Wastewater Treatment Technologies: A Review

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***Abstract*—Wastewater is the water that emanates from domestic sources, restaurants, establishment, industries, agriculture fields, etc. Around 80% of all wastewater is discharged into the world's waterways, and it creates health, environmental and climate-related hazards. The dissolved and suspended organic solids in wastewater are "putrescible" or biodegradable. It is important to treat the wastewater before discharging it. It is essential to reduce the impact created by the wastewater through different treatment methods and reuse the treated water for various purposes. The present study emphasis on various modern wastewater treatment technologies and compare their efficiency with traditional treatment methods, and also find the end-use possibility of treated water.**

Keywords— Wastewater, modern treatment methods, traditional treatment methods, water reuse.

I. INTRODUCTION

Water covers 71% of the earth's surface and makes up 65% of our bodies. We use clean water for various purposes including cooking, washing, gardening etc. and finally end up as wastewater. When water becomes contaminated, it loses its economic and aesthetic value, as well as posing a threat to our health and the sustainability of marine life that depends on it [1]. It is estimated that out of the total water supplied around 70% to 80% becomes wastewater. The wastewater that is generated is released into the natural water stream. Disposal of wastewater into the surface water sources causes significant issues and harms people's health the only solution for this is to treat the wastewater to the standards [2]. The wastewater contains many pathogenic bacteria, microorganisms, suspended solids, nutrients, minerals, toxic metals etc. For several years the primary goal of wastewater treatment was to reduce the number of suspended solids, oxygen-demanding materials, harmful bacteria, and dissolved inorganic compounds. However, in recent years more stress has been placed on improving the municipal treatment processes for the disposal of solid waste. In traditional wastewater treatment physical, chemical and biological processes are employed to remove organic matter, nutrients and solids from wastewater [3]. Preliminary, primary, secondary and tertiary treatments are the different treatment stages. Preliminary treatment includes the removal of coarse solids and other large materials from wastewater. The physical processes of sedimentation and flotation are used in primary treatment to remove organic and inorganic solids. In secondary treatment, the effluent is treated to remove the residual organics and suspended solids. Tertiary treatment includes all operations and processes used to remove the pollutant not removed in previous stages. Even though these steps can improve the water quality of normal wastewater, they cannot be a remedial option for treating the wastewater generated by the increasing industrial activities. The wastewater that we are dealing with may contain more pollutants that are difficult to remove by the conventional method. The wastewater that is to be treated may contain more contaminants that cannot be treated by traditional methods. The method of treatment to be used is decided by the nature of wastewater and therefore it is important to know the wastewater characteristics like COD, TS, VS and salt content [4-5].

II. METHODOLOGY

Even though more than 75% of the earth is covered by water the availability of pure water is short. There are places in India where people are having difficulty in finding pure water for their daily needs. So, it is essential to use what we have carefully. The conventional method of treating wastewater helps in reducing the adverse environmental and health problem created by them, but the quality of treated water is not up to the standards of pure water [6]. Also, various human activities have created new contaminants in wastewater called emerging pollutants. Their presence is challenging for the conventional wastewater treatment methods [7]. In the present study, the efficiency of modern technologies in wastewater treatment has been studied along with their limitations.

III. CONVENTIONAL WASTEWATER TREATMENT METHOD

Traditional wastewater treatment uses physical, chemical, and biological methods to remove solids, organic matter and, nutrients from wastewater. The different stages include preliminary, primary, secondary and tertiary.

A. Preliminary Treatment

The objective of preliminary treatment is to separate floating materials like dead animals, free branches, papers, pieces of rags, and also heavy settleable inorganic solids. This stage also helps in removing oils, grease, etc., from the sewage. This treatment reduces the BOD of wastewater by 15-30%.
Screening, detritus tank, comminutors, floatation unit and skimming tanks are the various units involved in preliminary treatment. Screening is used for the removal of floating matter. Detritus tank is also known as grit chamber, is used for removal of sand and grit. Comminutors are used for grinding and chopping large size suspended solids. Floatation units and skimming tanks are used to remove oils and greases [8].

B. Primary Treatment

The physical processes of sedimentation and floatation are used in primary treatment to remove organic and inorganic solids. During primary treatment, about 5-50% of the incoming biochemical oxygen demand (BOD5), 50-70% of the total suspended solids (SS), and 65% of the oil and grease are removed. Even though organic nitrogen, organic phosphorus, and heavy metals associated with solids are removed during primary sedimentation, colloidal and dissolved constituents are not affected. In many industrialized countries, the minimum level of pre-application treatment required for wastewater irrigation is the primary treatment. This can be considered to irrigate crops that are not consumed by humans or to irrigate orchards, vineyards, and some processed food crops [9].

