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A Sustainable Approach in Bioremediation of Textile Dye Effluent by Microbial Consortia

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Abstract: The humongous load on the environment due to the expulsion of textile dye wastewater has always been a major issue. Significantly, the dye is present in the wastewater due to its complex chemical structure, making it a recalcitrant pollutant. Therefore, becoming highly noxious to flora and fauna of the aquatic ecosystems and crop plants. Due to the low biodegradability, dyes are carcinogenic and mutagenic to plants and human beings. Various physicochemical strategies to treat textile effluent have been used, but because of several drawbacks, they are not implemented by most industries. Microbial decolorization is more eco-compatible and economical as it does not produce any intermediate by-products. Also, it can mineralize the dyes completely and efficiently. Microbes like bacteria, fungi, and algae possess enzymes capable of degrading dyes. These organisms are now in trend with the utilization of mixed culture in comparison to the use of individual strain. Bioremediation of pollutants reduces the toxicity from the soil and water source so that water used for irrigation will no longer be harmful to the plants and eventually to us.
Keywords: Textile, effluent, bioremediation, decolourization, pollutants

I. INTRODUCTION

Industrialization is seen as a critical aspect in a country's economic progress, and the textile industry is among the developing sectors. The number of textile industries is increasing with increasing demand for textile products. These industries thus consume large amounts of water at different processing stages, and at the same rate, wastewater is produced [1]. The mauve colour was the first artificial colourant was introduced by W.H. Perkin in 1856 [2]. After then synthetic dyes have widely substituted natural dyes because of their colour fastness, durability and wide range of shades. Industries use a combination of several hues and their types to get the desirable shades of colour [3]. The amount of these dyes which are consumed in the processing is highly concentrated, that is around 50–300 g/l, along with loads of chemicals [4]. Textile industries release wastewater with toxic substances, including reactive dyes, artificial azo dyes, along with numerous harmful chemicals that pollute the water and increase COD and BOD of water [5]. Specific chemical and physical techniques have been used for dyed textile waste. But these processes have several drawbacks, such as high operational capital and require large areas [1]. Also, it results in the production of intermediate amine residues containing sludge upon decomposition. If the untreated effluent is consumed frequently indicates carcinogenicity to humans. As environmental pollution is a major global threat to public health; and this has given rise to ingenious techniques to restore the environment. These innovative approaches are generally economically and ecologically friendly [6]. The biological treatment of textile dye wastewater varies largely, from any pure microbial cultures or with the combination of cultures because microbes possess dye degrading enzymes [7]. Therefore, enzyme-producing microorganisms can reduce water pollution as an effective alternative. Microbes significantly mineralize azo dyes under successive aerobic and anaerobic conditions. Our current review focuses on the native microbial culture showing the degradation of textile dye effluent and lowering the physicochemical parameters to the safe level. So that industries can discharge the effluent into the waterbody. Degradation of textile dye effluent and lowering the physicochemical parameters to the safe level. So that industries can discharge the effluent into the waterbody.

II. CHARACTERSTICS OF TEXTILE EFFLUENT

Because of the textile effluent’s complex property, industries face difficulty maintaining the WHO standards for the discharge of effluent safely into the waterbody or land in their vicinity. Textile wastewater consists of a mixture of chemicals such as dyes, salts, acids, heavy metals and pigments released at different wet processing stages [9], [10]. Wastewater is characterized by several physicochemical variables such as high pH, colour concentration, temperature, BOD, COD, total suspended solids, total dissolved solids, surfactants, dispersants, harmful chlorinated compounds, sulphide compounds, detergents and many other chemicals to increase the dye absorption on fibres.

Dyes are coloured chemical substance which has a great affinity to water. It is estimated that about 2% of the dye ends up directly into the aqueous wastewater, and approximately unused 10% of the dye is directly lost, during the wet processing and enters into the water source directly [7].

