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Types and Treatment Technology of Industrial Wastewater

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Abstract: In the recent past, water contamination is an alarming topic for humans, the environment and other living beings. Water becomes wastewater after its use for different purposes in daily life or industries. As the population is growing rapidly, the amount of wastewater is increasing day by day for its high demand which has a large adverse effect on our environment and daily life. Industries are the major consumers of fresh water and so they produce a large amount of industrial effluents. Due to the large effluents containing toxic pollutants (e.g., dyes, heavy metals, surfactants, personal care products, pesticides, pharmaceuticals) from agricultural, municipal, and industrial resources, water becomes contaminated and its properties like the smell, color, COD, BOD, Turbidity, pH, TDS, etc. have been changed drastically. This change in water quality has a great effect on human health and the aquatic environment. To maintain the ecological environmental balance and to ensure fresh water for living beings, water has to be treated effectively. There are several techniques for the treatment of industrial wastewater such as adsorption, coagulation/Flocculation, chemical precipitation, advanced oxidation process, anaerobic system, stabilization pond, etc. The selection of treatment procedure varies from one type of industry to another as wastewater contains different pollutants. This paper focuses on the characteristics of industrial wastewater, its treatment steps, different treatment methods and sludge treatment used in industries for the treatment of effluents.

Keywords: Wastewater Treatment, Characteristics, Treatment Methods, Filtration Process, Nanotechnology

1. Introduction

With the expansion in the human population, massive amounts of wastewater are created every day in the home, commercial, and farming sectors. Usually, wastewaters are clean water with contaminants. This wastewater gets mixed with clean underground water, and the clean water in the surface area also gets contaminated. Even though water covers more than 70% of the planet, this has resulted in fierce competition and unjust distribution of very limited freshwater resources among numerous industries. Nearly four billion people endure acute water scarcity for at least one month of the year, and 2.1 billion people lack access to clean drinking water at home. [1]

Clean water sources are necessary for human beings, and domestic and industrial purposes. However, this water contamination deprives us of this natural blessing and compels us to prepare for a more difficult world. Wastewater from different sources (like the leather industry, textile industry, paper industry, paint industry, pharmaceutical industry, and many others) causes pollution in the environment. The increasing pollution demands more water and so we have to recycle wastewater as much as possible. That's why we have to find a suitable and efficient way of recycling wastewater for our betterment.

Based on physical (color, odor, turbidity, etc.), chemical (VOC, COD, BOD, pH, inorganic and organic ones), and biological (estimation of oxygen demand and organic pollutants by pathogenic and non-pathogenic microbes) characteristics, wastewater is treated in several different ways.

Screening, grit chamber, coagulation/flocculation, membrane filtration, chemical precipitation, advanced oxidation process, anaerobic and aerobic process, disinfection, activated sludge process, stabilization pond and many others have been used. Although these methods are opening a new door for wastewater treatment, they have several disadvantages that hinder the way of treatment. These have been highly investigated. The treatment process has mainly four steps such as- preliminary treatment, primary-treatment, secondary-treatment, and tertiary-treatment [2, 3].

Sludge removal is a big challenge for industries as it hurts the environment at its disposal. However, several processes have been introduced for sludge management and its safe disposal in the environment. Electro-coagulated sludge was produced after using the electrocoagulation (EC) process in paper industry wastewater treatment that determines the conditions that are optimum based on Physico-chemical parameters (COD, color, total organic carbon, and chlorophenols (CPs). Study shows that the electro-coagulated sludge was used for the reusability for the growth of the plant. To assist the physicochemical and elemental phases, it is also used for safe disposal employing different techniques [4].

Researchers and scientists are focusing on the advanced oxidation processes (AOPs) for wastewater treatment in recent years. AOPs are a potentially sophisticated technology utilized to remove all organic material, harmful pollutants, fully or partially degraded organic materials, colors, etc. Several attempts have been made over the past two decades at wastewater treatment that has emphasized advanced oxidation treatment methods. A combination of the advanced oxidation process and biological method were widely investigated in dye industry wastewater [5]. The effectiveness of ozone-based AOPs in industrial effluents comprising organics, pharmaceuticals, insecticides, phenols, dyes, etc. has been demonstrated. To enhance the effectiveness of the treatment procedure, Ozone along with H_2O_2, Ultraviolet Light, catalyst and ultrasound are used to increase the hydroxyl radical generation [6]. Due to the special characteristics of nanomaterials, AOP and nanotechnology are increasingly being used together for the treatment of industrial wastewater [7]. Furthermore, because of their small size and high surface area, nanoparticles exhibit increased reactivity. While this trait has many advantages and uses, there may be concerns about environmental safety, such as suspended presence in the air for a long period of time. The number of contaminants caused by human activity that reach the water and environment has decreased because of nanotechnology. The use of carbon nano-tubes, nano-particles, nano-clays, nano-photocatalysts, nano-filters, and nano-particles in wastewater treatment as well as the use of bio-nano-sensors for rapid water pollution detection are among the most effective environmental uses of nanotechnology. [8].

Biological wastewater treatment is a common and widely used method of treatment. Among all biological methods**,** aerobic wastewater treatment is the fastest and most effective method of biological waste treatment, removing up to 98 percent of organic pollutants. Industrial filtration acts as a pre-treatment to alleviate waste concentration, improving the effectiveness of polishing in other stages of the water treatment process. To improve the quality of the wastewater, several biological filtration techniques can be considered as the secondary treatment process for example- trickling filters, rotating biological contactors, fixed bed filters, etc. [9, 10].

The possible uses of growing aquatic plants (duckweed, water hyacinth, and green algae) for wastewater filtration treatment were examined on the laboratory scale. Water hyacinth (WH) roots offer aerobic bacteria a favorable atmosphere to eliminate a variety of impurities found in water and naturally consume pollutants like lead, mercury, and strontium90. A study demonstrates a considerable reduction in turbidity as a result of the application of water hyacinth to eliminate flocs and minimize organic waste. [11]. Another study shows higher efficiency in eliminating heavy metals when they used water hyacinth and water lettuce for 30 days [12]. The capacity to remove carbon, nitrogen and phosphorus from effluents was established by agro-industries in enclosed batch biodegradation testing employing a mixed microalgae consortium. [13]. Moreover, sand filtration also uses in wastewater treatment. It has been found that slow sand filtration is a suitable treatment process as that can efficiently remove coliform microorganisms like *Giardia, Cryptosporidium,* etc. from wastewater and turbidity, suspended solids, and toxic metals after treatment of the water [14].

In this paper, a review of industrial wastewater characteristics and treatment technics is studied. The type of effluent, various conventional and cutting-edge treatment technologies, and contemporary approaches to wastewater treatment are all discussed in the study.

2. Importance of Industrial Wastewater Treatment

Unfortunately, wastewater is an unwanted byproduct that has been released from different manufacturing companies. It is a sophisticated mixture made up mostly of water (almost 99%), along with organic and inorganic components. Depending on the type of processing industry, industrial wastewaters (including agro-industrial wastewaters) have different compositions. Some of these wastewaters have a high organic content, are readily biodegradable, are primarily inorganic, or maybe inhibitive. Accordingly, values for BOD, COD, and total suspended solids (TSS) may be in the tens of thousands of mg/L [3, 15]. Industrial wastewater may generally be classified into inorganic and organic industrial wastewater. The coal and steel industries, the nonmetallic mining industry, and commercial organizations that use a lot of suspended materials are the principal producers of inorganic industrial wastewater. Pharmaceuticals, cosmetics, tanneries and leather manufacturers, textile industries, and other significant chemical industries all produce organic industrial effluent. [16].

Wastewater discharge directly enters the environment and increases innumerable environmental risks. 126 organic and inorganic hazardous compounds have been identified and recognized by the United Nations Environment Protection Agency and have particular discharge limits. The World Health Organization (WHO, 1989) also established the requirements for wastewater quality before release. In addition to the global standards, regional and national laws have also been established for European Union (EU) member states like Germany, Sweden, and Denmark as well as non-EU nations like Russia, Belarus, Switzerland, China, the United States, Canada, and Dubai. These laws have undergone extensive review. [17, 18]. Figure 1 shows the water discharge of the industrial effluent into the water body.

