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A CRITICAL REVIEW ON THE ROLE OF ELECTROCHEMISTRY IN THE TREATMENT OF TEXTILE WASTEWATER

CHANDRA KANT BHARDWAJ,
Department of Chemistry, Graphic Era Hill University,
Dehradun, Uttarakhand, India 248002

ABSTRACT -
The textile sector is one of the primary contributors of wastewater, and the discharge of textile wastewater that is highly pigmented and poisonous poses substantial challenges to the natural environment. This article provides an analytical analysis of many different treatment strategies for textile effluent, along with the costs associated with each approach. Several different techniques, such as oxidation (cavitation, photocatalytic oxidation, ozone, H2O2, and Fenton's process), physical (adsorption and filtration), and biological (fungi, algae, bacteria, and microbial fuel cell) techniques, are addressed in this article.
In addition to this, the article provides suggested remedial techniques for addressing the various forms of wastewater that are created from each textile process. This article's goal is to offer a full knowledge of the many treatment technologies that are available for textile wastewater and their efficiency in treating the highly pigmented and hazardous effluent. This information will be presented in the form of a review.

INTRODUCTION –

The textile industry is a significant contributor to the production of wastewater that has a limited potential for biodegradation and high concentrations of contaminants that are known to cause cancer and other harmful effects. As a result, the treatment of wastewater from the textile industry is necessary for the preservation of aquatic life and general public health (Azizi, 2019). Oxidation, physical, biological, and physiochemical treatment technologies are only some of the options that are now available for dealing with effluent from the textile industry. Phases referred to as primary, secondary, and tertiary are often included in the therapy process. For the treatment of textile wastewater, it has been discovered that both physical and chemical procedures, such as ion exchange and adsorption, as well as advanced oxidation techniques, such as electrocoagulation and photocatalysis, are efficient. In addition, bacterial microorganisms have been shown to be effective in degrading and decolorizing textile dyes that have been found in wastewater (Holkar, 2016).
Constructed wetland systems have been demonstrated to be an effective, low-cost solution for treating a wide variety of waste streams, including textile wastewater. These systems are also known as engineered wetlands. The use of nanotechnology as a cutting-edge method for the removal of synthetic dyes, heavy metals, and harmful compounds from textile wastewater is currently being researched (Basha, 2018, Azizi, 2019).
Treatment of textile wastewater can involve a variety of different approaches, including chemical, biological, and physical processes. These approaches are vital for conserving the environment and human health by minimising the harmful influence that textile dyes have on both the health of humans and the ecosystems in which they are found. The treatment of wastewater not only safeguards human health and the environment, but it also helps to save resources and restore lost energy (Khan, 2014).
Because of the enormous demand for polyester and cotton in India, which results in the consumption of 80% of the country's dyestuff output, there is a substantial negative impact on the environment caused by wastewater from the textile industry. Due to limited light penetration, oxygen consumption, and toxicity, the discharge of these colours into wastewater has significant repercussions for plant photosynthesis and aquatic life. These repercussions are caused by the dyes. According to Khan (2014), particles that are suspended in water can have a negative impact on marine life by obstructing the breathing of fish and reducing the ability of algae to create food and oxygen. In addition, the use of these dyes can disrupt particular processes that are utilised in the treatment of municipal wastewater, such as UV decontamination. According to Gosavi (2019), it is thus very necessary to put

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appropriate treatment technologies into place in order to reduce the harmful effects that textile wastewater has on the surrounding ecosystem.

Not just in textile wastewater, but also in any complex matrix, aromatic and heterocyclic dyes used in the textile industry provide a substantial problem when it comes to their degradation because of the intricate and stable structure of these colours. The mineralization of these dyes and other organic compounds in the wastewater from textile production is a significant difficulty and an environmental concern. As a result, it is necessary to get an understanding of and develop efficient technologies for the treatment of textile wastewater in order to solve this issue (Gosavi, 2019).

The purpose of this article is to offer a detailed review of the numerous wet processing procedures that are utilised in the cotton textile industry, as well as the expenses connected with the various ways that are utilised for the treatment of the colours that are present in textile wastewater. In addition, the methods of dye removal from industrial effluents that are most often utilised, such as chemical, physical, and biological treatments, will be subjected to an in-depth analysis within the scope of this review article.

2. TEXTILE OPERATIONS

The wet processing of textiles includes a number of phases, including the production of fibres, the transformation of the fibres into yarn, and the modification of the yarn into fabric. Fig. 1 (Vigo, 2013) illustrates some of the stages that are involved in the wet processing of textile materials; these stages will be discussed in greater depth in the subsequent sections.

In general, the following are included among the wet processing phases of textile fabrics:

• Pre-treatment: This step involves eliminating impurities from the fabric using procedures like as singeing, desizing, scouring, and bleaching in order to get it ready for the subsequent processing steps. These impurities include dirt, oil, and natural wax. (Jadhav, 2019)

• Dyeing: The material is given its colour using a variety of dyeing techniques, including direct, reactive, dispersion, vat, and acid dyeing, among others. (Jadhav, 2019)

• Printing: The fabric is embellished with designs by employing a variety of printing techniques, including rotary printing, screen printing, and digital printing, among others. (Jadhav, 2019)

• Finishing: The fabric is given a finish that consists of operations that improve its qualities, such as making it softer, making it water repellent, and making it less likely to wrinkle. (Jadhav, 2019)

Each of these phases results in the production of wastewater that contains a variety of contaminants, including dyes, chemicals, and suspended particles, and this water must be treated before it can be released back into the environment. Depending on the kind and number of contaminants that are found in the wastewater, a variety of treatment processes may be utilised.