Polluted water can easily be characterized by the presence of colour and becomes the indicator that the receiving water body is severely polluted. The colour of the dye is very strong and are visible even at a concentration of low amount, i.e., one ppm in water. There are many synthetic dyes used in dyeing industries which are categorised on the basis of their chromophore group present, such as azo dyes, disperse dyes, triphenylmethane, nitroso dyes and anthraquinone dyes. These compounds are highly stable and nonbiodegradable due to the complex structure of molecules. That is why conventional techniques cannot remove the colour from the textile dye effluent.

These effluents thus affect the aquatic flora and fauna both. If the same water is consumed for agricultural irrigation purposes affects the crop quality and is found to be carcinogenic and mutagenic because of the noxious components, eventually affecting human beings [10]. Another indicator is the 1:4 ratio of BOD and COD of the wastewater, which stipulates the presence of non-biodegradable substances [11]. Industrial effluent also carries many heavy metals like Cr, Ni, Pb, As, Cu, and Zn, which are again harmful to the environment.

III. TOXIC EFFECTS of TEXTILE DYE WASTEWATER

Based on the origin, dyes can be categorized into natural and synthetic dyes. On the basis of applications, dyes can be vat dyes, azo dyes and dispersive dyes, and on the basis of structures, dyes can be acridine, acidic, basic, oxidation, nitroso, anthraquinone etc. Generally, azo dyes are aromatic dyes used by textile industries for dyeing because of the availability of shades, stability, solubility, easy application and strong bonding to the fibres [12]. Azo dyes have azo (−N=N−) groups and sulfonic (SO^{3-}) groups [13]. Unfortunately, the chromophoric azo group undergoes reductive cleavage that give rises to form the aromatic amines which are highly toxic intermediate compound [14].

Dyes and their amines are found to be carcinogenic, mutagenic and teratogenic in nature. Dye in water lowers the sunlight penetration and can cause eutrophication, thereby affecting the water ecosystem. Moreover, it enters the food chain. If humans consume this water can cause many diseases such as cramps, hypertension, sporadic disorder, etc., with prolonged effect. On testing upon laboratory animals, benzidine-based azo dyes were tumorigenic and a carcinogen in the human urinary bladder. Also, people suffer from allergies to the skin and eye due to its easy inhalation [13].

Workers working in the textile industry were found to suffer from splenic sarcoma, hepatocarcinoma and cancer of the kidney [15]. [16] in 2005 on studying mutagenicity of dyes reported that textile industries use crude dyes without any tests and its effect on environment and observed that dyes which were widely used are harmful and mutagenic. In one of the case studies, farmers were bound to use toxic sludge for the irrigation because of the unavailability of canal water.

The harmful effect on crop plants can easily be recognised by the symptoms such as joint pain, grey hair and plaque in teeth which appeared on the farmers [7]. Therefore, it is strongly required to treat the textile effluents before the safe discharge into the surroundings. Biological treatment system was found to be more efficient and economical over the traditional practice of effluent treatment.

IV. APPROACHES TO TREAT INDUSTRIAL EFFLUENT

Various attempts have been made for the colour removal from textile dye industrial effluents. These methods are divided into physical, chemical and biological processes.

Physical and chemical methods are costly due to the presence of chlorinated lignin, toxicants, colours, suspended solids etc. Biological colour removal and COD reduction has been proven to be quite appealing. It has also decreased BOD and low-molecular-weight chlorolignins [17], [18].

Anaerobic treatment is a type of secondary treatment for industrial wastewater [19]. The electro-fenton procedure is used to remove a combination of synthetic colours from water, and their toxicological effects on the aquatic environment have been documented [20]. Many physical and chemical methods have been used during the treatment process.

Several industries have wastewater treatment plants, although they have not proven very successful. Furthermore, physicochemical treatment of textile effluents is difficult and expensive, resulting in the deposition of significant volumes of sludge and harmful compounds and a secondary degree of land contamination [21]. Only when the volume is limited is this strategy successful, but still, they cannot remove the colour from the water.