***Figure 1.** Wastewater is Discharged into Water.*

Wastewater typically has dangerous components that need to be processed before being discharged into bodies of water. Wastewater produces a variety of organic and inorganic chemicals, which have negative environmental consequences on all types of living creatures. Following are some justifications for treating wastewater before emission: [3, 19]

1) If we decompose the compounds that are organic to wastewater, they can produce significant amounts of bad-smelling fumes.
2) Raw wastewater containing organic matter will absorb the dissolved oxygen and lead the stream's dissolved oxygen level to decline, which will kill fish and have other adverse effects.
3) The wastewater was rich in nutrients that might promote the development of aquatic plants and algal blooms, which would subsequently eutrophicate lakes and streams.
4) The majority of dangerous or disease-causing microorganisms and hazardous substances found in raw wastewater are present in the intestinal tract and may pollute the surrounding land and water.
5) Reduction of light penetration caused by turbidity, resulting from organic and inorganic particulates, results in water clarity losses and reduced photosynthesis.
6) Oxygen is less soluble at temperatures that are significantly higher than the surrounding air temperature which may result in thermal shock for sensitive species.
7) Materials that are poisonous or inhibitive present in the water body may create biases towards a particular population in a community while eliminating species with less tolerance thus resulting in a loss of biodiversity.

3. Types of Industries Producing Wastewater

Water is used in industries for different types of purposes like cleaning, drying, drinking, generation and so on. The production of wastewater by these activities comprises many toxins that harm the environment and adjacent water sources. Effluent quality depends on the types of industries. Heavy metals and compounds that are organic or inorganic are present in high concentrations in industrial effluents including tannery and food processing sector. There are numerous factors impacting the variance in wastewater properties. In particular, the temperature is the most significant component as the reactions of chemical is affected by it. Water is typically polluted by industrial pollutants from two primary sources those are point and non-point [10, 15].

4. Characteristics of Industrial Wastewater

4.1. Physical Characteristics

4.1.1. Solids

Organic or inorganic matter can be present in solids. These matters could be soluble and insoluble or suspended materials that can easily dissolve in water. Another way to categorize solids is into volatile and non-volatile (fixed) solids. Non-volatile solids do not volatilize until a temperature of 600°C, whereas volatile solids do. Typically, organic stuff like proteins, lipids and carbohydrates makes up volatile solids. The effluent water contains inorganic chlorine compounds (chlorate) and organic chlorine compounds (dioxins, furans, chlorophenols). Organic chlorinated compounds are formed by the chlorination of lignin. Solids present in typical wastewater between 40% and 65% are suspended. The suspended solids can be found while cooling and measuring the residual removed by filtering. Solids that are volatile burn off when this residue is ignited. Although volatile solids are typically assumed to represent organic materials, when the temperature is high certain material does not burp up that are volatile and salts that are inorganic does break [17, 21, 22].

4.1.2. Color

The general quality of effluent can be measured by color and it changed with time. The color gets darkest as time goes by. This change happens because of decomposition in an anaerobic environment. Wastewater turned light brown when below 6 hours has passed. The water's light color indicates some degrees of breakdown. Under an anaerobic environment, wastewater that is colored black undergoes a large bacterial breakdown. Because of the sulfide composition, particularly ferrous sulfide, at the time of breakdown, black-colored effluents generate [17, 21, 22].

4.1.3. Odor

The release of bed-smelling materials occurs while biological breakdown happens in an anaerobic environment. Sulfur products are mostly unpleasant, especially hydrogen sulfide which smells like rotten eggs and is the principal odorous compound. Other compounds are indol, skatol, cadaverine, di-methyl-sulfide, ammonia, alcohols, mercaptan, etc. For example, ammonia, sulfur and alcohol produced by the food industry's effluent during anaerobic decomposition have a foul smell [17, 22].

4.1.4. Temperature

Wastewater has a greater temperature than usual water does, due to the activity of industries and various toxins present in it. The major treatment processes of wastewater including biological depend on temperature as a measurement of temperature is crucial. Varying seasons and geographical places have different temperatures. Like, temperature ranges from 7-18 degrees Celsius in colder parts and 13-24 degrees Celsius in warmer locations [22].

4.1.5. Turbidity

Turbidity in wastewater is caused by colloidal material or suspended solids. The aquatic environment is affected by turbidity. The inhibition of photosynthesis and benthic organism activity is caused by the reduced light penetration in water. Fish deaths also cause while solids clogged the gill part. It acts as a risk factor for the aquatic environment. Coagulation and filtration methods can be used for removing turbidity [17].

Some research work took place in evaluating physical properties on various scales. From different sources, Sudanese fermentation wastewater was collected molasses, separator, filter and wastewater from the main drain well. The liquid waste contained between 0.8 and 1% solids where between 51 and 75 percent were organic materials.

Total dissolved solids and suspended solids were found higher for molasses about 0.42×10^6 mgL^{-1} and 22.6 mg^{-1} respectively. Besides the temperature turbidity was found higher for filter wastewater at about 35°C and 6800 FTU respectively. Additionally, it is mentioned that an increase in the activity of bacteria happened up to a temperature of roughly 60 degrees Celsius. The final color was found blue, yellow, and red yellow for four different sources [23].

The physical characteristics of wastewater have improved after the fabrication of ceramic membranes typed tubular when permeability is high. The permeate's turbidity was found below 0.1 NTU, and the ceramic membrane's filtration process successfully removed 99.8% of the colloids responsible for the water's turbidity [24]. Physical properties in paper industry wastewater showed 1160-1380mg/l for suspended solids, 1043-1293mg/l for total dissolved solids before treatment, and 322-505 mg/l for suspended solids, 807-984 mg/l for total dissolved solids after treatment [25].

4.2. Chemical Characteristics

4.2.1. Inorganic Chemicals

Ammonia, organic and inorganic phosphorous, sulfate, etc. are examples of inorganic compounds. Among these, Nitrogen and phosphorous is significant for the growth of aquatic plants. The effluent from the pesticides and fertilizers industry typically has several amounts of these nutrients. To determine if it is appropriate to reuse treated wastewater and to control the various treatment procedures, chloride, sulfate, pH, and alkalinity are utilized. All living things need trace elements including heavy metals (e.g. iron, copper, zinc, and cobalt). When present in large amounts, heavy metals like arsenic, cadmium, mercury, and chromium have hazardous effects. Some of the gases are oxygen, carbon dioxide, methane, etc. Aerobic biological processing is impacted by dissolved oxygen, whereas anaerobic digesters are impacted by methane and carbon dioxide [22]. To remove heavy metals like Copper, Cadmium, Zinc, Nickel, and Plumbum from seven different industries, the ion-exchange method was used and Dowex 50WX8 (H) resin was used as adsorbent. The ion-exchange method helps to lower the concentration of heavy metals within pH (4-6) which indicate the improved quality of the effluent [26].

4.2.2. Organic Chemicals

Organic chemicals are determined by Biological Oxizyn Demand (BOD), Chemical Oxygen Demand (COD), and Total Organic Carbon (TOC). To determine the organic content of wastewater, different tests have been done. The testing can be classified between those being used measuring trace concentrations ranges 10-12 to 10-0 mg-L and those measuring gross concentrations of organic materials more than about 1 mg-L. Chemicals that are organic sometimes biodegradable which leads to toxicity. Treatment is therefore necessary before release. Other harmful organic chemicals include phenols, oils and insecticides. A huge amount of BOD, COD, sodium, micronutrients and heavy metals are being discharged with textile effluent [17, 21, 22, 27].

The raw wastewater of the paper industry contains a pH of 6.8-7.1, while BOD and COD values varied in the range of 268 to 387 mg-L and 1110 to 1272 mg-L respectively.

And after the treatment, pH is between 7.1 -7.3, while BOD value varied in the range of 176 to 282 mg-L and COD is 799 to 1002 mg-L [25]. COD, Ca and Sr were removed by electro-coagulation technique combined with the coconut husk carbon adsorption process. This treatment resulted in 52% removal of COD, 88% of calcium, and 72% of strontium which will improve the recovery water quality. While the adsorption process removes the organic materials, heavy metals are also removed by electrocoagulation [28]. The photo-oxidation technic (Fenton’s oxidation process) was used in wastewater generated from cosmetic production in removing the organic materials. With 95.5% of removals, pH level 3 was found to be ideal. This study highly recommended Fenton's oxidation technique for organic materials containing effluent treatment [29].

4.2.3. Volatile Organic Carbon (VOC)

Some of the VOCs are benzene, xylenes, toluene etc. VOCs are produced by subterranean storage tank leakage, inadequately disposed solvents, and landfills that are already present in industries. Commonly found soil contaminants are these VOCs can be found in industries and commercial sectors [22]. The advanced oxidation process that is Integrated photocatalytic ($TiO_2/UV/O_3/H_2O_2$) / ($TiO_2/UV/H_2O_2$) is considered an economically reasonable, efficient, and fast process in removing volatile organic compounds with a significantly low amount of chemicals. These technologies are promising for different industries containing VOCs at a high rate [30].

