Chapter 1
Environmental Issues: A Challenge for Wastewater Treatment

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Contents

Abstract In the present era, wastewater treatment is a challenging issue for living organism and biophysical environment. According to United Nation (UN) Office for the Coordination of Humanitarian Affairs (OCHA), climate change is not just a distant future treat, it is the main driver behind rising humanitarian need, and we are

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seeing its impact. Either there is a lot of environmental issue, but wastewater treatment is one of the main environmental issues for the twenty-first century. Wastewater challenges not only depend on legislations for controlled effluent but also on socioeconomic condition as well as regional characteristics. In this scenario, it is difficult to categorize a common reason to all these situations. In a note, there is a need for implementation of cost-effective and high-performance waste treatment system, and public awareness is of importance. Improper treatment of wastewater from industries and houses before disposal poses severe environmental as well as health issues to the surrounding communities. In this book chapter, we are highlighting several treatment techniques and approaches which have been developed and applied in making sure that these wastewaters are properly treated before being discharged into the environment.

Keywords Wastewater treatment · Water crisis · Environmental issue · Wastewater management

1.1 Introduction

It is very difficult for living organisms, i.e. both plants and animals, to survive without water; hence water is classified as the most essential resource for human life. Water is used extensively for many purposes which include among others drinking, agriculture, cleaning, industrial purposes, mining, etc. The quality of water is compromised by pollution caused by agricultural activities, human activities, mining, energy generation, deforestation, industries and urban settlements (Rangreez et al. 2015). Wastewater from the industries are discharged directly or indirectly into the water bodies and surrounding environment or in some cases used for irrigation purposes and, hence, need to be treated before discharge in order to save the life of aquatic animals and human health in general (Naushad et al. 2015; Ahlawat and Kumar 2009). It has been recorded that approximately 300–400 million tons of heavy metals, toxic sludge, solvents and other organic waste are being deposited into the surrounding environment by industrial plants every year worldwide (Alam et al. 2014; Xiao et al. 2015).

One of the most important raw materials used in the textile, food, paper and pulp and pharmaceutical industries are dyes. Wastewater from these industries usually contains dye residues which are not readily biodegradable. Wastewater containing these dye residues creates some negative effects on the environment especially when they enter into the water bodies. Colour hinders the penetration of light in water which in turn affects the process of photosynthesis in the aquatic system (Gupta 2009; Zhao et al. 2005). A large number of resources like chemicals, fuel and water are consumed in textile manufacturing processes leaving a large amount of waste behind. About 10–25% of textile dyes are lost during the dyeing process, and depending on the type of dye used, about 2% for basic dyes and about 50% for the reactive dye is usually discharged as aqueous effluents in different environmental sectors (Zaharia et al. 2012) leading to surface water and groundwater pollution. The loss of these dyes arises from the fact that not all of the dye binds to the fabric during the dyeing process.

Synthetic dyes can be grouped as anionic (direct acid and reactive), cationic (basic) and non-ionic (disperse) dyes (Mishra and Tripathy 1993). Due to its bright colour, water fastness, availability in different types, simple application techniques with low energy consumption (Zaharia et al. 2012) and also its ability to be applied to both natural and synthetic fibres, reactive dyes are the most commonly used dyes in the textile industry (Aksu 2005). Reactive dyes can pass through conventional treatment systems without undergoing much change, thus making its removal problematic (Anjaneyulu et al. 2005).

It is estimated that every year about 280,000 tons of textile dyes are lost in effluents from the textile industry worldwide. The amount of dissolved oxygen is decreased by the thin layer of discharged dyes that form over the surface of water bodies which in turn affects aquatic fauna (Arroyave Rojas et al. 2008). Apart from the effect of their colour, absorption of dyes on human health is also detrimental. The breakdown products of dyes through the gastrointestinal tract affect the haemoglobin, skin, lung and blood formation (Börnick and Schmidt 2006). With regard to their synthetic and aromatic nature, synthetic dyes are non-biodegradable and carcinogenic and may lead to dermatitis, allergies and skin irritation (Börnick and Schmidt 2006; Suteu et al. 2009; Zaharia et al. 2009). Hence, it is of the utmost importance to treat wastewater before discharging into the environment.

In this chapter, we are describing the concerned challenges for the wastewater treatment which is one of the very serious environmental issues nowadays. In addition we also described the possible approach to shoot out these environmental challenges. This chapter is also highlighting the photocatalyst which is very common and effective to shoot out this issue.

