industrial process often generates large volumes of wastewater containing harmful pollutants. These pollutants, such as suspended solids, chemicals, organic material, and heavy metals, can pose significant threats to ecosystems and human health if not treated properly before discharge. The primary objective of wastewater treatment in manufacturing is to reduce the pollutant load, ensuring that effluents meet regulatory standards before being released into water bodies or reused on production processes (Ranade & Bhandari, 2014). Suspended solids, Biochemical Oxygen Demand, and Chemical Oxygen Demand are the constituents of industrial effluent wastewater. Suspended solids refer to particles that are not dissolved in water and remain suspended in the liquid phase. In ceramic fiber manufacturing, suspended solids can originate from chopped ceramic fiber that do not dissolve and remain suspended during pulp making and vacuum shaping. Wastewater treatment plants using sequential batch reactors and continuous flow reactors are more efficient in capturing suspended particles up to 30μm and removing particles ranging from 30μm to 550μm from the outflow (Kusnierz & Wiercik, 2016). Hydraulic retention time (HRT) play crucial role in the removal of TSS, BOD, and COD (Bhattacharjee et. al. 2017). Coagulation-flocculation is a conventional yet critical and helpful processes in industrial wastewater treatment used to remove colloidal particles, and certain dissolved contaminants. Various chemicals, for example aluminum sulfate[Al2(SO4)3], ferric chloride (FeCl3), Poly aluminum chloride (PAC), aluminium chloride (AlCl3), copper sulphate (CuSO4.5H2O) etc. are used as coagulants. They are added to destabilize suspended particles by neutralizing their charge, causing them to clump together. During flocculation, gentle mixing allows these particles to form larger aggregates or "flocs," which can be more easily separated from the water. This combined process is effective for reducing turbidity and removing organic matter, heavy metals, and other impurities. Studies have also conducted to use plant-based coagulants such as opuntia stricta, hyacinth seed, nirmali seed, moringa seeds, tamarind seed etc. They can effectively reduce turbidity and remove suspended particles and certain organic compounds, making them a sustainable alternative to synthetic chemicals. Plant-based coagulants are eco-friendly, produce less sludge, which lowers disposal costs, and the environmental burden associated with sludge handling. However, their full-scale industrial use is not practiced widely. Biological processes are also very effective in treating industrial effluents, they utilize microorganisms, primarily bacteria, to break down organic pollutants, making it an effective and eco-friendly method for treating wastewater with high biochemical oxygen demand (BOD). In aerobic biological treatment processes, such as activated sludge or moving bed biofilm reactors (MBBR), oxygen is supplied to support microbial growth and activity, enabling the microbes to consume organic contaminants as a food source, converting them into carbon dioxide, water, and biomass. Anaerobic treatment, on the other hand, operates in the absence of oxygen, and is especially useful for treating wastewater with high organic content, producing biogas as a byproduct (Merlin Christy et al., 2014). The final products of anaerobic digestion are methane (CH4), carbon dioxide (CO2), and smaller amount of biomass (McCarty & Smith, 1986). Biological treatment is widely used due to its cost-effectiveness, ability to reduce organic loads significantly, and adaptability for integration with other treatment processes in industrial wastewater systems (Daud et al., 2018).

II. METHODOLOGY

The methodology section outlines the systematic approach used to analyze and treat effluent from a ceramic fiber products manufacturing factory. The primary objective is to identify key pollutants, particularly Biological Oxygen Demand (BOD), and Chemical Oxygen Demand (COD). Wastewater sample was collected from a ceramic fiber products manufacturing factory situated at Maharashtra Industrial Development Corporation (MIDC) Zone at Pimpri-Chinchwad, Maharashtra.

1) *Determination of BOD of ceramic fiber wastewater sample:* BOD of the wastewater sample was determined by dilution method as per IS 3025 (Part 44): 2023. The BOD test primarily follows a bio-assay procedure that measures the dissolved oxygen consumed by microorganisms as they break down and oxidize organic matter under aerobic conditions. The standard test involves incubating the sample in a sealed bottle, kept in the dark at a specific temperature for a designated period of time. The difference between initial dissolved oxygen (DO) and final dissolved oxygen determines BOD of the wastewater sample.
2) *Determination of COD:* COD of the wastewater sample was measured as per the guidelines laid down in IS 3025 (part 58): 2023. Standard Potassium Dichromate ($K_2Cr_2O_7$), Sulfuric acid (H_2SO_4), Standard ferrous ammonium sulphate (FAS) and Ferroin Indicator were used as reagents. The COD test measures the amount of oxygen required for the chemical oxidation of organic and inorganic matter in a wastewater sample. The sample is refluxed with a known quantity of potassium dichromate ($K_2Cr_2O_7$) in a sulfuric acid (H_2SO_4) medium. The dichromate acts as an oxidizing agent, breaking down the organic and inorganic compounds in the water. The amount of dichromate consumed during the oxidation is proportional to the oxygen required for this process.