Aerobic and anoxic biological treatment and BioNET-added moving bed bioreactors (MBBR) were used to investigate semiconductor industry wastewater containing low and highly volatile VOCs. This study shows 81% of COD removal in aerobic MBBR for low VOCs and 80% of COD removal in anoxic MBBR for high VOC [31].

4.3. Biological Characteristics

The biological characteristics include the estimation of pathogenic and non-pathogenic microorganisms, the oxygen demand by these microbes, and the level of organic pollutants in the industrial wastewater. Diseases caused by water for reasons of public health and biological mechanisms like bioaccumulation or eutrophication resulting from nutrient inputs are two kinds of biological features. Organisms like bacteria, and viruses are responsible for waterborne diseases. In the 1800s, cholera was among the most dangerous diseases, with high mortality rates and morbidity rates in the US and certain developing nations. Water contamination from nitrogen or phosphorus leads to excess biological growth, worsening the quality of water, and also has an impact on the growth of aquatic species by lowering levels of oxygen. To determine the biological characteristics in textile wastewater, a study has found the highest value of dissolved oxygen (DO) to be 9.17 mg^{-1}, also recorded the lowest value for equalization tank which leads to oxygen depletion. *E. coli* as a biological parameter, shows the lowest reading of 60.00 CFU/mL only at the final discharge tank, which was detected due to a nearby septic tank. These characteristics suggest treatment before the final discharge [17, 32]. By lowering BOD, COD, nitrate and phosphates' concentration, turbidity, and pH, gamma radiation provides appropriate disinfection and irradiated effluent quality improvement [33]. Biological characteristics along with chemical characteristics were enhanced after the ozonation treatment in coke-oven wastewater. Readily degradable contaminants became nearly fully destroyed when ozonation progressed through a 0.2 decrease in consumption ratio and a 20% increase in TOC removal [34].

5. Industrial Wastewater Treatment Steps

As for the environment to be safe, wastewater must be properly treated. The removal of solid and innocuous particles is the primary goal of purifying wastewater.

Wastewater treatment is usually classified into 5 steps: preliminary treatment, primary-treatment, secondary-treatment, and tertiary-treatment, and sludge management (Figure 2).

Figure 2. *Steps of the Industrial Wastewater Treatment.*

Tertiary treatment involves only when there is a requirement. Tertiary treatment is rare in developing countries. Since industrial wastewater comprises a variety of contaminants, each wastewater treatment method has to be unique. Industrial wastewater is treated using a unique method that is not used to treat municipal effluent. [17, 35].

5.1. Preliminary Treatment

To treat the wastewater pre-treatment is considered the first step of treatment. Physical methods are used mainly in removing massive waste materials from the effluent. The primary purpose of this process is to remove grit and coarse particles. Grease, oil, sticks, pieces of wood, and rags are additional removable elements that could lead to maintenance and operating issues in wastewater treatment plants (WTP). Floatation, equalization, neutralization, screening, grit chambers, and other processes are frequently used in this stage. At first, raw effluent goes for screening followed by grit removal in the grit chamber. After that, a floating tank is used to remove any remaining greasy matter, oil and suspended particles from the effluent. The BOD is also reduced by this treatment by 15 to 30 percent. Besides the coarse solids' removal units a flow measurement unit is to be found. This often entails the use of a standardized flume (such as the Parshall flume) where the flow and the measured liquid level may be correlated [2, 17, 35].

Pre-treatment stage removal was widely investigated. Removal efficiencies of COD, suspended solids, and color was determined by the process of coagulation in the preliminary treatment stage of paint industry effluent. Alum, ferrous chloride and PACI were used at higher concentrations and lower concentrations of coagulants were used. In both of these results, the efficiency in removing COD decreased by 10%, and the efficiency in removing color and suspended particles increased [36]. To decrease the heavy metal concentration of industrial wastewater from three sources in the pre-treatment process, Ultrafiltration (UF) method was used. The removal of heavy metal was accelerated after adding suitable minerals and dried activated sludge in the UF method through the process of adsorption [37].

5.2. Primary Treatment

Removal of settleable organic and inorganic materials is the primary goal of this treatment. Additionally eliminated are inorganic elements, organic nitrogen and phosphorus, floating debris like grease and oil, and heavy metals that are present in solids. Physical pollutant removal mechanisms are also used in this process such as sedimentation, skimming, coagulation, flocculation, etc. To remove the settleable solids, in the sedimentation tank the particles are mixed up with coagulates to settle and flocculation provides the gentle mixing and form flocs. For secondary or biological treatment, primary sludge is collected directly from the tank's bottom. TSS, BOD, and oil and grease are removed approximately at about 50-70%, 2-50% and 65% respectively during the initial treatment. Even after passing the initial phase, sewage does have non-coarse suspended particles. The sedimentation process can remove these particles in part, which indicates the BOD load reduction that is directed to the secondary treatment process, where the expense is high in removing these materials [17, 35].

5.3. Secondary Treatment

Removal of organic residue, suspended particles and nutrients by biological treatment directly from the primary stage is the initial focus of this treatment. Organic matter is present in wastewater as both soluble BOD and suspended BOD. The presence of a certain number and kind of microorganisms is only needed in this treatment process that could make happening the metabolism of organic materials and also make an efficient connection between organic matter and these microorganisms. Along with other types of microorganisms, bacteria, fungi and protozoa can participate in this procedure. Inorganic materials such as carbon dioxide, water and ammonia produce at the time of the biological treatment process that uses organic materials as food. Additionally, maintaining other beneficial environmental factors is required like temperature, pH, etc. The most common processes used in the secondary treatment are- the aerobic biological treatment process, trickling filtration, stabilization pond and some others [17, 35]. Another study found that the (dual membrane) UF-RO process improved organic tolerance when used to recover secondary treated sewer wastewater from industries for industrial application [38].

5.4. Tertiary Treatment

This treatment process removes materials like non-biodegradable particles, nutrients, suspended solids, and organic compounds that in secondary treatment are not efficiently removed. Some of those techniques include surface and depth filtration, coagulation/flocculation, membrane filtration, reverse osmosis process that is used for removing ion-dissolved solids to be reduced and so on. Membrane bioreactors that are an alternative to the traditional activated sludge process require no initial treatments before tertiary processing. To treat the untreated effluent, it is applied directly in membrane bioreactors. A tertiary processing coupled AC adsorption-EO system was used for better COD [17, 39, 40]. For tertiary treatments of extremely hot secondary wastewater of industries, the Moving bed biofilm reactor process gets recognized as a successful technique. With the treatment of ammonia, treatment reaching 95% effectiveness and concentration of wastewater get below 1 mg^{-1}, nitrification was accomplished at 35 and 40°C using this approach [41].

5.5. Sludge Treatment

Grit, screened material, scum, and primary, secondary and chemical sludge are the principal waste produced during the treatment of wastewater. These by-products' treatment is crucial in the treatment of wastewater. Over 95% of the sludge is made up of water. Some of these treatment processes for wastewater require that such biomass be continuously removed. Some of these treatment processes, like facultative ponds, may hold sludge for as long as the facility is in operation. Other processes, like anaerobic reactors, only need periodic withdrawals while still others require constant removal. The features of the sludge and how it is treated are significantly influenced by the storage duration. Table 1 lists the solid waste items produced during wastewater treatment along with a brief description. [35].

A batch-processing pilot device introduces a new way of sludge processing that allows the removal of heavy metal, microorganisms' disinfecting and drying which is energy effective at lower pressure and lower temperature [42]. Instead of using clay soil, textile waste that is 50% gamma radiated can be used as a substitute material, requiring substantially lower firing temperatures than the standard technique and also lowering the danger of NOXs and SOXs production [43].

Table 1. *Solid by-products and Treatment Descriptions.*

By-Products	Treatment Procedure	Description
Coarse solids	Screen	This process includes both organic and inorganic solids. Manual, as well as mechanical removal, can be applied.
Grit	Grit chamber	This process includes heavier inorganic solids, fats, and also grease.
Scum	1) Grit chamber 2) Primary and secondary settling tank 3) Stabilization pond 4) Anaerobic tank	Include grease, vegetable and mineral oils, animal fats and similar materials.