Approximately 75% of the dyes are thrown in rivers/ponds and lakes by textile processing industries which consist of mineral salts, acids and dyes [22]. Table I shows the drawback of conventional methods used to treat textile industry effluent.

Physical and Chemical Treatment Methods	Merits	Demerits
Coagulation-flocculation	Simple and economically feasible	Large amount of sludge production, Handling and disposal issue
Membrane separation	All chemical dyes decolorised	Expensive, incapable for large scale treatment
Adsorption on activated carbon	Effectively remove dyes from effluent	Inexpensive against disperse and vat dyes, requires long retention time
Ion exchange	Frequently used with no loss of absorbent	Not effective for disperse dyes
Irradiation	Effective for small scale industry	Huge amount of dissolved oxygen is needed
Oxidation	Efficient and rapid	High energy cost
Advanced oxidation process	No sludge production, efficient on recalcitrant dyes	Economically unfeasible
Fenton's reagent	Efficiently remove colours of insoluble and soluble dyes	Expensive and solid waste production
Photochemical	No sludge and odour produced	Secondary pollutants produced
Electrochemical destruction	Sludge is not produced	High amount of electricity required, poor colour removal

Table I: Merits and demerits of physicochemical treatment methods on textile effluent

V. MICROBIAL DEGRADATION OF DYES

Bioremediation is a new creative approach that is frequently utilised to clean polluted places. Study conducted and development are boosting the proficiency of this technique, which, in addition to the benefit of cost effectiveness, has led to bioremediation becoming a more efficient clean-up solution for the environment. The microbial bioremediation method boosts the rate of breakdown of toxins at contaminated locations, either naturally or by providing these microbes with optimum nutrition and supplement sources, as well as by altering various environmental parameters. This can be accomplished by employing prospective microbes or introducing a culture of enhanced microorganisms (bacteria/fungi) with particular features that allow them to function on the intended location and destroy it quicker while causing no dangers or harm. [14]. Consequently, bioremediation results in the full mineralization of pollutants to water and carbon dioxide with no intermediates formed. The most attractive nature of technology is due to low cost. Hence role of the bioremediation in a wide range of areas including treatment plants, industry effluents sites as well as contaminated soil and environments.

VI. BIOLOGICAL TECHNIQUES

Biological techniques of decolourization use various microorganisms mainly bacteria, fungi and algae to capability to reduced level of dyes/detergents from industrial effluents. Many researchers investigated partial as well as complete degradation of the dyes and detergents when inoculated effluents with microbes either in the form of pure culture or mixed culture.

A. Fungal Decolourization

Many investigations found that fungi with greater potential for degradation of chemical dyes for example, heterocyclic dyes, azo dyes, triphenylmethane, polymeric and phthalocyanine dyes etc [23]. *Irpex lacteus*, *Phanerochaete chrysosporium*, *Pleurotus* sp., *Trichophyton rubrum* and many other lignolytic fungi were commercially exploited for the textile dyes decolourization [24], [25], [26], [27]. It is well known that white-rot fungus release enzymes such as laccases, Manganese Peroxidases (MnP) and Lignin peroxidases (LiP). These enzymes possess the capability of the degradation of lignin [28]. Dye degradation by fungus is accomplished by mainly two methods such as biosorption as well as biodegradation. Textile dye waste has also been decolorised by yeast biomass [29]. White rot fungus *Sachhromyces commune* mainly used in paper and pulp industry for complete degradation [30]. *Tinctoporia borbonica* called white rot fungi consisting of enzyme for decolourize waste liquor release from kraft industry. Wide range of *Penicillum* species have been investigated for dye decolorization potential of effluents [31].