Table 1. Wastewater Parameters of Effluent from Ceramic Fiber factory

Parameters	Unit	Measured value	Regulatory limit
pH	-	8.43	5.5 – 9.0
Total Dissolved Solids (TDS)	mg/l	838	2100
Biochemical Oxygen Demand (BOD)	mg/l	1650	30
Chemical Oxygen Demand (COD)	mg/l	5095	250

3) *Laboratory treatment trials:*

a) *Chemical treatment study:* The effluent is subjected to coagulation-flocculation through Jar test. In this stage pH correction was done using potassium hydroxide (KOH). Coagulation process was conducted using Poly Aluminum Chloride (PAC) with the mixing speed of 160 rpm for 1 minute. PAC is an inorganic coagulant made from aluminum slats. PAC works primarily as a coagulant by neutralizing the negative surface charge of suspended particles (such as solids). Once neutralized, these particles no longer repel each other and can aggregate into larger particles (micro flocs) that can settle or be removed by filtration. Later, anionic polyelectrolyte was employed as flocculants with mixing speed of 30 rpm for 15 minutes. In the chemical trial, consumption of chemicals was noted as follows:

- Coagulation by Poly Aluminum Chloride (PAC) – 20ml
- Flocculation by anionic polyelectrolyte – 2ml

Chemical treatment reduces COD and BOD to an extent but increases the TDS of wastewater.

b) *Biological Treatment study:* Biological treatment of a wastewater sample in a laboratory typically involves simulating the process of microbial degradation of organic pollutants under controlled conditions. In this test, the wastewater sample is introduced to a bioreactor or aerobic digestion unit which mimics full-scale biological treatment systems used in wastewater treatment plants. The key objective is to reduce Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD). The MLSS (Mixed Liquor Suspended Solids) is monitored to measure the concentration of biomass in the reactor. The test is typically run for 5 days, during which DO, pH, and temperature are controlled to optimize the condition for microbial growth.

Lab process set up for biological treatment of ceramic fiber wastewater:

- ETP plant aerobic sludge was used for biomass development.
- Process was established in a 25 liters container.
- 2 kg of sludge slurry (90% Moisture and 10% Activated Sludge) was used.
- 14 liters of effluent wastewater was taken.
- 14 liters of Effluent and 2 kgs of sludge slurry were poured into 25 liters container.
- 100 ml of bio activator (A & B media culture) was initially added to the container.

Ozonation trail on biologically treated sample: Further, the biologically treated wastewater sample is taken for ozonation trail to evaluate the performance of this Advanced Oxidation Process (AOP) and obtain further reduction in BOD and COD levels. This results in the reduction of Biochemical Oxygen Demand and Chemical Oxygen Demand and the neutralization of pathogens and other harmful substances.

Procedure:

- 10 liters of wastewater sample already treated with biological processes was taken.
- A lab-scale ozonator was taken capable of producing ozone gas at the rate of 5 g O_3/h.
- The wastewater sample was placed in a reactor for ozonation.
- Ozone diffusion was done through a venturi injector.
- The ozone trail was run for approx. 45 minutes.

III. RESULTS AND DISCUSSIONS

Wastewater treatment tests were conducted in three stages: Chemical treatment, biological treatment, and ozonation, with the goal of reducing Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD) and Total Dissolved Solids (TDS) to comply with the regulatory limits. The first stage of treatment involved coagulation-flocculation to reduce suspended solids and organic load. The pH was corrected using potassium hydroxide (KOH). It was noted that the optimum pH range was 8.5 to 9.5 to get best results out of coagulation-flocculation process. Mixing speed has a greater role in the effectiveness of chemical treatment.

Coagulation is done with rapid mixing to ensure complete mixing of the chemicals, but the flocculation is done with slow mixing to help small flocs come together. The biologically treated wastewater showed further reduction in BOD and COD. The biological treatment was conducted in a 25-litre bioreactor with 14 liters of effluent and 2 kg of sludge slurry which was biologically activated. The ozonation process was carried out on biologically treated effluent to further reduce the levels of BOD and COD. The effluent wastewater was subjected to ozonation, and advanced oxidation process (AOPs), resulting in significant reduction in both parameters.