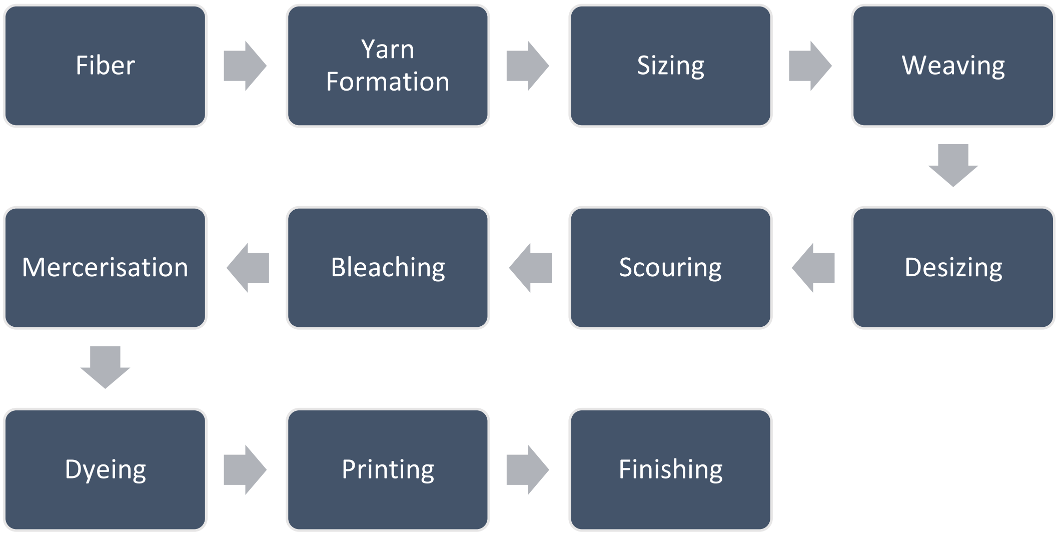

Fig. 1. A flow diagram illustrating the many procedures that go into the wet processing of cloth.

2.1. Sizing and desizing

Other chemicals, such as lubricants, surfactants, and sizing agents, can have an impact on the stages of the wet processing of textiles if they are present. Lubricants and surfactants are added to the

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manufacturing process to make it easier, but they need to be removed before the dyeing or printing process can begin.

According to Sivakumar et al. (2016), these compounds can be removed by the processes of coagulation, precipitation, and filtering. Some examples of these procedures are alum coagulation, lime coagulation, and activated carbon filtration. Polyvinyl alcohol (PVA), polyacrylates, polyethylene glycol (PEG), and starch are the primary components of the sizing agents, and all of these substances are non-toxic in their natural states.

But the levels of biological oxygen demand (BOD) and chemical oxygen demand (COD) in the effluent go up when there are sizing agents present in the wastewater. As a result, they need to be eradicated before the effluent is allowed to be released into the environment.

2.2. Bleaching

Bleaching is a technique that entails the removal of natural colour matter from fabrics in order to generate a white cloth that can then be used to create brighter tones of the same hue. Hypochlorite was the bleaching chemical of choice in the past, but today, more ecologically friendly alternatives like as hydrogen peroxide and peracetic acid are employed instead. (Hayat, 2019)

It is believed that peracetic acid is a superior substitute for hypochlorite since it is safer for the environment and has less adverse effects on the treated fabric than hypochlorite does. The use of peracetic acid has a number of advantages, one of the most significant of which is that it gives the fabric a greater lustre while simultaneously inflicting less damage to the yarn. Because of this, it is the material of choice for producers who want to develop high-quality fabrics that are not only long-lasting but also aesthetically pleasing. (Jadhav, 2019)

Therefore, the use of peracetic acid as a bleaching agent is a significant achievement in the textile sector, and its acceptance is expected to continue to expand as more manufacturers attempt to limit the impact that they have on the environment and create high-quality products.

2.3. Mercerization

The technique of treating cotton textiles with sodium hydroxide and so improving their qualities such as lustre, colour uptake, and absorbency is referred to as mercerization. The method is treating the fabric with a high concentration of sodium hydroxide solution, which causes the cotton fibres to expand and then shrink longitudinally. The end result is a fabric that has a unique texture and appearance. (Kousha, 2018)

During the treatment, the cloth may be stretched out or held under tension in order to prevent the longitudinal shrinkage that would otherwise occur. Following the application of the treatment, the excess caustic is removed from the cloth by washing it while the fabric is being stretched. As a consequence, the fabric acquires the desirable features of lustre, enhanced absorbency, and ease of colour uptake (Kousha, 2018). It is possible to employ membrane methods or multiple effect evaporators in order to recover the sodium hydroxide that was lost in the wash water. These methods serve to lessen the toll that the process has on the surrounding environment while also lowering its overall cost. (Jadhav, 2019)

2.4. Processes of colouring and printing

The technique of colouring cloth or yarn by applying it with dye is known as dying. Dyeing can be done on either fabric or yarn. The colour originates from chromophore groups such as azo, carbonyl, nitro, and quinoid groups, as well as auxochrome groups including amine, carboxyl, sulphonate, and hydroxyl. According to Kousha (2018), the two most significant categories of chromophores are azo and anthraquinone. However, these chromophores are also capable of causing pollution, which can result in an unacceptably coloured effluent from the textile industry.

Figure 2 illustrates the several categories of dyes that may be utilised for colouring a variety of fibre types. The primary reactions that take place during the printing process are quite comparable to those that take place during the dying process. However, in order to keep the dye from spreading, it is often placed in the form of a thick paste while printing. The waste components found in printing effluent are quite similar to those found in dyeing effluent.