1.2 Waters Become an Environmental Challenge

The earth's surface is covered with about 70% of water. Water from the sea and ocean which make up about 97% of the earth's water entities is saline (i.e. contain a high amount of salt) and cannot be used for drinking, industrial and agricultural purposes. While only about 3% of the earth's water is freshwater. About 69% of this available freshwater for human and animal consumption is trapped in places like mountainous regions, Greenland, ice caps and glaciers, and only about 30% is underground which in most cases are very deep and difficult to access for uses. The only accessible water source available for human and animal consumption is less than 1% of the freshwater, and it is found in water bodies like the lakes, rivers, ponds, streams and reservoirs; hence, keeping these water bodies clean should be our utmost priority on earth for survival (Freeman 2017; Perlman 2017.) Water pollution, that is, the release of unwanted substances into the water bodies to the extent that it interferes with the functional ecosystem, is one of the major problems we are facing in the twenty-first century. The world's population is growing at ~ 80 million people per year (mppy), and this has resulted in the demand for freshwater consumption along with increase at about 64 billion metres cube per year. This breakneck in populations and urbanisation is giving rise to an increase in the amount of wastewater generated and disposed of into the environment both from the industries and human activities (Junior 2017; Karasov 2017).

The ability of countries, cities and towns to grow, attract investors and at the same time fulfil the fundamental needs of the populations and also take care of the environment properly will be in danger, if water sources and wastewaters from industries including dye-producing and dye-using industries are not well managed.

Water is one of the essential commodities on earth and a valuable facility for human advancement. All living things depend on it for survival. Approximately two-thirds of the earth is covered with water. However, human activities, rapidly growing worldwide population, advance in technology, and large demand and supply of available water to agriculture, textile industries, cities and town as well as climate change are some of the contributing factors to water scarcity (Cosgrove and Loucks 2015). Reports from the 2010 Pan African Chemistry Network revealed that the population of Africa in 2009 exceeded more than one billion with a continuous growth rate of 2.4%. Moreover, about 340 million people from this population were found to lack access to safe drinking water, while about 590 million also lack access to proper sanitation practice (Oleszczuk and Baran 2004). In addition, the 2006 United Nations Development Programme (UNDP) reports show that more than 1.1 billion people from most developing countries do not have access to water and 2.6 billion people also do not have proper sanitation practice (Pink 2006). There is, therefore, the need to improve sanitation and proper use of water to achieve more than 50% of clean water supply to meet the needs of the population. It has been estimated that by 2030, more than 3.9 billion people worldwide will experience water scarcity (West 2017). The intensity of water crises is mostly due to improved agricultural practices (use of herbicides, pesticides, fertilizers, etc.), human activities arising from the pollution of the waters, and rapid industrialisation as a result of releasing unpleasant and toxic chemicals into the environment especially the sources of water. It is, therefore, important to equip the monitoring authorities to check industrial activities on the environment so that our water bodies will be free from these harmful substances.

1.3 Water Pollution: Factors and Effect

Water pollution occurs when wastes from agricultural, domestic and industries (e.g. textile) are discharged directly or indirectly into water bodies (e.g. rivers, lakes, aquifers and groundwater) without prior filtering processes to remove harmful substances. These harmful substances (organic pollutants) can persist in the water for a prolonged period of time and are absorbed by the plants and animals in the lower chain harming the food chain of the larger living organisms (Harrison 1997; Office 2002). Therefore, nowadays water pollution is a major environmental issue, which demands regular revision and assessment of water resource policy worldwide. Recent studies reveal that water pollution is the main cause of diseases and deaths in the world (Larry 2015; Pink 2015). In China, 90% of water in the cities is polluted (China 2007), while as of 2007 about 500,000 peoples from China had no access to clean drinking water (Bank 1999). Moreover, apart from the severe water pollution problems in developing countries, developed countries also continue to struggle with increasing water pollution issues. For example, reports on assessed water quality of 45% stream, 47% lakes and 32% estuarine in the USA were classified as polluted water (Sheet 2004). The release of dye-containing wastes into the environment is undesirable and poses threats to our water bodies since the presence of the colour of the dyes affects the penetration of light and inhibits the process of photosynthesis and other biotic activities in the ecosystem. Furthermore, the colour again reduces gas solubility resulting in insufficient oxygen and activating anaerobic respiration along with suppressing aerobic organisms. The low level of dissolved oxygen also affects the bacterial growth, which lowers the breakdown of dead organic matter and the production of the corresponding nutrients (Rai et al. 2005). A number of health effects arising from water pollution such as damage to the kidney, central nervous system and reproductive system, ulceration of the skin and mucous membrane, haemorrhage and brain and liver disorder are also reported (Zhang et al. 2012). Metals associated with dyes such as Cr^{6+} when accumulated to a very high level are found to be carcinogenic and mutagenic (Anjaneyulu et al. 2005). Dyes are stable towards sweat, microbial degradation, detergents and photolysis and therefore can persist in the environment for relatively long period of time (Vilar et al. 2011). For example, hydrolysed Reactive Blue-19 has a half-life of about 46 years at pH 7 at room temperature (Soloman et al. 2009). The dissolved solids from textile effluent, when discharged, can lead to high levels of total dissolved solids (TDS) in the waters, which are harmful to vegetation and therefore prevent its utilisation for agriculture activities (Solís et al. 2012). Effects of residual chlorine from dye effluents can cause depletion of dissolved oxygen and affect aquatic life, especially aerobic living organisms. In addition, this residual chlorine may react with some aromatic compounds to produce toxic chlorinated aromatic (Merzouk et al. 2009). There are other non-biodegradable organic compounds in textile effluents, which may cause an increase in the COD of the effluent thereby disturbing the balance of the aquatic environment (Manu and Chaudhari 2002).