Table 2. Reduction in ceramic fiber wastewater parameter

Parameters	Initial concentration	After chemical trail	After biological trial	After ozonation treatment	Unit
pH	8.43	7.54	7.41	7.35	-
TDS	838	1228	1187	1195	mg/l
COD	5095	1324	487	215	mg/l
BOD	1650	493	113	28	mg/l

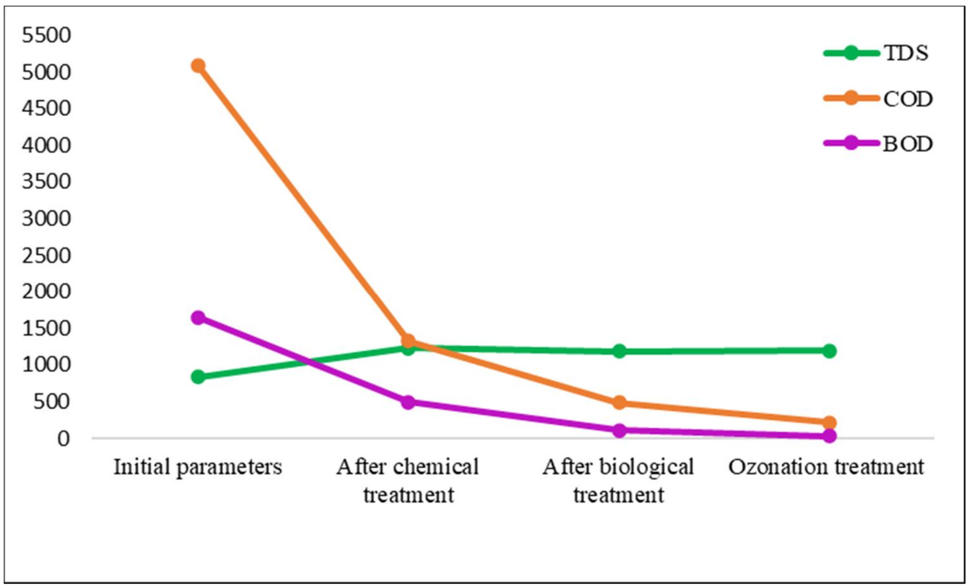

Fig. 1. Overall treatment results on ceramic fiber wastewater

The results indicate that initially the chemical process successfully targeted suspended solids and organic load. However, there was a slight increase in TDS level, from 838 to 1228 mg/l, which was likely due to the addition of Poly Aluminum Chloride (PAC) and Potassium Hydroxide (KOH) during coagulation and pH adjustment. In the chemical treatment, two aspects are very important, coagulant dose and mixing rates. The optimum coagulant dose and mixing rate are determined by simulating both coagulation and flocculation in “Jar Tests”. The biological treatment further reduces the level of BOD from 493 mg/l to 113 mg/l and COD from 1324 mg/l to 487 mg/l. The results show that this stage was effective in reducing biodegradable organic matter present in the wastewater sample. It also shows that biological treatment has no or a limited effect on dissolved inorganic compounds. Ozonation is highly effective in oxidizing complex organic molecules into smaller, more biodegradable fragments or completely mineralizing them into CO_2 and H_2O (Rittmann & McCarty, 2001). In the case of ceramic fiber wastewater, the presence of binder content, particularly acrylic polymers, may not be adequately treated biologically. Ozonation can target and degrade these synthetic organic polymers, improving the overall treatment effectiveness.

IV. CONCLUSION AND SCOPE OF FURTHER WORK

This study focuses on examining the characteristics of wastewater generated from a ceramic fiber products manufacturing factory. It also investigates possible treatment methods, which can be employed to treat the effluent water generated after wet processes involved in ceramic fiber production. The primary objective of the study was to evaluate the level of pollutants like Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD).

The results of the wastewater sample analysis confirmed that the wastewater from a ceramic fiber production factory contains a significant level of suspended solids, dissolved solids, and high concentrations of COD and BOD.

These findings are similar to the effluent characteristics observed in nearly related industries, such as textile and pulp & paper industries. From the results it was concluded that the wastewater from a ceramic fiber factory has high BOD and COD, but the level of dissolved solids was found within the range of regulatory limits. The proposed treatment methodology involves multistage correction or treatment of wastewater, these stages are chemical treatments like coagulation-flocculation, aerobic process of biological treatment. During the lab trials it was observed that the ozonation treatment demonstrated efficient reduction of COD and BOD level playing an important role in bringing the parameters of wastewater with the regulatory limits.