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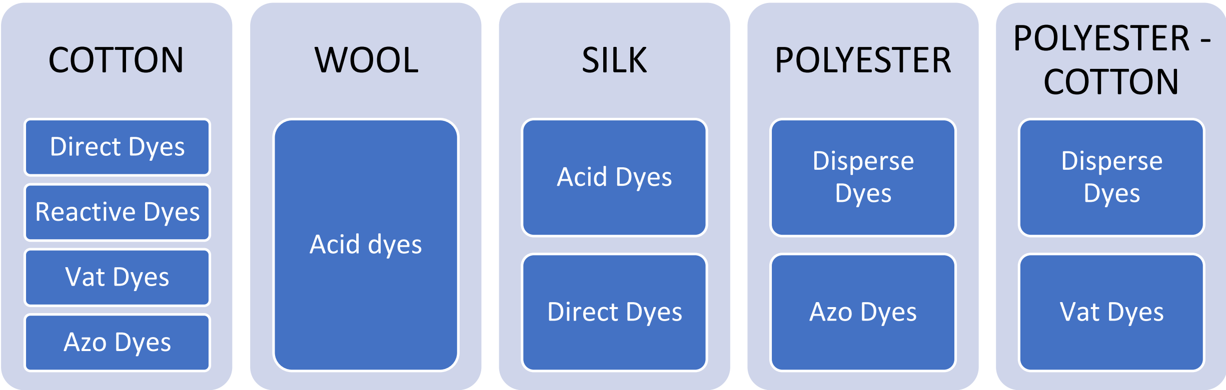
In general, the dyeing and printing processes can both produce wastewater that may contain toxins and waste components. This wastewater must be handled appropriately in order to reduce its negative influence on the environment.

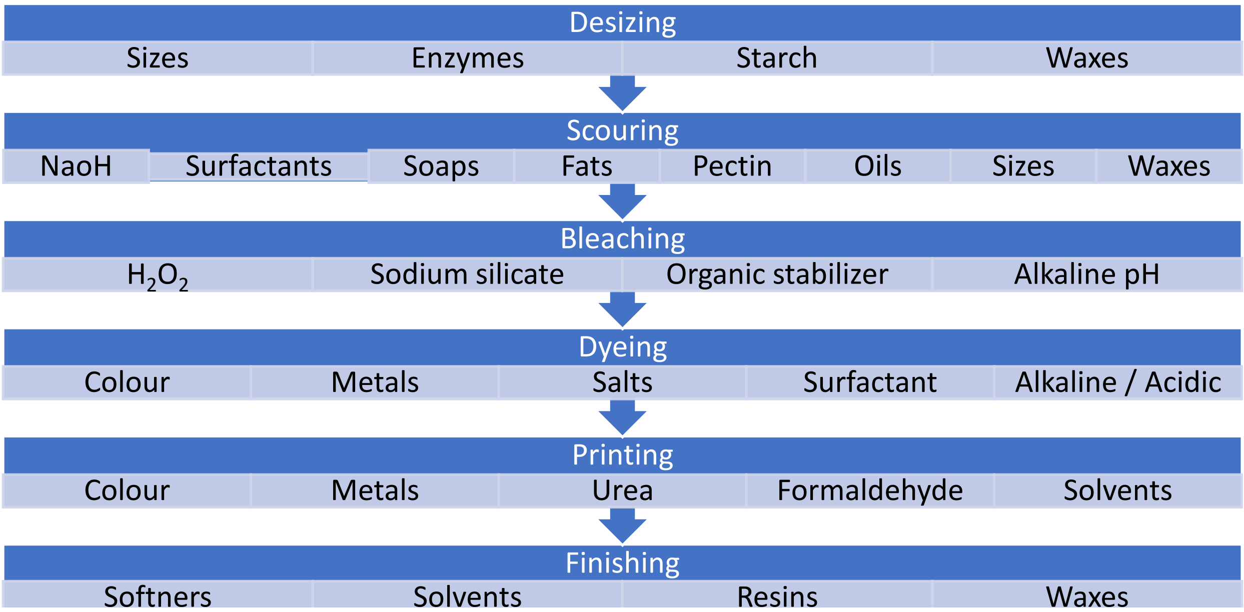
2.5. Finishing



Finishing techniques are performed on fabrics in order to improve particular features of the fabric, such as its level of softness, waterproofing, antibacterial capabilities, and UV protection. However, due to the release of a wide variety of contaminants throughout the various phases of wet processing, these finishing procedures can also contribute to the contamination of water. (Kara, 2018)

In the textile business, several steps of wet processing might potentially result in the production of a number of typical water pollutants, which are listed in Fig.3. Compounds that are both organic and inorganic can be considered pollutants. Examples of organic pollutants include dyes, surfactants, and solvents, whereas examples of inorganic pollutants include salts, acids, and alkalis.

These contaminants have the potential to have a negative impact, not only on aquatic life but also on human health. Because of this, it is essential for the textile industry to make use of effective methods for the treatment of wastewater in order to get rid of these pollutants and lessen the damage they do to the environment. Biological treatment, chemical treatment, and membrane filtration are all popular types of wastewater treatment practises utilised in the textile sector.



3. THE TEXTILE INDUSTRY STANDARDS FOR WATER POLLUTANTS

In the textile business, the criteria for the discharge of wastewater might vary based on the types of raw materials, colours, and equipment that are used, in addition to a number of other considerations. As a consequence of this, the criteria for the release of wastewater can be fairly complicated and comprehensive, as shown in Table 1 of the research carried out by Paul et al. (2012).

In most cases, the national environmental protection department, such as the Central Pollution Control Board (CPCB), is the one responsible for establishing these criteria in order to guarantee the

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wellbeing of the environment as well as the communities located in its immediate vicinity. The particular standards, on the other hand, are subject to change based on the local environment and the prerequisites for environmental safety. For this reason, it is very necessary for companies related to textiles to comply with these regulations and take preventative measures to guarantee that their wastewater is treated and managed appropriately.