By-Products	Treatment Procedure	Description
Primary sludge	1) Septic tank 2) Primary settling tank	Sludge is removed from primary sedimentation tanks, and can have a strong odor.
Non-stabilized aerobic biological sludge	1) Conventional activated sludge 2) Aerobic biofilm reactors (high rate trickling filter, submerged aerated biofilter, rotating biological contactor)	Include biomass of different aerobic microorganisms that are generated from the removal of the matter that is organic. If biological solids are not stabilized, bad odors can be released during treatment and final disposal.
Aerobic biological sludge (stabilized)	1) Activated sludge – extended aeration 2) Aerobic biofilm reactors (low-rate trickling filter, rotating biological contactor, submerged aerated biofilter)	This biological sludge is composed of aerobic microorganisms. Sludge doesn't need a separate digestion stage because it has a high amount of inorganic solids and a low level of organic matter.
Stabilized anaerobic biological sludge	1) Stabilization ponds (anaerobic facultative ponds, facultative aerated lagoons) 2) Anaerobic-reactors (UASB reactors, anaerobic filters)	The organic matter is eliminated by the anaerobic biomass as it expands and multiplies. Dead algae and deposited solids from untreated sewage are also included in the sludge in stabilization ponds. This sludge doesn't need to go through a second digesting stage.
Chemical-sludge	1) Chemical deposition in primary settling tanks 2) Chemically precipitated phosphorus in activated sludge	This sludge is typically developed as a result of chemical precipitation using lime or metallic salts. Both odor and decomposition rates are less than primary sludge.

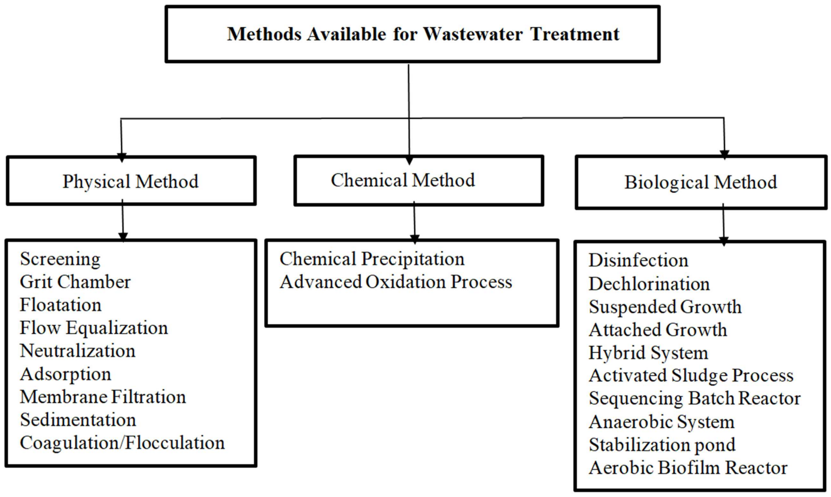

Figure 3. *Classification of Methods Available for Industrial Wastewater Treatment.*

The main steps include sludge treatment: (1) Thickening: removal of water, (2) Stabilization: removal of organic matter, (3) Conditioning: Getting ready for dewatering, (4) Dewatering: Removing water, (5) Disinfection: Removing pathogenic organisms, (6) Final Disposal: where the waste will be placed. Every step of the sludge treatment has a specific purpose that is determined by the qualities of the produced sludge. If the sludge management method doesn't meet high-temperature treatment, then the main problem is organic contaminates that are quite complicated to determine. To solve this problem, analytical technics like gas or liquid chromatography and chemical technics can be very essential. On the sludge release aspect, further investigation is required into the thermal process development with heavy metal migration and transformation at the time of treatment. [44, 45].

6. Industrial Wastewater Treatment Methods

Typically wastewater treatment is categorized into 3 types: physical method, chemical method, and biological method. These techniques are used to eliminate solids from wastewater, such as colloids, organic material, nutrients, and soluble contaminants. Figure 3 summarizes a variety of strategies.

6.1. Physical Methods

6.1.1. Screening

Screening is the oldest method and the first stage of wastewater treatment. Here, the effluent is cleaned and screened to remove any larger materials before being ground up, burned, or interred. Gross contaminants are eliminated from effluents in this process. Additionally, it keeps offensive suspended material out of the initial settling tanks. The next step is the removal of the grit. The screens must be cleaned either manually or automatically and are positioned vertically at 45 to 60 degrees [17, 46].

6.1.2. Grit Chamber

An inorganic matter that is suspended like sand that contains gravel, cinder, and other heavy particles, is removed using a grit chamber. Grit chambers are cleaned mechanically or manually and avoiding any type of machine damage is essential. Once a week, manual cleansing is done with a shovel to remove the grit and mechanical cleansing is performed by removing the grit chamber's blades [17].

6.1.3. Floatation

Suspended materials, oil and grease matter, fine fibers, effluent with heavy metal and anions, and calcium ions are removed using a tank following this process. Grease and oils' presence in wastewater prevents the solids from settling at the time of sedimentation. Forming tiny air bubbles by injected air and aeration process helps speed up the process, and particles to be easily removed. API separator and CPS are used to remove oil globules of size 0.015cm and 0.01 cm respectively [17, 46]. 43% of BOD5, 85% of fats and oil and 88% of COD are typically removed by the natural flotation process of industrial wastewater from refined vegetable oils. The flotation method enables the removal of 10659 Kg of grease per day from wastewater produced during the refining of vegetable oils [47]. Coagulation micro-bubble floatation showed better results than coagulation conventional air bubble flotation for the pretreatment of dyeing wastewater. The coagulation micro-bubble floatation process enhanced the pretreatment rate by removing oil, a higher oxygen transfer rate, and enhancing COD, color [48].

6.1.4. Flow Equalization

The efficiency of secondary and primary wastewater treatment procedures is increased by equalization. At the time of neutralization, the relative flow and concentrations are maintained with help of equalization [17, 46]. Flow equalization systems reduce the shock loads. An industrial case study investigates equalization systems for multi-product batch production facilities and shows that a combined segregation tank has more production flexibility than distributed segregation tanks [49].

6.1.5. Neutralization

Industrial effluent requires to be neutralized because of its high pH and concentration of pollutants. Usually, equalization is followed by the neutralizing process. Flue gas for alkaline wastewater, HCl, or acidic or alkaline flows can all be neutralized [17]. Without using any external carbon source for highly alkaline wastewater, *Exiguobacterium sp.* and *Enterococcus faecalis* can be a potential use as it is capable of lowering the pH. *Exiguobacterium sp.* hydrolyzes starch, and both aerobic and anaerobic conditions are grown at a variety of temperatures like 5 to 40 degrees celsius by it. Compared with the traditional chemical neutralization technique, Enterococcus faecalis is just as effective, affordable, and environmentally friendly because it can function when sources of N and C are present [50, 51].

6.1.6. Adsorption

Adsorption is a dependable, economical, and environmentally friendly approach to treating wastewater. Mass transfer is the actual function of the adsorption process. One can remove up to 99.9% of waste by using this process. Three types of adsorbents are there: low-cost adsorbent, nano adsorbent, and bio adsorbent. Three processes of adsorbate migration take place in this process: adsorbate migration to the adsorbent's border shell, intraparticle diffusion in pores, and solution desorption and adsorption. To determine the maximum adsorption capacity of the material, adsorption isotherms are utilized [52]. The capacity to lower pH, electrical conductivity, TSS, chemical oxygen demand (COD), turbidity, and hardness for food industrial effluents was demonstrated to be improved by the adsorption method using an adsorbent named activated charcoal (powdered) [53]. Biochar with effective absorbance capacity demonstrated a significant ability to soak up inorganic and organic contaminants from effluents. Additionally, biochar highly absorbs 80% of the dyes of industries and also lowers the rate of bioavailability and toxicity of both organic and inorganic contaminants [54].

6.1.7. Membrane Filtration

The benefits of using membrane technology include removal of TSS, high disinfecting ability, effective removal of organic and nutrient materials, and lower carbon emissions. However, designing membranes with adequate thermal stability and enhanced performance is still a difficult task. Many procedures that the membrane filtration methods fall under are listed below: electrodialysis, reverse osmosis, micro-filtration, ultra-filtration, and nano-filtration [17, 46, 52]. After the coagulation/flocculation, a combined (ultrafiltration/reverse osmosis) membrane filtration process works well for the remaining organic compounds. It removes almost organic content from the remaining [55].

6.1.8. Sedimentation

The sedimentation process involves removing the settleable solids into a big tank where gravity is used for settling them. This process is widely used and it removes sand, grit, particulate matter, silt, and clay along with contaminants that are biological. To hasten the sedimentation process, coagulants like ferric sulfate, liquid alum, and aluminum sulfate are added [17, 46]. The sedimentation process works well with ultrafiltration where the coagulation/flocculation process is attached to it. COD, color, percentage of fouling, and turbidity removal is found to be the highest for this combined process at 99.9% for turbidity and color, 98.5% for COD, and 59.8% for the percentage of fouling [56].