Primary sedimentation tanks may be round or rectangular basins, typically 3 to 5 m deep, with hydraulic retention time between 2 and 3 hours. Settled solids (primary sludge) are normally removed from the bottom of tanks to a central well from where it is pumped to sludge processing units. Scum is also removed from the tank surface by water jets or mechanical means to sludge processing units [10].

C. Secondary Treatment

The effluent from the primary sedimentation tank contains 60 to 80% of the unstable elementary organic matter originally present in sewage. The colloidal organic matter which passes the primary clarifiers has to be removed by further treatment. The secondary or biological treatment of sewage involves modifying the character of the organic matter and thereby transforming it into stable forms through oxidation or nitrification. [11].

Secondary treatment of sewage involves various methods; these methods are broadly classified into two categories called filtration and activated sludge process. Contact beds, intermittent sand filters and trickling filters are the various filters used in the secondary treatment [12].

D. Tertiary Treatment

Tertiary treatment is performed when specific wastewater constituents which cannot be separated by secondary must be removed. The final cleaning process improves the wastewater quality before it is reused, recycled, or discharged to the environment. The treatment removes inorganic compounds and substances such as nitrogen and phosphorous [13].

IV. MODERN WASTEWATER TREATMENT TECHNOLOGIES

Legislation and hefty fines for the disposal of wastewater that does not meet the safety limits are the primary reasons that led to the inception of new or improved wastewater treatment technologies. Due to this the factories and industries have fuelled the introduction of new or improved treatment technologies [14]. The eco-friendly nature and cost-effectiveness of anaerobic and aerobic technologies have caused them to be used in the treatment of organic wastewater. However, anaerobic technologies have an added advantage of low energy consumption among their peers. The first step to choose an adequate treatment technology is to find the nature of the wastewater; thus, it is crucial to characterize water to determine key wastewater characteristics, such as chemical oxygen demand, total solids, volatile solids, salt content etc. [6].

A. Nanofiltration (NF)

Membrane filtration processes such as nanofiltration have recognized as effective means of providing a safe and reliable source of supply water by reuse for both drinking water and non-drinking water purposes [15]. Before the membrane filtration process, wastewater was pre-treated by suitable techniques to remove most of the suspended or un-dissolved ingredients like suspended solid, inorganic and organic compounds. this is done to protect the high-cost membrane from damage [16]. Residual contaminants are mainly dissolved heavy metals salts. In the treatment technique, we try to increase the molecular size of the pollutants then selected the suitable membrane filtration procedure for pollutants separation [17]. The basic science of the membrane processes can be explained by the formation of the heavy metal of cationic forms which are initially complexes by a bonding agent which will increase the molecular weight of the bonded cations and increase the size of the molecule to a size greater than the pores of the membrane which is used for separation [18-19]. Membrane filtration has two aspects that discriminate membrane filtration compared to other conventional filtration techniques. The first aspect is, membranes are asymmetric and the feed is faced by the small pore size, which reduces the pressure drop across the membrane and eliminates membrane plugging tendency. The second aspect is, a strong cross-flow over the membrane surface is necessary to operate membrane systems. The cross-flow eliminates the possibility of filter cake build-up [17].

The membrane filtration is distinguished by the following advantages compared to the other conventional separation technologies: low-energy requirements, the high selectivity of separation, and very fast reaction kinetics [20]. It is expected that the flexibility of preparation and the variety of raw materials for NF preparation will increase and spread its application in different processes [21]. NF is distinguished with the removal of calcium and magnesium ions resulting in water softening, and no addition of sodium ions during filtration [22] compared to ion exchange units.NF does not require additional chemical treatment to reduce hardness. NF does not require heating or cooling of feed like distillation for example which will reduce the cost of separation effectively. In addition, no mechanical stirring is required which will maintain gentle molecular separation. NF has the important benefit of handling a high volume of feed continuously and a stable flow rate of permeate.

NF has a limited application in the industry due to the pore size of the membrane, which is limited to nanopore size. Reverse osmosis and ultrafiltration are preferred since they can cover the UF range effectively without the cost limitation of NF due to high initial, operating and maintenance cost [23]. Based on the amount of total dissolved solids, membranes have to be changed before the actual life which increases the NF cost.