Sl. No.	Parameters	Standards
1	pH	6.9
2	BOD	30 ppm
3	COD	250 ppm
4	TDS	2000 ppm
5	Sulphide	2 ppm
6	Chloride	500 ppm
7	Calcium	75 ppm
8	Magnesium	50 ppm

Table 1 Standards for water contaminants imposed by the Indian Textile Industry In addition, it is of the utmost importance to emphasise that it is not sufficient to only comply with legal criteria in order to accomplish sustainable practises in the textile business. In order to lessen the negative effects that the manufacture of textiles has on both the environment and society, it is essential to take a comprehensive strategy that places a premium on the conservation of resources, the avoidance of pollution, and the implementation of environmentally responsible manufacturing practises. (Hayat, 2019)

Metal ions, dyes, and the colours they produce are key causes for worry when it comes to textile wastewater because of the damage they do to both the environment and human health. A large area of effort in recent years has shifted towards the recovery and reuse of wastewater. This is a direct result of the limited availability of water resources. Therefore, there has been a rise in the popularity of technologies that can create water that can be reused, eliminate toxicity, mineralize aromatic chemicals, recover dyes and salts, and either do not produce hazardous sludge or produce minimum amounts of sludge overall. (He, 2020)

In spite of the fact that colour removal technologies were absolutely necessary thirty years ago, now days they are well-established and generally understood. As a result, the focus of current research is on developing treatments for wastewater that can mineralize dyes while also removing their hazardous effects. These procedures encompass physical, chemical, and biological treatments such as advanced oxidation processes, electrochemical processes, and microbial degradation. Other examples are advanced oxidation processes, electrochemical processes, and advanced oxidation processes. The goal of these technological advancements is to convert the dye molecules into non-hazardous byproducts like carbon dioxide and water. (Hayat, 2019)

Furthermore, due to the high economic worth of precious materials such as dyes and salts, recovery and reuse of these resources is becoming an increasingly important practise. For the purpose of extracting useful materials from textile wastewater, innovative methods such as membrane filtration, adsorption, and ion exchange are now in the research and development stage.

4. TREATMENT PROCESSES FOR TEXTILE WASTEWATER

The wastewater produced by cotton dyeing companies is particularly contaminated due to the presence of reactive dyes, which are difficult to treat using biological processes (Lade, 2020). Textile wastewater is highly coloured, has a high biological oxygen demand and chemical oxygen demand (BOD/COD), and has a high salt load (TDS). The dark colour of the wastewater blocks out a significant portion of the light that is necessary for the growth of aquatic species, which in turn generates an unnatural state of affairs in the surrounding environment. Therefore, it is very necessary to treat wastewater from textile industries before discharging it into rivers in order to both avoid the pollution of water resources and reduce the expense of treating river water that is used for purposes of drinking(Kousha, 2018).

It has become possible to treat textile wastewater in a manner that is both cost-effective and effective thanks to the development of a number of different treatment procedures, including physical, chemical, biochemical, and hybrid treatments. It is possible for suspended particles and colour to be

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successfully removed from wastewater via the utilisation of physical treatments such as sedimentation, filtration, and membrane techniques. Chemical treatments such as coagulation, adsorption, and oxidation are three examples of processes that have the potential to successfully remove colour and other impurities from wastewater. Activated sludge, anaerobic digestion, and biofilm reactors are all examples of biochemical processes that are capable of efficiently degrading organic materials found in wastewater(Lade, 2020).

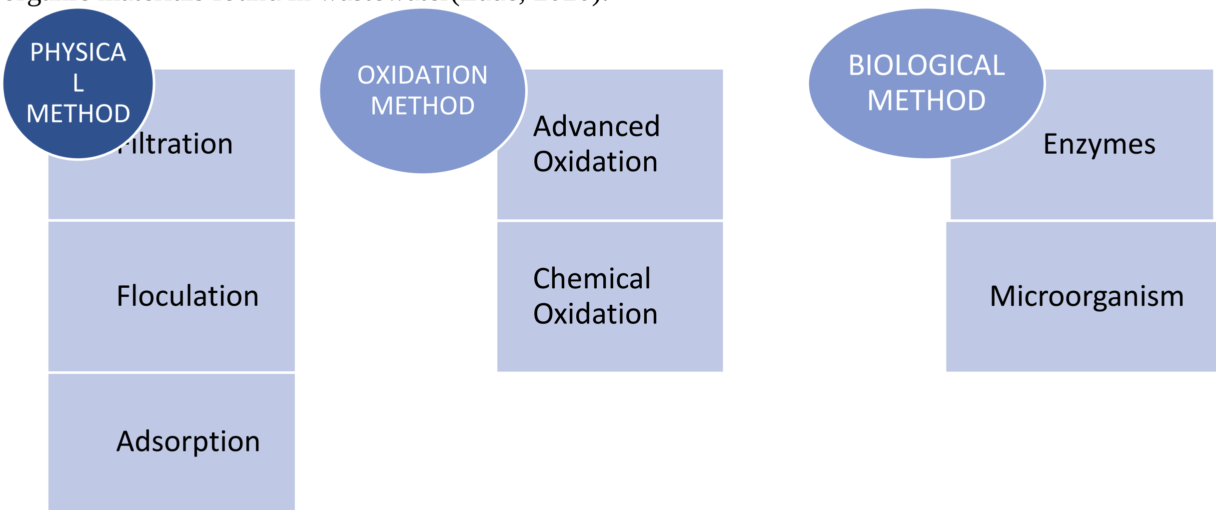

Fig. 4. Methods of treatment for the breakdown of colours in wastewater from the textile industry.

Additionally, hybrid treatments that mix physical, chemical, and biological processes can achieve better removal efficiency and higher cost-effectiveness than traditional treatments can. The efficacy of these methods in the treatment of wastewater from the textile industry has been demonstrated and substantiated. It is imperative that the textile industry put into place these treatment techniques and give priority to sustainable practises in order to lessen the negative effects that the manufacturing of textiles has on both society and the environment.