B. Algal Decolourization

Algal species are also useful for absorption of dyes from textile effluents. Many reports on alga such as *Chlorella kessleri*, *Chlorella vulgaris*, *Scenedesmus bijugatus* and *Scenedesmus obliquus* and cyanobacteria strains. Some has reported that many algal species namely *Nostoc muscourm*, *Oscillatoria angusta*, *Anabaena laxa*, *Anabaena subcylindrica*, *Nitzschia perminuta*, *Cosmarium* sp. and *Enteromorpha prolifera* were shown to be an efficient technology to decolorization triphenylmethane dyes [32], [33].

C. Bacterial Decolourization

Many bacterial species degrade azo dyes from textile effluents paves. The decolourization and mineralization of dyes by bacteria has been extensively researched technology that may be used on a broad range of colours [34]. According to the research conducted on real wastewater effluent, a native microbial consortium is an efficiently preferable solution for the breakdown of a wide range of dyes used in industries [35].

The operational expenses are quite minimal, and the finished product is nontoxic Several types of bacterial decomposition of synthetic colours have previously been explored [36]. Breakdown of azo dyes by using anaerobic bacteria is a highly reproducible method that contains degradation of azo dyes and releases degradative products such as aromatic amines. A range of bacteria can discolour and metabolise colours, and their toxicity is comparable to aniline, benzenediazonium chloride, or phenol compounds [37]. Azoreductase is a major enzyme generated by microorganisms that degrade azo dyes, particularly by bacteria and fungus. These enzymes have the capacity to decolorize azo dyes under anaerobic settings by the reduction of an azo bond, resulting in the formation of hazardous aromatic compounds [36].

The other bacteria convert this deadly aromatic chemical to an innocuous substance in an aerobic environment [38]. Azoreductases derived from several bacterial groups and their influence on azo dye decolourisation. [1] has isolated indigenous native bacterial species, *Bacillus cereus, Exiguobacterium aurantiacum, Exiguobacterium indicum and Acinetobacter baumannii* from textile dye effluent of Bhilwara district, Rajasthan and can degrade dye anaerobic bacteria species degrade azo bond and produce non-toxic amines.

1) *Anaerobic Decolorization Process:* Reduction of dyes anaerobically with azo bonds using microorganisms is a cost-effective and an efficient treatment procedure for removing colour from effluent treatment facilities. Few studies reported that anaerobic bacteria break azo bond of dyes [14]. Many of the complex aromatic compounds easily destroy by anaerobic digestion. Some studies in anaerobic environments suggest that some azo dyes and their intermediates can be entirely stabilised or destroyed. Investigation conducted using anaerobes and revealed seven azo dyes' degradation. Several investigations were also conducted employing isolated bacterial strains in vitro cultured for the full removal of dyes from effluent discharge locations. Furthermore, several of the intermediates have been discovered to be mutagenic. These colours can be degraded in both anaerobic and aerobic environments [14]. They evaluated the anaerobic microbe degradability of twenty-two commercial azo dyes [39]. It was confirmed by the breaking of azo bonds, as well as the generation of intermediates. Both observed outcomes showed effective decolorization with minimum nutrient loss. As a result, it was found that anaerobic conditions result in high dye degradation and declourization of textile effluents [40].
2) *Aerobic Decolorization Process:* Waste activated sludge treatment has proven to be cost-efficient in lowering organic contaminants from wastewater systems. It was reported that in some circumstances, aerobic treatment of azo dye wastes was less efficient, but it has proven to be a common technique of treatment utilised today [41]. As aerobic microbes unable to destroy azo linkages, however, anaerobic bacterium able to digest degrades. Aromatic compounds led to accumulation in living tissue and further created health hazards and found severe disease complication. *Bacillus subtilis* degraded an aromatic amine, p-aminoazobenzene in a batch experiment [42]. Several investigators have also reported for the decolorization of azo dyes aerobically [14].
3) *Anaerobic-Aerobic Process:* Basically, degradation of azo dye has been successfully reported by bacterial action. Initially reduction of azo dyes by anaerobic-aerobic produce non-hazardous compounds. The second way consists of the complete detoxification of noxious aromatic amines under anaerobic conditions, whereas, biodegradation using microbes containing aromatic amines is completely an oxidative method [7]. One of the robust methods for removing azo compounds from the effluent is the use of both anaerobic and aerobic technique subsequently. Azo dyes are degraded by anaerobic reduction which can led to form intermediate aromatic amines. Secondly, followed by aerobic treatment of aromatic amines which are generally hazardous and carcinogenic. Furthermore, multiple investigations have shown a substantial amount of data for the elimination of intermediates using both anaerobic-aerobic method. Hence, it is recognised as the most dependable and efficient instrument for the complete decomposition of azo dyes from wastewater [3]. Many studies have been conducted to compare anaerobic and aerobic efficient methods for decomposing textile colours. The most common way for azo compounds to enter the soil and waterbody is through the discharge of wastewater on agricultural field or in landfills. Because dyes are insoluble, some of them will persist in soils after they are discharged into the environment. In soil, several azo colourants bio transform into aromatic amines [43].