As scope of further work Investigation can be conducted for the further optimization of ozonation process (e.g., dosage, reaction time, and contact time). An analysis of energy efficiency of treatment process can be conducted to explore ways to reduce energy cost or increase overall energy efficiency. The possibility of reuse of treated water can be examined to reduce freshwater consumption by a ceramic fiber factory and enhance sustainability. This study was conducted on limited pollutants, so further analysis can be done to find out traces of heavy metals in wastewater. Investigation can be conducted to propose ceramic fiber industries alternatives to acrylamides which are used in their manufacturing processes. Effectiveness of organic or natural coagulants can be investigated to treat wastewater from ceramic fiber industry. Develop and implement automated monitoring system for the assessment of key water parameters.

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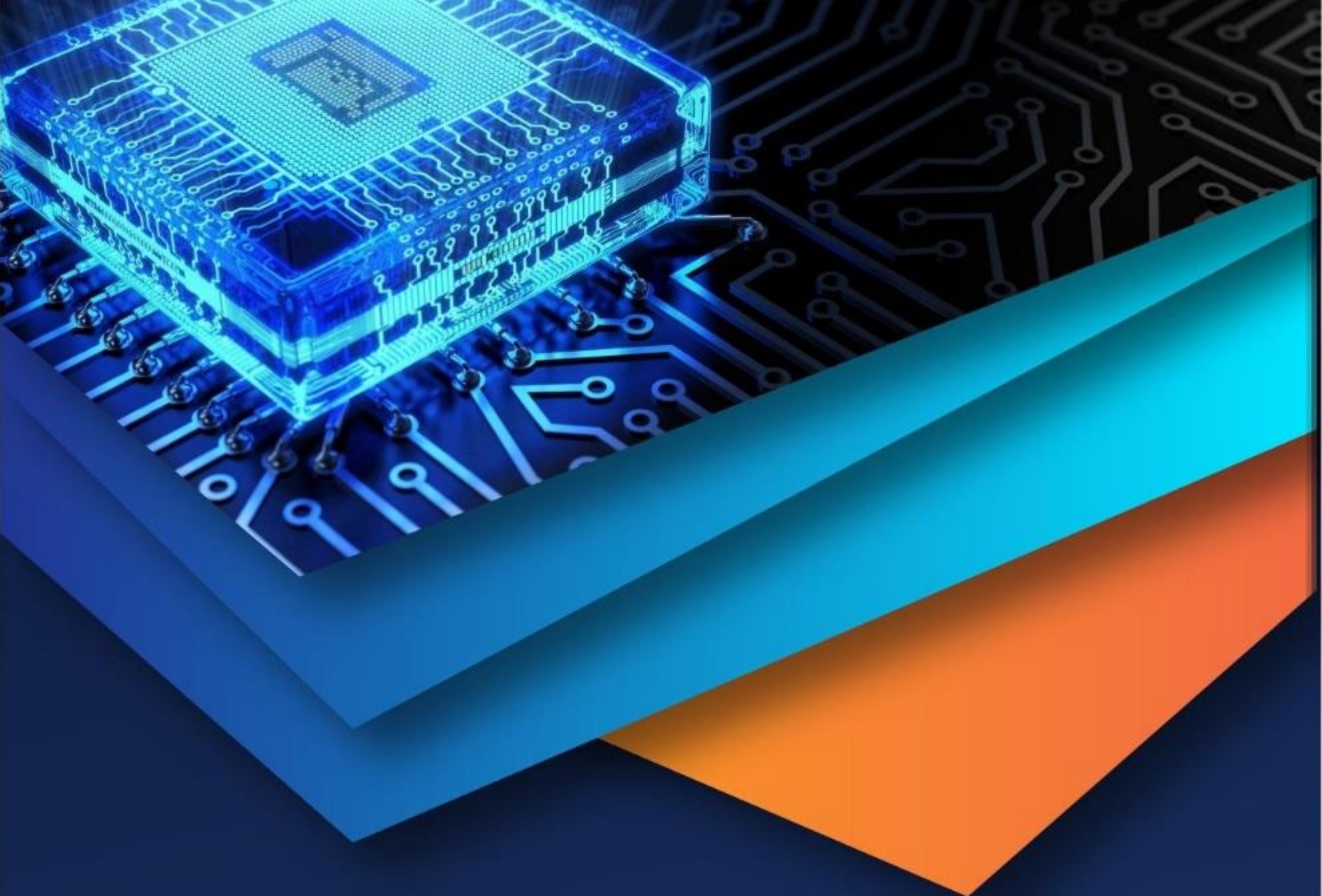

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