4.1. Physical methods

The treatment of wastewater that contains dispersion colours often involves the use of physical procedures that are based on either coagulation or flocculation. These techniques involve adding chemicals to the wastewater, such as coagulants and flocculants, which causes the production of bigger particles that are then able to be readily separated from the water. (Kousha, 2018)

On the other hand, the efficacy of these procedures is reduced when used to the treatment of wastewater that contains vat and reactive dyes. While vat dyes are very stable and require harsher treatment conditions, reactive dyes are highly soluble and can withstand the coagulation-flocculation process. In addition to this, the physical methods can produce enormous volumes of sludge, the correct disposal of which can be difficult and expensive.

As a consequence of this, it is possible that further advanced treatment strategies, such as membrane filtration, sophisticated oxidation processes, and biological treatments, will be necessary in order to treat wastewater that contains reactive and vat dyes. When it comes to eliminating dyes and cutting down on the production of sludge, some approaches may prove to be more successful and efficient than others.

In order to salvage and repurpose water, the textile industry frequently makes use of filtration processes such as ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO). The composition of the textile wastewater as well as the temperature of the wastewater are factors that must be considered when selecting a filter and determining the permeability of the filter. (Rodrigues, 2021). The utilisation of membranes in the textile sector carries with it the intriguing possibility of recycling hydrolyzed reactive dyes and auxiliaries that are utilised during the dying process. A substantial advantage for the environment may be realised as a result of this, which is a reduction in both the biological oxygen demand (BOD) and the chemical oxygen demand (COD) of colour found in textile effluent. (Rodrigues, 2021)

However, membranes also have a number of significant drawbacks, such as their high initial investment cost, the possibility of fouling of the membrane, and the formation of extra waste

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comprising water-insoluble colours (such as indigo dye) and starch, both of which require further treatment.

4.2. Oxidation methods

Oxidation methods, which are often straightforward to implement, are the most frequent means of accomplishing the chemical destruction of colours. Chemical oxidation and advanced oxidation processes (AOP) are the two distinct types of this technology that may be distinguished from one another. Under natural conditions, any one of these processes has the potential to entirely or partially breakdown the initial hazardous chemicals, dyes, and pesticides, as well as the byproducts of these substances. (Miralles-Cuevas, 2017)

The degradation of the target chemicals can be accomplished by the use of advanced oxidation processes (AOP), which entail the use of highly reactive oxidising agents such hydroxyl radicals (OH). Photolysis, sonolysis, and the Fenton reaction are all examples of alternative oxygen processes. Chemical oxidation, on the other hand, involves the use of powerful oxidising agents like chlorine, ozone, or hydrogen peroxide in order to break down the chemicals that are the focus of the process. (Paul, 2018)

The hybrid advanced oxidation process, also known as AOP technology, is a combination of many distinct oxidation processes that can improve the efficacy and efficiency of the degrading process. In the realm of environmental remediation, the utilisation of hybrid procedures like these, which are able to treat a wide variety of contaminants, is becoming an increasingly common practise. (Paul, 2018)

The formation of hydroxyl radicals, which are vigorous oxidising agents with a high oxidation potential, is essential to the operation of advanced oxidation processes (also known as AOP). They are capable of oxidising a large variety of complex organic and inorganic compounds that are found in textile effluent water, and they react fast with the majority of the dyes. (Miah, 2019)

Cavitation, which may be created either by ultrasonic irradiation or using hydraulic devices such as orifices and venturis, is one way to accomplish AOP processes. Cavitation can be used to achieve AOP processes. Another type of AOP is called photocatalytic oxidation, and it is characterised by the utilisation of light from the sun to activate semiconductor catalysts. The Fenton reaction is a kind of aerobic oxidation process (AOP) that includes the interaction between $Fe3+$ ions and $H2O2$. This reaction accelerates the oxidation of complex organic contaminants that are resistant to being broken down by biological means. In this procedure, Fenton's reagent is frequently utilised as a chemical promoter, and its most common application is with an iron salt. (Song, 2019)

Although it has been demonstrated that the Fenton approach is successful in the degradation of both soluble and insoluble dyes, this method does have the downside of producing iron sludge as a result of the simultaneous flocculation of the reagent and dye molecules. In general, AOP procedures provide a potential technique for the degradation of dyes and other contaminants that can be found in textile effluent water. It is conceivable that these procedures will become even more successful and efficient as research into this field progresses. (Miah, 2019)

In addition, the production of ozone necessitates a significant amount of energy, which results in a high level of energy consumption during the process. The concentration of hydrogen peroxide ($H2O2$) in a solution, as well as the pH of the solution and the presence of transition metal ions, all have a role in determining how efficient $H2O2$ is as an oxidising agent. In the presence of transition metal ions like $Fe2+$ or $Cu2+$, $H2O2$ has the potential to produce hydroxyl radicals, which can ultimately lead to the effective degradation of dyes. However, because of its relatively expensive price, $H2O2$ is not widely used in industrial applications. Additionally, the utilisation of $H2O2$ might result in the production of poisonous byproducts, particularly when it is combined with metal ions in the environment.

Ozonation as a technique for treating textile wastewater is fraught with various drawbacks that must be considered. Because the half-life of ozone in water at neutral pH is so short, constant ozonation is required, which incurs additional costs. In addition, the stability of ozone is affected by a number of factors, including the presence of salts, pH, and temperature, which requires continuous monitoring of the effluent (Khan, 2014). In addition, the combination of ultraviolet radiation (UV) and hydrogen peroxide in a treatment can degrade dyes by creating large concentrations of hydroxyl radicals, which is a necessary step in the process. Although this approach does not result in the production of sludge or unpleasant smells, it does require the optimisation of numerous factors, such as the strength of the

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UV radiation, the pH, and the structure of the dye molecule, in order to get the best possible outcomes (Khan, 2014).