VII. IMPORTANCE OF TREATMENT WITH MICROBIAL CONSORTIUM OVER PURE CULTURE

Textile effluent dye decolourisation is effective when treated with bacterial pure cultures; however, some bacterial isolates are unable to degrade azo dyes completely and are responsible for the genesis of intermediate compounds such as aromatic amines. Aromatic amines are carcinogenic and is required to be treated ahead [14]. Therefore, if the treatment consists of mixed community of microbes, then aromatic amines will be mineralised by metabolic actions of the microbial communities. In a consortium, different strains attack the complex dye molecule at different sites or may use secondary products produced by the microbes for further complete mineralization. Co-culture or mixed cultures are significantly beneficial over the use of pure/mono cultures [44], [45], [46]. The bacterial and fungal consortium has significantly found to be an effective, eco-friendly, and has the capability of degrading the dyes in less time. Table II and table III depicts the decolourization by pure cultures as well as by the consortium.

VIII. IMMOBILIZATION OF MICROBIAL CELLS/ ENZYMES

Another recent technique which has gained attention in decolourization of textile effluent is immobilization. Either immobilising whole cells of bacteria, fungi and both or their enzymes after extraction. Moreover, immobilised technique has more advantage over freely suspended cells as immobilised cells can be further recovered and reused again. Thus, it protects the biomass from direct exposure of toxicants and are economical too. In this technique natural gels are used for cell immobilization. Synthetic gels are also used but it can decrease the cell viability [47]. [48] showed the bioremediation efficiency of co-culture of *Pseudomonas aeruginosa* and *Bacillus subtilis* when used in immobilized form on industrial effluent. Another report which showed the remediation of textile effluent efficiently by using immobilized *Streptococcus faecalis* gave the highest decolorization activity and pH reduction [49].

Strain	Dye	Time	Reference
Candida krusei	Basic Violet 3	24 hours	[50]
Candida tropicalis TL-F1	Acid Brilliant Scarlet GR	24 hours	[51]
Trichosporon beigelii	Navy Blue HER	24 hours	[52]
Trichoderma tomentosum	Acid Red 3 R	72hours	[53]
Trametes versicolor CBR43	Acid, Disperse and Reactive dyes	9 days	[54]
Marasmius cladophyllus UMAS MS8	Remazol Brilliant Blue R	15 days	[55]
Aspergillus niger	Congo Red	6 days	[56]
Coriolopsis sp. strain arf5	Biebrich Scarlet, Direct Blue 71, Orange G, and Ponceau 2R	12 days	[57]
Alcaligenes aquatilis	Synazol Red 6HBN	4 days	[58]
Providencia rettgeri strain HSL1	Reactive Blue 172	20 hours	[59]
Arthrobacter soli BS5	Reactive Black 5	5 days	[60]
Pseudomonas extremorientalis BU118	Congo Red	24 hours	[61]
Halomonas sp. strain A55	Reactive Red 184	24 hours	[62]
Bacillus cereus	Textile effluent	48 hours	[1]