B. Use of Algae in Wastewater Treatment.

In the last 50 years, biological wastewater treatment systems using microalgae have grown in popularity, and it is now commonly believed that algal wastewater treatment systems are just as successful as conventional treatment systems. Because of their characteristics, algal wastewater treatment systems have become a viable low-cost alternative to more sophisticated and expensive treatment systems, particularly for municipal wastewater. Algae recovered from treatment ponds are commonly utilised as a nitrogen and phosphorus supplement in agriculture, and they may also be fermented to produce energy from methane. Algae are capable of eliminating toxic substances such as selenium, zinc and arsenic from the aquatic environment by accumulating those substances inside them. [24]. Many algae can take up and accumulate many radioactive minerals in their cells even their concentration in water is more. For example, spirogyra can accumulate radio-phosphorus. Considering all these abilities of algae to purify the wastewater of many types, it is worth noting that algal technology in wastewater treatment systems is expected to get even more popular in the coming years. Standard culture medium has been designed for certain microalgae strains and has since been modified to produce a wide range of different microalgae strains. These are later used as templates to define wastewater characteristics and to select the microalgal strain of the microalgae consortium that would best be able to treat a particular wastewater source. Various research teams [25] reported the presence of emerging pollutants (EP) in wastewater and the possible undesirable effects they can cause on the environment and living organisms. This EP includes, among others, pesticides, pharmaceuticals, and cosmetics; and some technologies have been proposed for their removal; such as Physico-chemical and biological treatment strategies. The use of pure microalgae strains to remove EP has been proven to be beneficial. However, microalgae-based EP removal technologies have not received much attention in the global research community.

In aquatic habitats, bacteria and algae have a symbiotic relationship. Algae aid aerobic bacterial oxidation of organic materials, by providing oxygen through photosynthesis and consume carbon dioxide and nutrients that produced through aerobic bacterial oxidation, for their development. The majority of nitrogen in algal cell bound to proteins which composes to 45-60% of dry weight and phosphorous is essential for the synthesis of nucleic acids, phospholipids and phosphate esters. Algae that need nitrogen and phosphorus in their development can remove the nutrients from wastewater in a short period [26]. Oxidation ponds that promote the growth of particular species may be more successful in removing nutrients than traditional treatment methods. Phosphorus sedimentation, ammonia, and hydrogen sulphur removal are caused by increasing dissolved oxygen concentration and pH. High pH in algal ponds also leads to pathogen disinfection. Also, the removal efficiency of heavy metals by algae shows changes among species [27].

There are challenges such as the need for large land area, separation of algal biomass from the water, decrease in the efficiency during cold climate and the limited ability of the algae biomass to reduce micropollutant content in the wastewater. Although algae can adapt to sub-lethal quantities, heavy metal build-up in cells may have a deleterious effect on other food web cycles [25].

C. Biosorption

Biosorption is a Physico-chemical process that occurs naturally in certain biomass which allows it to passively concentrate and bind pollutants onto its cellular structure. It can be defined as the ability of biological materials to accumulate heavy metals from wastewater through metabolically mediated or Physio-chemical pathway of uptake [25]. It does not require energy, and the number of contaminants a solvent can remove is dependent on kinetic equilibrium and composition of the cellular sorbent surface. Contaminants are adsorbed onto the cellular structure. Even though the term biosorption is relatively new, it has been put to use in many applications for a long time. It is widely known to be used in Activated Carbon Filter. They can filter air and water by letting pollutants bind to their porous and high surface area structure. It also has many industrial applications and is used as an alternative to human-made ion exchange resins, which cost ten times more than biosorbents. It is used to remove effluents containing toxic metals. A conventional technique like coagulation, electrocoagulation, electro-floatation, and electro-deposition have been used for the removal of heavy metals from the wastewater. However, they have various disadvantages like incomplete metal removal, generation of sludge, high energy requirements etc. because of these disadvantages, a cost-effective, efficient and eco-friendly alternative technology called ‘biosorption’ can be employed for the removal of heavy metals from wastewater [27-32]. This includes the use of microorganisms, plant-derived materials, agriculture or industrial wastewater, biopolymer as biosorbent [26]. It is a reversible rapid process involved in binding of the biosorbent in aqueous solution by mean of various interactions rather than oxidation through aerobic or anaerobic metabolism. The advantage includes simple operation, no additional nutrient requirement, low quantity of sludge, high efficiency, regeneration of biosorbent and no increase in COD of water. It can remove contaminants even in dilute concentration.