1.4 Nanotechnology and Environmental Issue

Nanoscience and nanotechnology are branches of engineering and science that deal with the manipulation of materials or emphasize the importance of matter on the nanometre scale (1–100 nm). Nano is a prefix applied in metric for measurements of length as nanometres, which can be used to specify the amount of a quantity such as nanoamperes (an amount of current in electricity) or nanolitres (an amount of a volume) or nanograms (an amount of mass). A nanometre is, therefore, defined as a one-billionth of a metre (1×10^{-9} m). Nanoscience is the process of studying the existence and monitoring of resources at microscopic, molecular and macromolecular scales where the properties of the synthesized composite considerably vary from those at a larger scale. Besides, it is involved with the convergence of material science, physics, chemistry and biology, which deals with the controlling and characterisation of matter on larger scales between the molecular and the micron size. Nanotechnology, therefore, is synthesizing, designing, characterisation, production and application of device, structures and systems by controlling the size and shape at the nanometre scale. In addition, it is an emerging discipline in engineering that relates the various methods from nanoscience to generate marketable and inexpensive viable products (Matsuda and Hunt 2005; Sahoo et al. 2007). Nanoparticles range in size from 1 nm to 100 nm and have large surface area compared to the volume, which makes them react very quickly than other molecules. There is intense research in nanoparticle currently because of its potential application in biomedical, environmental remediation, optical and electrical fields (Islam et al. 2015; Nabi et al. 2010). They showed great scientific interest by forming a bridge between bulk materials and atomic or molecular structures. A bulk material has constant physical properties irrespective of its size, while size-dependent properties are observed at the nanoscale. Therefore, material properties change as their size proceeds towards the nanoscale and as the proportion of atoms, the surface, becomes significant. Moreover, their high surface-to-volume ratio provides a huge driving force for diffusion at a higher temperature, while the optical properties confined their electrons and produced quantum effect (Hewakuruppu et al. 2013; Taylor et al. 2013a, b; Taylor et al. 2012). Current research into nanoscience and nanotechnology points to the fact that essential structures of materials can be tailored at the nanoscale to achieve specific properties using the tools of material science. In addition, these materials can be made effectively stronger, lighter, more reactive, more durable or good electrical conductors. Besides, nanotechnology has been found to meet the need for affordable, clean drinking water through rapid, low-cost detection of pollutants in water. It is anticipated that the applications of nanoparticles will in the future be used to treat industrial pollutants in groundwater through chemical reactions at a much lower cost than pumping the water out for treatment. One advantage of nanotechnology in terms of photocatalysis is that it offers extensively higher surface-to-volume ratio and this help decreasing the recombination of charge carrier to pave way for a chemical reaction, thereby increasing the surface area of the photocatalyst (Adams et al. 2003; Peter et al. 2018). The study of nanoparticle in recent times has generated a great interest in the field of photocatalysis due to its potential to enhance photocatalytic activity (Linic et al. 2011; Warren and Thimsen 2012). Therefore, research into nanoscience and nanotechnology has the abundant potential towards the enhancement of photocatalytic activity.