Table II: Report on Microbial Pure Culture Capable of Dye Decolourization

Consortium	Dye	% Degradation	Reference
Trametes sp. SQ01 *Chaetomium* sp. R01	Acid Blue17 Acid Blue15 Crystal Violet Malachite Green Brilliant Green	86 % 85 % 82 % 82 % 85 %	[63]
Aspergillus lentulus *Aspergillus tereus* *Rhizopus oryzae*	Acid Blue 98 Pigment Orange	100 %	[64]
Bacillus flexus NBN2 *Bacillus cereus* AGP03 *Bacillus cytotoxicus* NVH *Bacillus* sp. L10	Direct Blue 151 Direct Red 31	98 % 95 %	[65]
Providencia sp. SDS (PS) *Pseudomonas aeuroginosa* strain BCH	Red HE3B	100 %	[66]
Citrobacter freundii (2 strains), *Moraxella osloensis, Pseudomonas aeruginosa and Pseudomonas aeruginosa* BL22	Mordant Black 17	95 %	[67]
Proteus vulgaris *Miccrococcus glutamicus*	Green HE4BD	100 %	[46]
Aspergillus ochraceus NCIM-1146i *Pseudomonas sp.* SUK1	Rubine GFL	95 %	[68]
Bacillus subtilis Bacillus cereus	Textile effluent	84 %	[69]
A. ochraceus NCIM 1146 and *P. rettgeri* strain HSL1	Textile effluent	92 %	[70]
Pseudomonas sp., *Brevibacillus* sp. and two strains of *Stenotrophomonas* sp.	Dye mixture	94 %	[71]
Pseudomonas, Arthrobacter, and Rhizobium	Acid Orange 7	90.97 %	[72]
Escherichia sp., Enterococcus sp. and Pseudomonas sp.	Remazol Brilliant Violet 5R	100 %	[73]
Consortium of *Purple Non-Sulfur Bacteria (PNSB)*	Reactive Red	97.68 %	[74]

Table III: Dye Decolourization by Consortium

IX. BIOREMEDIATION: CURRENT LIMITATION AND INDUSTRIAL RESOURCES IN INDIA

There have been several accounts of indigenous microorganisms, such as dye-degrading bacteria and fungus, being employed to remove colour from industrial wastewater simultaneously. Chemical, sugar, distillery, paints, dyes, and textiles are only a few of the industries in Tamil Nadu's Chennai, Coimbatore, Tirupur, and Kurur. The textile effluents in the southern region have received a lot of attention in the discovery of possible dye-decolorizing bacteria and demonstrating the bioremediation property. Tanda, Varanasi, Lucknow, Kanpur and other places in Uttar Pradesh have industries, particularly the carpet sector in Bhadohi, where a lot of work is being done to clean the effluent produced. Bacteria with good bioremediation properties are separated from their natural environment. Jaipur and the surrounding areas of Rajasthan such as Bhilwara, Pali, Sanganer have thousands of printings and dyeing sectors, the majority of them are from these areas. These regions are suffering a lot with water pollution from textile industries [75], [76].

X. CONCLUSION

When dealing with textile effluents, a strong and proficient method of treatment is essential to solve the issue of residual colour and preventing costly post-treatment processes. Recently decolorization of dyes using microbes has earned a lot of attention because it is a cost-compatible dye removal process. In recent years, the trend has shifted toward using mixed bacterial cultures rather than practicing using particular strains. It is widely known that pollution reduces the quality of the environment in a variety of ways and has an impact on health and life expectancy; consequently, bioremediation of toxic pollutants to reduce their harmful effects is uttermost importance.