6.1.9. Coagulation/Flocculation

Coagulants, which usually have an opposing charge to the particles in the effluent, are mixed up for neutralizing particle charges. Particles settled down to the bottom after becoming attached. In the flocculation process, tiny charged particles attach to oppositely charged particles to create flocs through a gentle mixture. Commonly used coagulation and flocculation additives include iron or aluminum salts, lime ($Ca(OH)_2$), $FeCl_3 \cdot 7H_2O$, $Fe_2(SO_4)_3 \cdot 7H_2O$, $Al_2(SO_4)_3 \cdot 18H_2O$, polymers, activated carbon or silica and talcum.

For the decolorization of wastewater containing dispersion dyes, coagulation/flocculation techniques are adequate. Since coagulation/flocculation is a cost-effective method with a short detection time and easy handling, it is frequently used in the textile industry to treat wastewater [17, 52]. Coagulation with the filtration method shows efficient color, BOD, COD, suspended solids, and Cr, Na, and SO_4^{2-} removal which are the physicochemical parameters for lather industrial effluents [57]. Rice starch as an organic coagulant used in agro-industrial wastewater treatment shows potentiality in shortening the settling time and removing total suspended solids (TSS) by up to 84.1%. Moreover, rice starch with alum increases the TSS removal by 88.4% [58].

6.2. Chemical Method

6.2.1. Chemical Precipitation

Heavy metals react with specific chemical compounds to generate precipitates, which is a process that leads to precipitation. The resulting precipitates can either be discarded or utilized again after being filtered or sedimented out of the water [46]. The best precipitating agent (with a dosage of 100 mg-l at pH 7.0) is discovered to be a mixture of sodium hydroxide and calcium hydroxide, with a 100% removal efficiency of total chromium from effluent [59]. Heavy metal ions are removed from untreated wastewater using calcium hydroxide, however, problems arise when heavy metal ions rise from the initial concentration, causing a decreased rate of removal. [60].

6.2.2. Advanced Oxidation Process

The following process is regarded as a crucial method for treating wastewater. The organic products or dyes in textile effluents may completely or partially degrade with the help of this method. Oxidation may involve electrochemical, photo-electrochemical, Fenton's, and ozonation processes described below [46, 52]. Electrochemical oxidation is used in actual textile industrial wastewater treatment with graphite electrodes, which concurrently reduce particular consumption of energy, and improve COD and color removal efficiency. Sludge and scum generated from this process are used as fuel [61]. The combination treatment of *Thiobacillus ferrooxidans* (aerobic) and Fenton's oxidation also show the maximum effect on COD and BODs' reduction, sulfide, color and total chromium than the alone treatment of aerobic or oxidation process [62].

(i). Electrochemical Oxidation

For the removal of dye, the electrochemical advanced oxidation processes (EAOPs) successfully emerged as a promising and sustainable method. As the electrons are inherently clean species, no supplementary procedure (e.g., high pressure, high temperature) is required for the removal of dye sludge. But it has low selectivity and low reaction rates. The increasing energy cost with comparatively lower oxidation efficiencies is the main challenge that obstructs the EAOP process where the pollutants are strongly bounded to the adsorbents.

(ii). Photo-Electrochemical Oxidation

AOPs that use OH-based electrochemical processes (e. g. hydroxyl (•OH) radicals), are becoming more and more crucial for achieving high removal efficiency and pollutant degradation.

(iii). Fenton's Oxidation

Free radicals (e. g. hydroxyl radicals) with greater oxidation potential are produced by this process. Fenton's oxidation is regarded as being the most useful and cutting-edge water treatment technique out of all the oxidation processes. To produce powerful oxidizing agents (hydroxyl radicals), $FeSO_4$ and H_2O_2 are used in this process. Numerous flocs of varying sizes have been observed for their development during the Fenton oxidation process.

(iv). Ozonation

Ozone is a powerful agent that interacts chemically with both organic and inorganic substances. At a specific pH, the ozonation procedure might be regarded as an AOP. Two reactions in ozonation are taken into account when pH is a factor: the direct and the indirect pathway. This process can treat a wide variety of contaminates but still a controlled pH medium is required to make its performance better.

6.3. Biological Method

6.3.1. Disinfection

Preventing the development or destruction the microbes is the primary aim of this procedure. This procedure inactivates the microbes utilizing physical, chemical and biological methods. The four most frequently employed methods of disinfection are Physical agents, Mechanical methods, Radiation, primarily gamma rays, and finally Chemical agents. [46].

6.3.2. Dechlorination

This procedure involves removing the free and complete mixed chlorine residual from the effluent of chlorinated wastewater. Dechlorination is accomplished with activated carbon or by adding a reducing agent like sodium sulfite, sodium metabisulfite, or sulfur dioxide [46].

6.3.3. Suspended Growth

In this process, microorganisms are maintained with liquid in the batch reactor in suspension mode. Both aerobic and anaerobic circumstances are permitted for the operation of this liquid. ASS is a plug-flow, total mix, and sequencing batch reactor process that is commonly used in treating wastewater. sequencing batch reactor requires only clarifiers but plug-flow and total mix activated sludge requires both clarifiers and return activated sludge system. [15, 63]. A suspended growth bioreactor (i-SGBR) with aerobic, anoxic, and anaerobic digester has achieved effective removal of Total COD, BOD5, TSS, and simultaneous sludge degradation [64].

6.3.4. Attached Growth

Microorganisms grow attached to inert surfaces like rocks, in this growth process, which makes microorganisms enable in producing biofilm containing extracellular polymeric compounds. Biofilm-covered bioreactors have higher biomass concentrations and more active metabolic processes. Different types of bacteria, fungi, algae, and yeast create tiny colony clusters in biofilms, which are made of an extracellular polymeric substances (EPS) matrix that resembles glue. Extracellular polymeric substances play a great role in enhancing the mechanical and chemical stability of the biofilm and defending against various physio-chemical stresses [15, 63]. A submerged attached growth bioreactor is used in removing isobutanol, ethylene and propylene glycol in the paint industry, and maximum removal efficiency is found to be 97% [65].

6.3.5. Hybrid System

The hybrid system combines the processes of attached and suspended growth in fixed-bed biofilters. Aeration or mechanical mixing keeps a carrier material in suspension in the moving bed reactor. [63]. **A** hybrid process which includes the process of adsorption, electrocoagulation, and photo Fenton, shows greater removal in TOC, COD, turbidity, color and suspended solids than the sole treatment of electrocoagulation and adsorption [66]. Other hybrid approaches enhanced the quick deterioration of color, COD, phenolic compounds concentration, chloride, and ammonia using ozone-based advanced oxidation (with H_2O_2 and activated char). [67].

6.3.6. Activated Sludge Process

This process has several variants but the main ones are classified according to three categories such as sludge age, flow, and treatment technics. To do the post-treatment of wastewater received from anaerobic reactors, those mentioned methods are used. The anaerobic reactor thus replaces the primary sedimentation tanks (if any are present), and the extra sludge is sent back to thicken and digest. Among all, the main systems are sequencing batch reactors, traditional activated sludge, N and P removal activated sludge and extended aeration [35]. When the adsorption process with powdered activated carbon (PAC) is attached to the activated sludge (AS) biodegradation process, it worked well in removing COD and TOS from wastewater [68].

6.3.7. Sequencing Batch Reactor (SBR)

The SBR is a batch fill-and-draw system. Because of its excellent BOD, COD, and suspended particle removal performance, it has been used for the treatment of wastewater from the industrial and municipal sectors. Microalgal bacterial (MaB) flocs developed in sequencing batch reactors provide a cutting-edge method for treating industrial effluent. the recovery of High biomass was achieved after Microalgal bacterial flocs were effectively dewatered using a 200lm pore-sized filter press. The efficient removal rate of various nutrients and higher production of Microalgal bacterial flocs (0.14 - 0.26gm of TSS per day) was observed through this process. This study recommended this process for aquaculture and food-processing wastewater [69].

6.3.8. Anaerobic System

There are many variants of anaerobic systems named Upflow anaerobic sludge blanket reactor (UASB), anaerobic reactor and others [35]. Up-flowing of an anaerobic sludge blanket where reactor non-granular anaerobically digested sewage sludge is seeded with that achieved maximum COD removal efficiency. At room temperature, this effluent could be processed with a maximum input of 16g COD/L. [70].

6.3.9. Stabilization Pond

There are many variants of stabilization ponds named maturation ponds, facultative ponds, facultative aerated lagoons and some others [35]. In removing phenol with 10 days retention time, the facultative stabilization pond demonstrated higher efficacy in removing phenol and carbon. But phenol concentration at 300mg/L showed minimum removal efficiency [71].