4.3. Biological methods

There is a wide variety of biological treatment methods available for textile wastewater. These biological procedures involve the employment of microorganisms to remove dissolved materials. The effectiveness of this process is determined by a number of criteria, the most important of which are the ratio of organic load to dye, the load of microorganisms, the temperature, and the concentration of oxygen. (Khan, 2014). Based on the amount of oxygen that is required, there are three different types of biological processes: aerobic, anaerobic, and anoxic or facultative. Anaerobic processes include the use of microorganisms in the absence of oxygen, in contrast to aerobic processes, which involve the use of bacteria in the presence of oxygen. Anaerobic techniques are utilised to treat wastewater with high COD, followed by aerobic polishing treatment (Gogate, 2018). The combination of anaerobic and aerobic treatments is a popular treatment strategy.

Treatment with anaerobic bacteria can result in the production of methanogenic biogas, which has the potential to have some calorific value and can be employed in the production of energy. Microorganisms are able to acclimatise to the textile dyes used in these biological processes, and as a result, new strains arise spontaneously to convert the colours into less harmful forms. (He, 2020). In the process of biodegradation for refractory colours, enzymes including laccase, lignin peroxidase, NADH-DCIP reductase, tyrosinase, hexane oxidase, and aminopyrine N-demethylase play important roles. According to Gogate (2018), biological approaches are not only an effective but also ecologically beneficial solution to remediate wastewater from the textile industry.

The total decomposition of textile wastewater may be accomplished by the use of biological processes, which have a number of benefits, including the following:

• Beneficial to the environment: Biological processes are an environmentally beneficial coice for treating wastewater since they rely on naturally occurring processes. They do not rely on the usage of harsh chemicals, which is advantageous because such substances may be detrimental to the environment.

• Biological techniques can be cost-competitive when compared to physical or oxidation methods since they do not require expensive equipment or chemicals. This makes it possible for biological methods to be more cost-effective.

• Produces less sludge than physical or oxidation procedures: In general, biological methods create less sludge than physical or oxidation methods. This results in a reduction in both the expense and the impact that the disposal of the sludge has on the environment.

• Production of non-hazardous metabolites or complete mineralization: Biological processes have the ability to either generate non-hazardous metabolites or complete mineralize the contaminants that are present in wastewater. This indicates that the treated wastewater may be safely released into the surrounding environment without causing any harm.

• Less water is used: When compared to physical or oxidising procedures, biological processes often use less water than their counterparts. This is due to the fact that biological approaches may treat larger quantities of contaminants or need less dilution of the wastewater than conventional methods.

The effectiveness of biological approaches for the degradation of pollutants, such as dyes, is dependent on a number of parameters. Two of these elements are the adaptability of the bacteria that are picked and the activity of the enzymes. Microorganisms have developed a wide variety of methods for decomposing complex organic compounds; nevertheless, the degree to which these mechanisms are efficient in removing pollutants is contingent on the particular microbial species and the enzymatic activity of those species. (Song, 2019)

When it comes to the treatment of wastewater from the textile industry, a broad variety of microorganisms, such as bacteria, fungus, and algae, have been isolated and examined to see whether or not they are capable of breaking down various colours. A significant component of the biological treatment options for textile wastewater is the isolation of effective bacteria and the use of these microbes to the degradation process. (Paul, 2018)

In addition, the efficacy of biological approaches can be affected by a variety of environmental conditions including pH, temperature, and the availability of nutrients. These aspects of the environment might have an effect on the development and activity of microorganisms. Therefore, the

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efficiency of biological degradation processes may be improved by optimising these circumstances to their full potential.

4.3.1. Fungal cultures for degradation of dyes

It is essential to the survival of fungal cultures that they are able to adapt their metabolic processes to the constantly shifting circumstances of their surrounding environment. In addition, fungal cultures create intracellular and extracellular enzymes, both of which are essential contributors to the metabolic activity of the fungi. These enzymes have the capacity to break down a wide variety of contaminants, including the colours that are found in textile effluent. (Garcia-Segura, 2018)

Due to the synthesis of lignin peroxidase (LiP), manganese peroxidase (MnP), and laccase enzymes by fungal cultures, these organisms are particularly well-suited for the breakdown of dyes (Gogate, 2018). Enzymes known as LiP and MnP are both capable of degrading a wide variety of difficult chemical compounds, including a number of different colours, and are involved in the process of lignin degradation. Laccase, on the other hand, is an enzyme that catalyses the oxidation of phenolic compounds, which are typically present in dyes. This reaction is necessary for the production of certain colours. (Jadhav, 2019)

In particular, white rot fungal cultures have been the subject of a significant amount of research about their capacity to remove azo dyes from wastewater. These fungi are well-known for their capacity to breakdown lignin and other complex organic compounds, which enables them to be utilised effectively in the process of colour degradation.

The employment of white-rot fungus for the breakdown of colours in textile wastewater is connected with a number of inherent drawbacks on its own. The fact that these fungi have such a prolonged development phase is one of their most significant drawbacks since it might result in slower breakdown rates and longer treatment periods. In addition to this, the habitats in which white-rot fungi thrive must be nitrogen-deficient, which can be challenging to achieve in large-scale treatment systems. (Jadhav, 2019)

The heterogeneity in enzyme output presents another another obstacle that must be overcome when working with white-rot fungus. The generation of enzymes by fungi can be influenced by a number of environmental conditions, including the availability of nutrients, the pH of the environment, and the temperature, which can result in inconsistent degradation rates.

In addition, it is possible that a system that relies solely on fungus for the removal of dyes from wastewater may not be stable over the long term. After a particular amount of time, often between 20 and 30 days, bacteria can begin to proliferate and compete with fungus for space as well as resources. (Paul, 2018). This can lead to a reduction in the dominance of the fungus in the system, which in turn can lead to a reduction in the overall efficiency of the degrading process.