The first stage in biosorption is that the biosorbent should be suspended in the solution containing the biosorbrent (metal ion). After incubation for a particular time interval, equilibrium is attained. At this stage, the metal-enriched biosorbent could be separated. The biosorption capacity of biosorbent can be defined as the amount of biosorbate (metal ion) biosorbed per unit weight of biosorbent [33].

The challenges encountering in biosorption are similar to those faced by membrane filtration technology before achieving relevance and popularity as today. This includes the cost and stability of the biosorbent (membrane), the decrease in binding sites (fouling), and poor understanding and general reluctance to adopt new technologies etc. [33]

D. Advanced Oxidation

Advanced oxidation processes (AOPs) are a set of chemical treatment procedures designed to remove organic and inorganic materials in wastewater by oxidation through reactions with hydroxyl radical (OH). In practical cases, we use ozone (O3), hydrogen peroxide (H2O2) and UV light.

Their application becomes essential because many of the organic compounds present in industrial water are resistant to conventional treatment. The AOP procedure is useful in cleaning biologically toxic or non-degradable materials such as aromatics, pesticides, petroleum constituents, and volatile organic compounds present in wastewater [34].

Rather than collecting or transferring contaminants into another phase, they can efficiently remove organic compounds in the aqueous phase. Due to the reactivity of OH, it reacts with many aqueous pollutants. AOPs are applicable in a situation where many organic contaminants must be removed at the same time. Some heavy metals can also be removed in the forms of precipitated M(OH)X. Disinfection is possible in some AOP designs, making these AOPs an integrated solution to some water quality issues. This method does not produce any hazardous substance into the water, because the byproduct formed by reducing OH is H2O. [35].

AOPs are relatively costly since it requires a continuous input of chemical reagents to maintain the operation of this AOPs systems. AOPs need hydroxyl radicals and other reagents in proportion to the number of pollutants to be eliminated by their very nature. Some techniques require pretreatment of wastewater to ensure reliable performance, which could be expensive and technically challenging. The presence of bicarbonate ions (HCO3−) can significantly lower the concentration of OH due to scavenging processes that yield H2O and a much less reactive species, such as CO3- [36]. As a result, bicarbonate must be eliminated from the system otherwise AOPs will not be efficient. Using AOPs alone to handle a large amount of wastewater is not cost-effective; instead, AOPs should be deployed in the final stage only after ensuring that primary and secondary treatment has successfully removed a large proportion of contaminants. Recent studies are mainly focusing on reducing the cost of treatment through combining AOPs with biological treatment [35].

This field has witnessed a fast advancement both in theory and in application. TiO2/UV systems, H2O2/UV systems, and Fenton, Photo-Fenton, and Electro-Fenton systems have received extensive scrutiny so far. [37].

V. CONCLUSIONS

Wastewater generation is unavoidable, but it can be treated in an effective way to minimize environmental impacts. Industrialization led to the introduction of new contaminants in pesticides, pharmaceuticals, cosmetics, etc. which have complex compositions and are hazardous in nature. Even though 75% of the earth's surface is covered by water the availability of drinking water is less than 1%. Putting this available water in jeopardy will bring us much more risk. In this situation, it is essential to treat the wastewater, to satisfy the drinking water standards. Many treatment methods are emerging for the ultra-purification of wastewater. Water treatment technology development and implementation have been primarily driven by three primary factors: the discovery of new rarer contaminants, the adoption of new water quality standards, and cost. During yearly periods, chemical clarification, granular media filtration, and chlorination were virtually the only treatment processes used in municipal water treatment. However, today we can see a dramatic change in the industry's approach to water treatment as they are seriously considering alternative treatment technologies to the traditional filtration/chlorination treatment approach. The NF technique can be applied for treating wastewater containing small contaminants. Also, it can soften the water along with purifying the water. However, it is observed that they are not durable which makes them uneconomical. The use of algae for wastewater treatment is a fascinating technique since it is highly economical, but it is seen that their efficiency depends on the climatic conditions. Biosorption is another emerging technology that is efficient in removing toxic ions and also their operation is simple. When it comes to cost, their application is not preferred. Advanced oxidation is a chemical treatment method, that is highly efficient in eliminating organic compounds, but their operation is also costly. Even though most of the emerging water treatment methods are highly efficient in removing contaminants, their cost of operation is expensive. Using algae bacterial symbiosis in treating wastewater shows much efficiency and is economical at the same time. Combining other treatment methods along with algae bacterial symbiosis can make the system more efficient and economical.

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