6.3.10. Aerobic Biofilm Reactor

To support the aerobic biofilm reactors, biofilm binds to the medium. There are many types of aerobic biofilm reactors named high-rate and low-rate trickling filters, aerobic moving bed biofilm reactors, rotating biological contactors, etc. [35]. In comparison with an anoxic system, a moving bed-biofilm reactor (MBBR) that is aerobic, has exhibited more equitable bacterial group distribution [72].

7. Biological Filtration Technology

The biological filtration method is employed as a secondary treatment technology for enhancing specific types of wastewater. Some biological filtration methods are trickling filters, moving bed biofilm reactors, rotating biological contactors, fixed bed filters and many others. Biological filtration technology is efficient for the treatment of wastewater with low strength rates that is weak. Wastewaters are strong with large quantities of organic material, nitrogen, heavy metal, oil, phenols, and grease, as well as a poor biodegradability ratio, these procedures are ineffective to them [10].

The combined bio-filtration processes with *Eichornia crassipes* and *Lemna minor* with the ozonation process significantly remove poisonous heavy metals at a high rate and improve the value of BDOC in secondary industrial effluent. This study also recommended this combined process to treat the wastewater that is compounded with sewage [73].

8. Nanotechnology

In recent years, Potential pollutant removal candidates include nanomaterials. Some technologies available are: metal and metal oxide nanoparticles (e. g. titanium dioxide, silver nanoparticles, iron nanoparticles, TiO_2 Nanoparticles, iron oxide nanoparticles), carbon-based nano adsorbents (carbon nanotubes, graphene-based materials), nanomaterial-based membrane processes (nanofiber membranes, nanocomposite membranes) are used to remove pollutants [74]. Nanotechnology produces materials, structures, gadgets, and systems through the modification, regulation and integration of atoms and molecules just at the nanoscale. This is possible since nanomaterials are small, highly reactive, more accurate, and most importantly, environmentally friendly methods can be used to produce nanoparticles and these methods are sufficiently economical.

Three types of nanotechnology are introduced as promising technologies: (i) Photocatalysis (ii) Nanofiltration (iii) Nano-adsorbents [75]. Nanomaterial technology is used in removing dyes, pesticides, heavy metals etc. Recent studies are focusing on removing heavy metals like lead, and copper like influential metals by using nanomaterials. Reusing nano adsorbents and recovering components from a liquid dissolution are extremely challenging and could harm the environment as the compounds stay in the absorbed position. Due to cost and general health issues, continuous chemical use is made possible by nanotechnology's essential qualities of nanomaterial retention and re-utilization through membrane filtration [76].

9. Polypropylene Fiber

Polypropylene fiber is among the frequently utilized polyamide fibers for building filtration modules. in recent, Flexible fiber filters have been developed and used to treat wastewater. To assess their suitability as filter media, polypropylene fibers were studied [77, 78]. Polypropylene nanofibers are used to make a nanofibrous membrane with high efficiency was found to be more promising than the conventional PP fibrous membrane in textile wastewater treatment. Characteristics of pore and surface were shown to be significantly influenced by the fiber diameter in PP fibrous membrane [79]. Furthermore, nonwoven polyethylene/ Polypropylene fibers with plasma-coated are also used medium for decolorization that achieves a decolorization efficiency of 39.8% [80].

10. Conclusion

Wastewater treatment technologies are an important concept and challenging task to manage the resources of water. For a particular industrial wastewater treatment application, there are many treatment facilities and technologies. Different approaches have been introduced by researchers in recent years. Several combined processes have been introduced for different types of industries. Also, treatment with nanotechnology and biological filtration with selective aquatic plants have been growing interest. The treatment plants established in industrial settings are determined by the properties of the produced wastewater. The specific treatment technics help in reducing the pollutants of different industries. Although the installation of water treatment plants in industries, the effect cannot be lessened as expected as some treatment technologies are costly, time-consuming, and not reliable to operate. With these prospects, more advanced, safe, and cost-effective technologies are needed to discover for the sake of health and environmental safety, and also to assure the quality and performance of the treatment plants.

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References

[1] Elorm Obotey Ezugbe and Sudesh Rathilal, 2020, Membrane Technologies in Wastewater Treatment: A Review, *Membranes*, vol: 10 (5), pp: 89-116.

[2] Grégorio Crini and Eric Lichtfouse, 2019, Advantages and disadvantages of techniques used for wastewater treatment, *Environmental Chemistry Letters*, vol: 17 (1), pp: 145-155.

[3] NG Wun Jern, 2006, Industrial Wastewater Treatment, *World Scientific*.

[4] Dushyant Kumar and Chhaya Sharma, 2019, Reduction of chlorophenols and sludge management from paper industry wastewater using electrocoagulation process, *Separation Science and Technology*, vol: 55 (15), pp: 2844-2854.

[5] Toral Shindhal, Parita Rakholiya, Sunita Varjani, Ashok Pandey, Huu Hao Ngo, Wenshan Guo, How Yong Ng and Mohammad J. Taherzadeh, 2020, A critical review on advances in the practices and perspectives for the treatment of dye industry wastewater, *BIOENGINEERED*, vol: 12 (1), pp: 70-87.

[6] Chhaya V. Rekhate and J. K. Srivastava, 2020, Recent advances in ozone-based advanced oxidation processes for treatment of wastewater- A review, *Chemical Engineering Journal Advances*, vol: 3, pp. 100031.

[7] Bhaskar Bethi Shirish H. Sonawane Bharat A. and Bhanvase Sarang Gumfekar, 2016, Nanomaterials based Advanced Oxidation Processes for Waste Water Treatment: A review, *Chemical Engineering and Processing*, vol: 109, pp: 178-189.

[8] Mojtaba Taran, Mohsen Safaei, Naser Karimi and Ali Almasi, 2020, Benefits and Application of Nanotechnology in Environmental Science: an Overview, *Biointerface Research in Applied Chemistry*, vol: 11 (1), pp: 7860-7870.

[9] Sigma Earth, 2022, Biological Methods of Wastewater Management, *Wastewater Management*.

[10] Shuokr Qarani Aziz and Sazan Mohammed Ali, 2016, Performance of Biological Filtration Process for Wastewater Treatment: A Review, *ZANCO Journal of Pure and Applied Sciences*, vol: 28.2, pp: 554-563.

[11] Rajendra B. Magar, Afroz N. Khan and Abdul razzak Honnutagi, 2017, Waste Water Treatment using Water Hyacinth.

[12] Violeta Monica Radu, Petra Ionescu, Elena Diacu and Alexandru Anton Ivanov, 2017, Removal of Heavy Metals from Aquatic Environments Using Water Hyacinth and Water Lettuce, *Rev. Chim*, vol: 68, pp: 2765-2767.

[13] E. Posadas, S. Bochon, M. Coca, M. C. García-González, P. A. García-Encina, and R. Muñoz, 2014, Microalgae-based agro-industrial wastewater treatment: a preliminary screening of biodegradability, *Journal of Applied Phycology*, vol: 26, pp: 2335-2345.

[14] Srishti Verma, Achlesh Daverey, and Archana Sharma, 2017, Slow sand filtration for water and wastewater treatment – a review, *Environmental Technology Reviews*, vol: 6 (1), pp: 47-58.

[15] Lakshmi Machineni, 2020, Review on biological wastewater treatment and resources recovery: attached and suspended growth systems, *Water Science & Technology*, vol: 80 (11), pp: 2013-2026.

[16] Hanchang SHI, 2009, Industrial Wastewater-types, amounts and effects, *Point sources of pollution: Local effects and their control*, vol: 2, pp: 191-300.

[17] Shivani Garg, 2022, Industrial wastewater: Characteristics, treatment techniques and reclamation of water, *Advanced Industrial Wastewater Treatment and Reclamation of Water*, pp: 1-23.

[18] Michał Preisner, Elena Neverova-Dziopak and Zbigniew Kowalewski, 2020, An Analytical Review of Different Approaches to Wastewater Discharge Standards with Particular Emphasis on Nutrients, *Environmental Management*, vol: 66, pp: 694-708.

[19] Khandakar M. Nahiun, Bijoyee Sarker, Kamrun N. Keya, Fatin I. Mahir, Shahirin Shahida and Ruhul A. Khan, 2021, A Review on the Methods of Industrial Waste Water Treatment, *Scientific Review*, vol: 7 (3), pp: 20-31.

[20] K. Sarayu and S. Sandhya, 2012, Current Technologies for Biological Treatment of Textile Wastewater–A Review, *Applied Biochemistry and Biotechnology*, vol: 167, pp: 645-661.