It is possible to overcome these obstacles by utilising a variety of different tactics, such as utilising a combination of fungus and bacteria for the treatment of wastewater, optimising the growth conditions for fungi, and utilising immobilised enzyme systems to boost the enzyme's stability and effectiveness. These are just a few examples.

4.3.2. Algae for degradation dyes

Due to the fact that algae can effectively breakdown dyes through a variety of different processes and that they are abundant, they are gaining traction as a viable option for the treatment of wastewater from the textile industry. Several types of algae, such as green macroalgae Cladophora species and Enteromorpha species, have been employed effectively for the breakdown of dyes (Rodrigues, 2021).

The ingestion of dyes by algae for their own development, the transformation of dyes into non-colored intermediates or CO2 and H2O, and the adsorption of chromophores on algae are the three main methods that algae use to breakdown colours. Both biosorption and biodegradation are distinct processes; it is essential to keep this distinction in mind (Rodrigues, 2021; Miralles-Cuevas, 2017). In biosorption, the dye is transferred from the liquid phase into the solid phase, but in biodegradation, chemical bonds within the dye are broken by enzymes, resulting in the transformation of the dye into various chemical compounds (Rodrigues, 2021).

Due to the existence of an azoreductase enzyme, it has been discovered that some species of the green macroalgae genus Cladophora are capable of degrading azo dyes in particular. In addition, the use of algal waste in a bio-sorption process as a means of colour removal has the potential to serve as a cost-effective replacement for more pricey materials such as activated carbon (Paul, 2018).

Therefore, algae-based treatment technologies have the potential to be an efficient and environmentally friendly option for the treatment of wastewater produced by the textile industry. However, further research is required to build efficient large-scale treatment systems, as well as to optimise the growing conditions of algae and increase the efficiency with which it degrades organic matter.

4.3.3. Pure culture and mixed culture for degradation of dyes

Using a variety of bacterial cultures allows for the full breakdown of colours that have been extracted from textile effluent. For this aim, both aerobes and anaerobes, as well as facultative anaerobes, are utilised. Under anaerobic circumstances, the reductive breaking of azo bonds by azo-reductase enzymes is how bacteria are able to degrade azo dyes. This process takes place in the absence of oxygen. However, individual microbe cultures might not completely digest azo dyes and might generate harmful intermediate chemicals, necessitating further decomposition, thus requiring extra processing(Liang, 2017, Paul, 2018).

Consequently, bacterial consortia are advantageous because they are able to jointly carry out degrading activities that no single bacterium culture is capable to beginning well. Mixed culture systems, which take use of the complementary effects of the metabolic activities of a bacterial population, result in greater degrees of biodegradation and mineralization of colours. Nevertheless, bacterial consortiums can only offer an average macroscopic observation regarding biodegradation, and the outcomes of biodegradation cannot be replicated. (Paul, 2018)

Therefore, it is essential to apply these findings to the degradation of the dye of interest in actual wastewater utilising the single bacterium or bacterial consortium that has been described. In conclusion, the text highlights the significance of doing further research on the enzyme assay and phytotoxicity studies of degraded substances in order to investigate the value of investigating the degradation process.

4.3.4. Microbial fuel cell: sustainable technology for textile wastewater treatment

Microbial fuel cells, often known as MFCs, are devices that harness the power of microbes to transform the chemical energy stored in organic substances into usable electrical energy. The microorganisms in the anode chamber of the MFC system are responsible for oxidising the organic compounds found in the wastewater. The microorganisms in the cathode chamber are responsible for reducing oxygen to water. The microorganisms in the anode chamber are responsible for the production of electrons and protons, which are then transferred to the cathode chamber and employed in the generation of electricity. An external resistor positioned between the anode and cathode provides a simple method for efficiently harvesting the power (Lade, 2020).

MFCs, on the other hand, have a few drawbacks, including a poor power output and a high cost of materials. Researchers have explored a variety of various designs, membrane materials, electrode materials (both cathodes and anodes), microbial populations, and wastewater containing azo dyes in an effort to increase the amount of power that can be produced by MFCs. However, the membrane, which is made of Nafion, the anode, which is made of carbon cloth and carbon paper, and the cathode, which is made of platinum, are all expensive and delicate materials, which restricts the scalability of MFCs and their applicability in the real world (Abdul Halim, 2016, Chollom, 2015).

Therefore, MFCs that have high power outputs, low costs for electrode and membrane materials, and good scalability should be created in order to make them more practically applicable for the treatment of various effluents such as desizing, bleaching, dyeing, and printing effluents. In order to make MFCs more accessible for use in large-scale applications, more research into ways to boost the efficiency of MFCs and bring down their prices is required.

5. FACTORS AFFECTING BACTERIAL DEGRADATION

It is absolutely necessary to optimise the physicochemical parameters in order to achieve successful and productive bacterial breakdown of contaminants. In the process of bacterial degradation, the physicochemical characteristics that you specified, such as oxygen, temperature, pH, concentration of dye, structure of dye, concentration of carbon and nitrogen sources, amount of electron donor, and redox mediator, all play important roles. According to Abdul Halim (2016) and Chollom (2015), the optimisation of these factors can greatly increase the rate of bacterial degradation while simultaneously lowering the cost of the process.

As a result, it is essential to ascertain the influence of each parameter on the biodegradation process and then optimise those parameters in accordance with the findings. The process of bacterial

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degradation may be made more efficient and cost-effective by optimising the physicochemical parameters, which can then lead to the development of methods for the treatment of wastewater that are more environmentally friendly and cost-effective (Blanco, 2019).

6. BIOLOGICAL AND PHYSICOCHEMICAL COMBINATION PROCESSES

Although biological technologies are efficient in the removal of some pollutants from textile wastewater, it is possible that they are unable to entirely decompose some of the more complicated and harmful dye molecules or other components generated by the textile industry. This is as a result of the complex and varied character of textile wastewater, which may contain a wide variety of contaminants that may be difficult to degrade using only biological approaches (Benghazi, 2020, Chollom, 2015). The reason for this is due to the fact that textile wastewater can contain a large variety of substances.