1.5 Current Approach for Wastewater Treatment (e.g. Organic Pollutant)

The treatment methods for dye removal are grouped into (i) biological, (ii) physical/physiochemical, (iii) chemical and (iv) advanced oxidation processes (AOPs). The biological method, which consists of biodegradation, bioaccumulation and biosorption, is mostly employed for removal of colour from effluents. These methods are found to be economical and environmentally friendly but cannot be used on large scale due to fluctuating effluent parameters (temperature, pH, etc.) which make them less effective. Besides, controlling the effluent parameters for optimum microbial growth is difficult (Vijayaraghavan and Yun 2008). The complex nature of dye structures coupled with its stability towards biodegradation makes biological processes ineffective under aerobic conditions. The anaerobic condition can be employed for decolourizing of the effluent, but the possible formation of aromatic amines known to be carcinogenic and mutagenic during the process is not advisable. The physical/physiochemical methods include adsorption, chemical- and electrocoagulation, membrane processes and ion exchange. The most widely used physical method for removing colour from effluents is adsorption, but this only transfers the pollutants from aqueous phase to the solid phase. Therefore, high-concentrated sludge is generated leading to handling and disposal challenges (Adewuyi 2005). Chemical- and electrocoagulation also generate large volumes of sludge during its operation causing secondary pollution, which needs additional treatment. Moreover, the large doses of chemical coagulates added to increase coagulation in chemical coagulation (for neutralisation of charges) are also not environmentally friendly (Aksu and Dönmez 2005). There is the need to add more chemicals, such as soda, ash or lime, for pH adjustment before and after treatment. It is also sensitive to temperature changes. Ion exchange methods are not often used due to lack of adaptability in its application because it works only for a narrow range of ionic dyes (Robinson et al. 2001). Moreover, the precipitate formed from cation resin recharger (H_2SO_4) and calcium from water can foul the resin beads and block the pipes in the vessels preventing effective exchange of ions (Lower 2007). When the ferrous ion in water comes in contact with air, it forms ferric ion and precipitates to ferric hydroxide which then clogs the resin beads and affects the resin efficiency (Zingaro et al. 1997). Membrane processes (microfiltration, ultrafiltration, nanofiltration, reverse osmosis and forward osmosis), when coupled with other pretreatment methods, can remove colour, inorganic ions, microbes and other organic compounds from effluents. The main drawback is the high operating pressure and sensitivity to fouling, which affect permeation and therefore need to change membranes regularly giving rise to extra operation cost (Fersi and Dhahbi 2008). They are not recommended for the removal of microorganism, some pesticides and volatile organic chemicals (VOCs) due to the membrane deterioration by bacteria (Skipton 2008). Chemicals like chlorine, chlorine dioxide and hypochlorite have been employed as oxidation agents in chemical oxidation processes. However, the formation of toxic chlorinated organic compounds due to the stability of the dye makes this method ineffective (Merzouk et al. 2009). The use of AOPs, which involves the generation of hydroxyl radical (^{-}OH), with powerful non-selective ability, has been found to be excellent treatment methods compared to the conventional methods (Elahmadi et al. 2009). The hydroxyl radical operates by attacking and mineralizing the molecules of the dye into less complex colourless molecules (CO_2, H_2O). This new set of oxidizing agents such as hydrogen peroxide (H_2O_2), Fenton's reagent (Fe^{2+}/H_2O_2) and ozone (O_3) when coupled with others and UV radiation can improve and activate the hydroxyl radical during its operation (Brillas and Martínez-Huitle 2015; Kiwi et al. 2000). Examples of such coupling are O_3/H_2O_2/UV, H_2O_2/UV/Fe^{2+}, H_2O_2/UV, O_3/UV, O_3/H_2O_2, etc. Advantages of AOPs over conventional treatments are (i) they are able to mineralize completely the dye molecules, (ii) they eliminate the formation of sludge to avoid further treatment, (iii) the non-selectivity nature of hydroxyl radical protects the versatility of AOPs in mineralizing a wide spectrum of dyes and other organic compounds (Vilar et al. 2011), and (iv) there is no occurrence of fouling because AOPs are resistant to textile effluent toxicity (Crini 2006; Singh and Arora 2011).

However, the sustainability of UV is the main challenge in this method, since UV accounts for only 4% of the solar radiation, and using UV artificial sources is expensive (Perez et al. 2002). The operational cost of AOPs is very high because a continuous input of expensive chemical or reagents is required to maintain the operation of most AOP system. In addition, AOPs require hydroxyl radicals and other reagents proportional to the quality of contaminants to be removed. Some techniques need pretreatment of wastewater to ensure reliable performance, which may require extra cost. Moreover, it is expensive to employ AOPs to treat large quantities of wastewater, and therefore such AOPs should be employed in the ultimate stage after removing a lot of contaminants through primary and secondary treatments.

1.6 Conclusion

In this chapter, we focused on the challenges for the wastewater treatment which is one of the serious environmental issues. The dangers posed on the environment by improper treatment of wastewater—wastewater from the textile industry—before discharging was highlighted in this chapter too. The nature of dyes in effluents and while they tend to stay in the environment for a longer period as well as their negative impact on the environment was discussed. Improper treatment of wastewater from industries before disposal poses severe environmental and health hazards to the surrounding communities. Several treatment techniques have been developed and applied in making sure that these wastewaters are properly treated before being discharged into the environment.

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