[21] Ji-Whan Ahn and Mihee Lim, 2009, Characteristics of Wastewater from the Pulp, Paper Industry and its Biological Treatment Technologies, *Resources Recycling*, vol: 18 (2), pp: 16-29.

[22] Rein Munter, 2003, Industrial wastewater characteristics, *The Baltic University Programme (BUP), Sweden*, pp: 185-194.

[23] Abdel Moneim El-Hadi Sulieman, Abdel Wahid Mohammed Yousif and Abdel Moneim Mustafa, 2010, Chemical, physicochemical and physical properties of wastewater from the Sudanese Fermentation Industry (SFI), *Fourteenth International Water Technology Conference*, vol: 14, pp: 302-315.

[24] Chan-Young Yun, Woo-Yeol Kim, Dong-Jin Son, Dae-Gun Kim, Duk Chang, Sung-Oun Chang, Young Sunwooa and Ki-Ho Hong, 2015, Fabrication of tubular-type MF ceramic membrane with enhanced permeability by addition of PMMA in the support and evaluation of physical characteristics for wastewater treatment, *Ceramics International*, vol: 41 (9), pp: 10788-10794.

[25] V. P. Kesalkar, Isha. P. Khedikar, and A. M. Sudame, 2012, Physico-chemical characteristics of wastewater from Paper Industry, *International Journal of Engineering Research*, vol: 2 (4), pp: 137-143.

[26] S. M. Moosavirad, R. Sarikhani and S. Z. Mohammadi, 2015, Removal of some heavy metal from inorganic industrial wastewater by ion exchange method, *Journal of Water Chemistry and Technology*, vol: 37, pp: 191-199.

[27] Sana Khan and Abdul Malik, 2014, Environmental and Health Effects of Textile Industry Wastewater, *Environmental Deterioration and Human Health*, pp: 55-71.

[28] Elbert M. Nigri, André L. A. Santos and Sônia D. F. Rocha, 2020, Removal of organic compounds, calcium and strontium from petroleum industry effluent by simultaneous electrocoagulation and adsorption, *Journal of Water Process Engineering*, vol: 37, pp: 101442-101256.

[29] Ebrahiem E. Ebrahiem, Mohammednoor. N. Al-Maghrabi and Ahmed R. Mobarki, 2013, Removal of organic pollutants from industrial wastewater by applying photo-Fenton oxidation technology, *Arabian Journal of Chemistry*, vol: 10 (2), pp: 1674-1679.

[30] André Fernandes, Michał Gągol, Patrycja Makoś, Javed Ali Khan and Grzegorz Boczkaj, 2019, Integrated photocatalytic advanced oxidation system ($TiO_2/UV/O_3/H_2O_2$) for degradation of volatile organic compounds, *Separation and Purification Technology*, vol: 224, pp: 01-14.

[31] Hai-Hsuan Cheng, I-Chun Lu, Po-Wei Huang, Yi-Ju Wu, and Liang-Ming Whang, 2021, Biological treatment of volatile organic compounds (VOCs)-containing wastewaters from wet scrubbers in semiconductor industry, *Chemosphere*, vol: 282, pp: 131-137.

[32] Muhammad Haziq Hisham, N. Othman, Nur Salsabila Norisman and Norshila Abu Bakar, 2019, Physical and Biological Characteristics of Textile Wastewater, *Journal of Applied Geoscience and Built Environment*, vol: 1 (2), pp: 1-7.

[33] B. Asgari Lajayer, N. Najaf, E. Moghiseh, M. Mosaferi and J. Hadian, 2019, Effects of gamma irradiation on physicochemical and biological characteristics of wastewater effluent and sludge, *International Journal of Environmental Science and Technology*, vol: 17 (2), pp: 1021-1034.

[34] E.-E. Chang, Hao-Jan Hsing, Pen-Chi Chiang, Mei-Yin Chen, and Jhieh-Yu Shyng, 2008, The chemical and biological characteristics of coke-oven wastewater by ozonation, *Journal of Hazardous Materials*, vol: 156, pp: 560-567.

[35] Marcos von Sperling and Carlos Augusto de Lemos Chernicharo, 2005, Biological Wastewater Treatment in Warm Climate Regions, *IWA publishing*, vol: 1, pp: 857.

[36] Omer Yasin Balika and Serdar Aydin, 2015, Coagulation/flocculation optimization and sludge production for pre-treatment of paint industry wastewater, *Desalination and Water Treatment*, vol: 57, pp: 12692-12699.

[37] E. Katsou, S. Malamis, T. Kosanovic, K. Souma and K. J. Haralambous, 2012, Application of Adsorption and Ultrafiltration Processes for the Pre-treatment of Several Industrial Wastewater Streams, *Water Air Soil Pollution*, vol: 223, pp: 5519-5534.

[38] Jian-Jun Qin, Maung Nyunt Wai, Maung Htun Oo, Kiran Arun Kekre and Harry Seah, 2006, Feasibility study for reclamation of a secondary treated sewage effluent mainly from industrial sources using a dual membrane process, *Separation and Purification Technology*, vol: 50 (3), pp: 380-387.

[39] Niraj S. Topare, S. J. Attar and Mosleh M. Manfe, 2011, Sewage/Wastewater Treatment Technologies: A Review, *Science Reviews and Chemical communications*, vol: 1 (1), pp: 18-24.

[40] Jesús Castillo-Monroy, Luis A. Godínez, Irma Robles and Arturo Estrada-Vargas, 2020, Study of a coupled adsorption/electro-oxidation process as a tertiary treatment for tequila industry wastewater, *Environmental Science and Pollution Research*, vol: 28, pp: 23699-23706.

[41] Jennifer L. Shore, William S. M'Coy, Claudia K. Gunsch, and Marc A. Deshusses, 2012, Application of a moving bed biofilm reactor for tertiary ammonia treatment in high temperature industrial wastewater, *Bioresource Technology*, vol: 112, pp: 51-60.

[42] Bozidar Bratina, Andrej Sorgo, Janez Kramberger, Urban Ajdnik, Lidija Fras Zemlji, Janez Ekart and Riko Safari, 2016, From municipal/industrial wastewater sludge and FOG to fertilizer: A proposal for economic sustainable sludge management, *Journal of Environmental Management*, vol: 184 (3), pp: 1009-1025.

[43] Mohammad Sohrab Hossain, Subrata Chandra Das, Jahid M. M. Islam, Md. Abdullah Al Mamun and Mubarak Ahmad Khan, 2018, Reuse of Textile Mill ETP Sludge in Environmental Friendly Bricks – Effect of Gamma Radiation, *Radiation Physics and Chemistry*, vol: 151, pp: 77-83.

[44] Bartłomiej Michał Cieslik Jacek Namiesnik and Piotr Konieczka, 2015, Review of sewage sludge management: standards, regulations and analytical methods, *Journal of Cleaner Production*, vol: 90, pp: 1-15.

[45] Quanguo Zhang, Jianjun Hu, Duu-Jong Lee, Yingju Chang, and Yu-Jen Lee, 2017, Sludge Treatment: Current Research Trends, *Bioresource Technology*, vol: 243, pp: 1159-1172.

[46] Manar Elsayed Abdel-Raouf, Nermine E Maysour, Reem Kamal Farag, Abdul-Raheim and Mahmoud Abdul- Raheim, 2019, Wastewater Treatment Methodologies, Review Article, *International Journal of Environment and Agricultural Science*, vol: 3 (1), pp: 18-42.

[47] Malika Kastali, Latifa Mouhir, Laila Saafadi, Levent Yilmaz and Salah Souabi, 2021, Pretreatment of industrial wastewater by natural flotation: application to pollution reduction from vegetable oil refinery wastewaters, *Environmental Science and Pollution Research*, vol: 28, pp: 34598-34610.

[48] Shu Liua, Qunhui Wanga, Hongzhi Maa, Peikun Huang, Jun Li and Takashige Kikuchi, 2010, Effect of micro-bubbles on coagulation flotation process of dyeing wastewater, *Separation and Purification Technology*, vol: 71, pp: 337-346.

[49] Vaidehi Bhatt, Meka. Srinivasarao and Anand Dhanwani, 2010, Selection of Waste Water Equalization Systems for Multi Product Batch Production Facility: An Industrial Case Study, *AIP Conference Proceedings, American Institute of Physics*, vol: 1298 (1), pp: 559-563.

[50] Niha Mohan Kulshreshtha, Anil Kumar, Purnima Dhall, Saurabh Gupta, Gopal Bisht, Santosh Pasha, V. P. Singh, and Rita Kumar, 2010, Neutralization of alkaline industrial wastewaters using Exiguobacterium sp. *International Biodeterioration & Biodegradation*, vol: 64, pp: 191-196.