On the other hand, chemical oxidation has the potential to be efficient in the process of breaking down some of the more complex contaminants that are found in textile wastewater; nevertheless, it may also have certain limits. For instance, complete mineralization of some dye molecules might not always be attainable, and the procedure can be pricey since it requires more energy and chemical reagents (Chollom, 2015). In addition, it's possible that some of the byproducts produced during the chemical oxidation process are dangerous, in which case they'll need further treatment before being released. Accordingly, in order to successfully treat textile wastewater, it may be necessary to combine biological and chemical treatment approaches (Daud, 2019, Gogate, 2018). This requirement is contingent on the unique properties of the wastewater as well as the outcomes that are wanted from the treatment process.

In general, the use of biological processes in conjunction with chemical oxidation is a viable strategy for the treatment of wastewater from the textile industry. Both the pre-treatment with oxidation techniques and the post-treatment with biological methods can help to increase the biodegradability of the wastewater. Additionally, the pre-treatment with oxidation methods can help to reduce the pollutant load at a lower cost than the post-treatment with biological methods. The properties of the wastewater, as well as the treatment objectives, should guide the selection of the particular oxidation and biological processes to use. It is essential to get biodegradable intermediates while keeping operating costs to a minimum by optimising the pre-treatment conditions as much as possible. According to Chen (2018), the combination method may also be used in a variety of various sequences, which are determined by the characteristics of the contaminants that are present in the wastewater.

When evaluating the efficacy of the combined oxidation and biological approaches in treating textile wastewater, it is essential to utilise a holistic approach, which takes into consideration both the biodegradability and toxicity of the treated wastewater.

- The production of stable compounds that are not capable of biodegradation in comparison to the molecules of the original dye.
- Oxidants, also known as biocides, such as O3 and H2O2 should not be employed unless there is a specific purpose to do so.

In order to do this, a thorough investigation should be carried out making use of sophisticated analytical methods such as gas chromatography-mass spectrometry (GC-MS), liquid chromatography-mass spectrometry (LC-MS), and toxicity testing using a variety of species. According to Blanco (2019), the findings of these kinds of investigations might give extremely useful information regarding the routes that lead to the degradation of the dye molecules, the creation of intermediate chemicals, and the toxicity of these dyes to the environment.

In a nutshell, the treatment of textile wastewater by a combination of oxidation and biological processes offers a significant amount of untapped potential; however, in order to realise this potential, the conditions must be optimised, and an all-encompassing technique must be utilised to assess the efficacy of the treatment. Because of this, the treated wastewater will not only be biodegradable, but it will also be safe for the environment and any living creatures that could be exposed to it.

7. COSTS ASSOCIATED WITH TECHNIQUES FOR THE TREATMENT OF TEXTILE WASTEWATER

It is essential to point out that the expense of treating textile industries' wastewater is a primary concern for businesses since it has the potential to greatly influence the financial choices they make.

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The amount of research that has been done on this subject is few, with just a handful of papers concentrating on the quantitative cost analysis of different treatment methods (Blanco, 2019).

Because the cost of water pollution management can be affected by a variety of factors, including geographical distribution, the kind of textile business, and various pollution control technologies, it is essential to take these things into consideration. It is vital to discover the treatment components that are the most expensive in order to optimise expenses. Once this has been accomplished, it is necessary to locate alternatives that are either less expensive or more effective. More study is required in general in order to fully comprehend the financial consequences of textile wastewater treatment and to determine the methods that are the most cost-effective overall.

8. CONCLUSION AND RECOMMENDATIONS

Effluent Treatment Plants, also known as ETPs, are facilities that are intended to treat the wastewater that is produced by the textile industry in order to reduce or eliminate the negative impact that it has on the surrounding environment. In spite of this, there is no universally applicable method for treating textile effluents since the make-up and properties of textile effluents might change based on the particular manufacturing techniques that are employed. Therefore, in order to properly treat textile wastewater and limit the amount of pollution it causes, a mix of physical, chemical, and biological treatment procedures is utilised. The study has covered a variety of approaches that may be used to treat colours that are found in textile wastewater and reduce the negative impact that these dyes have on the surrounding environment.

In point of fact, the employment of biological methods for the treatment of effluent can have various benefits over the use of chemical methods, such as a reduced formation of inorganic sludge, decreased operating costs, and full mineralization and stabilisation of colours. However, it is essential to keep in mind that the characteristics of the treated wastewater after biological treatment could not always comply with the norms for disposal. This is something that should be kept in mind. It may be necessary to pre-treat the wastewater using chemical oxidation or other advanced oxidation methods in order to convert recalcitrant organic compounds and dyes into biodegradable constituents before subjecting the wastewater to bacterial treatment in order to meet these standards and reduce the effect of toxic or inhibitory compounds on bacteria. This can be done in order to meet the standards and reduce the effect of toxic or inhibitory compounds on bacteria.

In order to improve the biodegradability of wastewater from the textile industry, it is required to do research on the degradation of anthraquinone-based dyes utilising integrated solutions such as anaerobic oxidation process (AOP) and biological treatment. In order to increase the effectiveness of treatment operations and determine the settings and parameters that are ideal for the degradation of these dyes, further research is required.

In addition, the creation of materials for microbial fuel cells (MFC) that are available at a reasonable cost has the potential to have a good effect on local textile wastewater treatment facilities. The utilisation of MFC technology can facilitate the recovery of energy from wastewater, which in turn can be put to use to compensate for the energy requirements of the effluent treatment plant. This may result in a treatment method for textile wastewater that is more environmentally friendly and efficient in terms of cost.

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