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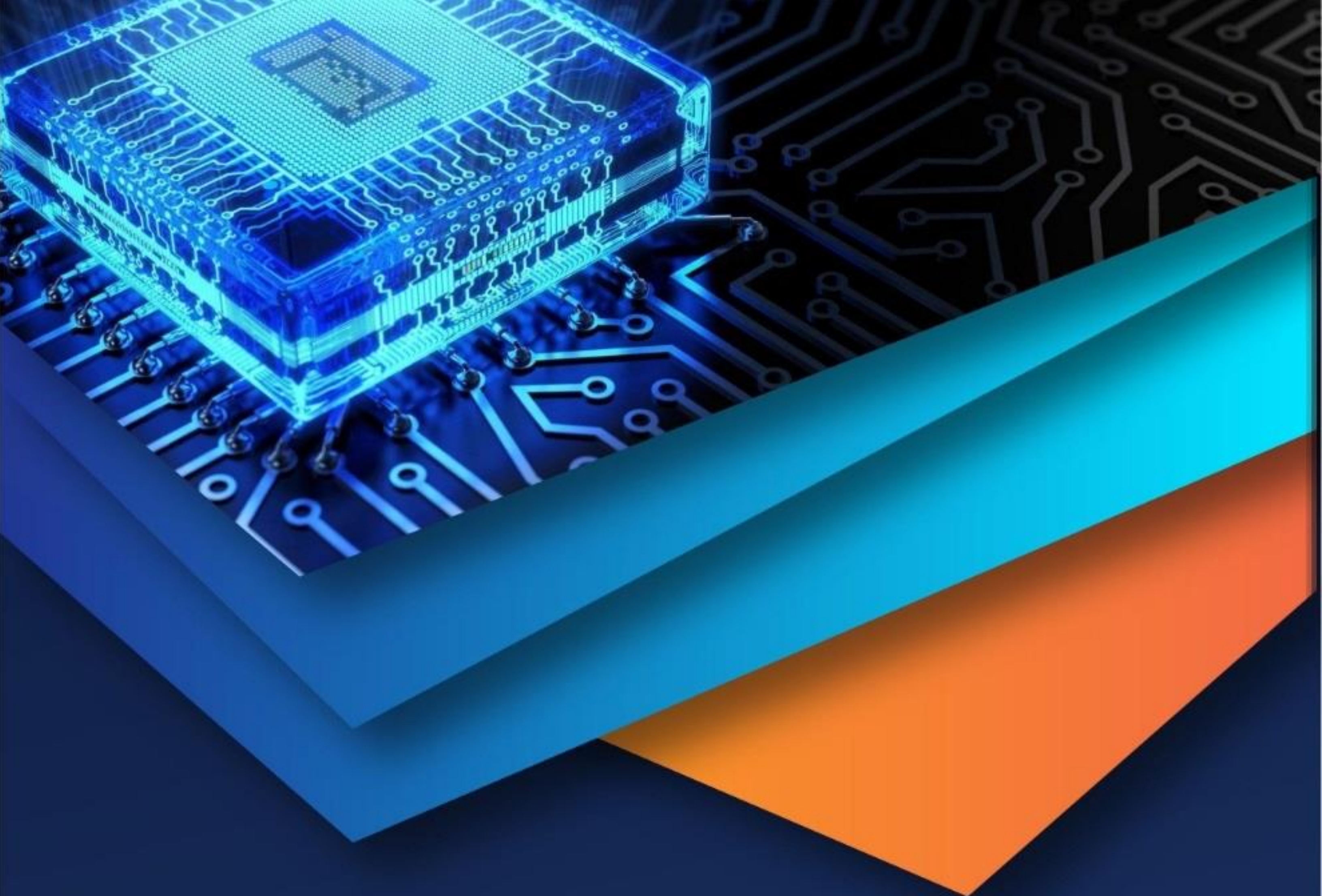

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