[51] Rakeshkumar M. Jain, Kalpana H. Mody, Jitendra Keshri, Bhavanath Jha, 2014, Biological neutralization and biosorption of dyes of alkaline textile industry wastewater, *Marine Pollution Bulletin*, vol: 84, pp: 83-89.

[52] Ruhma Rashid, Iqrash Shafiq, Parveen Akhter, Muhammad Javid Iqbal, and Murid Hussain, 2021, A state-of-the-art review on wastewater treatment techniques: the effectiveness of adsorption method, *Environmental Science and Pollution Research*, vol: 28, pp: 9050-9066.

[53] Wael Qasim and A. V. Mane, 2013, Characterization and treatment of selected food industrial effluents by coagulation and adsorption techniques, *Water Resources and Industry*, vol: 4, pp: 1-12.

[54] T. G. Ambaye, M. Vaccari, E. D. van Hullebusch, A. Amrane, and S. Rtimi, 2020, Mechanisms and adsorption capacities of biochar for the removal of organic and inorganic pollutants from industrial wastewater, *International Journal of Environmental Science and Technology*, vol: 18, pp: 3273-3294.

[55] Dimitris P. Zagklis, Petros G. Koutsoukos, and Christakis A. Paraskeva, 2012, A Combined Coagulation/Flocculation and Membrane Filtration Process for the Treatment of Paint Industry Wastewaters, *Industrial & engineering chemistry research,* vol: 51 (47), pp: 15456-15462.

[56] Dalila Maria Formentini-Schmitt, Álvaro Cesar Dias Alves, Márcia Teresinha Veit, Rosângela Bergamasco, Angélica Marquetotti Salcedo Vieira, and Márcia Regina Fagundes-Klen, 2013, Ultrafiltration Combined with Coagulation/Flocculation/ Sedimentation Using Moringa oleifera as Coagulant to Treat Dairy Industry Wastewater, *Water, Air and Soil Pollution*, vol: 224, pp: 1-10.

[57] Manjushree Chowdhury, M. G. Mostafa, Tapan Kumar Biswas, and Ananda Kumar Saha, 2012, Treatment of Leather Industrial Effluents by Filtration and Coagulation processes, *Water Resources and Industry*, vol: 3, pp: 11-22.

[58] Chee Yang Teha, Ta Yeong Wua, and Joon Ching Juan, 2014, Potential use of rice starch in coagulation-flocculation process of agro-industrial wastewater: Treatment performance and flocs characterization, *Ecological Engineering*, vol: 71, pp: 509-519.

[59] Dr. C. R. Ramakrishnaiah and Prthima B. 2012, Hexavalent Chromium Removal from Industrial Wastewater by Chemical Precipitation Method, *International Journal of Engineering Research and Applications*, vol: 2 (2), pp: 599-603.

[60] Ruiping Wu, 2019, Removal of Heavy Metal Ions from Industrial Wastewater Based on Chemical Precipitation Method, *Ekoloji*, vol: 28 (107), pp: 2443-2452.

[61] Rajendra Bhatnagar, Himanshu Joshi, Indra D. Mall and vimal C. Srivastava, 2014, Electrochemical oxidation of textile industry wastewater by graphite electrodes, *Journal of Environmental Science and Health*, vol: 49, pp: 955-966.

[62] Tamal Mandal, Dalia Dasgupta, Subhasis Mandal and Siddhartha Datta, 2010, Treatment of leather industry wastewater by aerobic biological and Fenton oxidation process, *Journal of Hazardous Materials*, vol: 180, pp: 204-211.

[63] S Ishak, A Malakahmad and M H Isa, 2010, Refinery wastewater biological treatment: A short review, *Journal of Scientific & Industrial Research*, vol: 71, pp: 251-256.

[64] Nasiru Aminu, Shamsul Rahman Mohamed Kutty, Mohamed Hasnain Isa and Ibrahim Umar Salihi, 2018, Performance and Kinetics Evaluation of Integrated Suspended Growth Bioreactor Treating Beverage Industry Wastewater, *Water Conservation Science and Engineering*, vol: 3, pp: 235-252.

[65] D. Krithika and Ligy Philip, 2016, Treatment of wastewater from water based paint industries using submerged attached growth reactor, *International Biodeterioration & Biodegradation*, vol: 107, pp: 31-41.

[66] Sırma Bener and Süheyda Atalay and Gülin Ersöz, 2020, The hybrid process with eco-friendly materials for the treatment of the real textile industry wastewater, *Ecological Engineering*, vol: 148, pp: 105789.

[67] Surabhi Patel, Somen Mondal, Subrata Kumar Majumdar, Papita Das, and Pallab Ghosh, 2020, Treatment of a Pharmaceutical Industrial Effluent by a Hybrid Process of Advanced Oxidation and Adsorption, *ACS omega*, vol: 5 (50), pp: 32305-32317.

[68] Dong Wang, Qing-yuan Hu, Meng Li, and Can Wang, Min Ji, 2014, Evaluating the Removal of Organic Fraction of Commingled Chemical Industrial Wastewater by Activated Sludge Process Augmented with Powdered Activated Carbon, *Arabian Journal of Chemistry*, vol: 9, pp: 1951-1961.

[69] Sofie Van Den Hende, Erwan Carré, Elodie Cocaud, Veerle Beelen, Nico Boon and Han Vervaeren, 2014, Treatment of industrial wastewaters by microalgal bacterial flocs in sequencing batch reactors, *Bioresource Technology*, vol: 161, pp: 245-254.

[70] Hampannavar U. S. and Shivayogimath, C. B, 2010, Anaerobic treatment of sugar industry wastewater by Upflow anaerobic sludge blanket reactor at ambient temperature, *International Journal of Environmental Sciences*, vol: 1 (4), pp: 631.

[71] Ali Almasi, Mojtaba Mahmoudib, Mitra Mohammadi, Abdollah Dargahic and Hamed Biglari, 2019, Optimizing biological treatment of petroleum industry wastewater in a facultative stabilization pond for simultaneous removal of carbon and phenol, *Toxin Reviews*, vol: 40 (2), pp: 189-197.

[72] Joao P. Bassin, Caio T. C. C. Rachid, Caren Vilela, Sandra M. S. Cao, Raquel S. Peixoto, and Marcia Dezotti, 2017, Revealing the bacterial profile of an anoxic-aerobic moving-bed biofilm reactor system treating a chemical industry wastewater, *International Biodeterioration & Biodegradation*, vol: 120, pp: 152-160.

[73] Smriti Tripathi and B. D. Tripathi, 2011, Efficiency of combined process of ozone and bio-filtration in the treatment of secondary effluent, *Bioresource Technology*, vol: 102, pp: 6850-6856.

[74] Sabah Mohamed Abdelbasir and Ahmed Esmail Shalan, 2019, An overview of nanomaterials for industrial wastewater treatment, *Korean Journal of Chemical Engineering*, vol: 36 (8), pp: 1209-1225.

[75] Tanujjal Bora and Joydeep Dutta, 2014, Applications of Nanotechnology in Wastewater Treatment—A Review, *Journal of Nanoscience and Nanotechnology*, vol: 14, pp: 613-626.

[76] Geetha Palani, A. Arputhalatha, Karthik Kannan, Sivarama Krishna Lakkaboyana, Marlia M. Hanafiah Vinay Kumar and Ravi Kumar Marella, 2021, Current Trends in the Application of Nanomaterials for the Removal of Pollutants from Industrial Wastewater Treatment—A Review, *Molecules*, vol: 26 (9), pp: 2799.

[77] Anna Cescon and Jia-Qian Jiang, 2020, Filtration Process and Alternative Filter Media Material in Water Treatment, *Water*, vol: 12 (12), pp: 3377.

[78] Alice K. M. Morita and Marco A. P. Reali, 2018, Fiber filter built with polypropylene fibers applied to water clarification, *Water Science & Technology: Water Supply*, vol: 19 (4), pp: 1036-1043.

[79] Mohammad Zakaria, Kanta Shibahara, Anamul Hoque Bhuiyan and Koji Nakane, 2022, Preparation and characterization of polypropylene nanofibrous membrane for the filtration of textile wastewater, *Journal of Applied Polymer Science*, vol: 139 (35), pp: e52657.

[80] So Hee Lee, Sang Young Yeo, Pieter Cools, and Rino Morent, 2018, Plasma polymerization onto nonwoven polyethylene/polypropylene fibers for laccase immobilization as dye decolorization filter media, *Textile Research Journal*, vol: 89 (17), pp: 3578-3590.