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Review

Remediation of textile effluents by membrane based treatment techniques: A state of the art review

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ABSTRACT

The textile industries hold an important position in the global industrial arena because of their undeniable contributions to basic human needs satisfaction and to the world economy. These industries are however major consumers of water, dyes and other toxic chemicals. The effluents generated from each processing step comprise substantial quantities of unutilized resources. The effluents if discharged without prior treatment become potential sources of pollution due to their several deleterious effects on the environment. The treatment of heterogeneous textile effluents therefore demands the application of environmentally benign technology with appreciable quality water reclamation potential. These features can be observed in various innovative membrane based techniques. The present review paper thus elucidates the contributions of membrane technology towards textile effluent treatment and unexhausted raw materials recovery. The reuse possibilities of water recovered through membrane based techniques, such as ultrafiltration and nanofiltration in primary dye houses or auxiliary rinse vats have also been explored. Advantages and bottlenecks, such as membrane fouling associated with each of these techniques have also been highlighted. Additionally, several pragmatic models simulating transport mechanism across membranes have been documented. Finally, various accounts dealing with techno-economic evaluation of these membrane based textile wastewater treatment processes have been provided.

1. Introduction

Today's world stands as a witness to the revolutionizing socio-economic impacts of various industries. Unfortunately, the development of industrial sector has whipped up certain unintended repercussions, resulting in an unavoidable trade-off between industrial progress and environmental degradation. Textile industries, for instance, are one of the largest consumers of water, dyes and various processing chemicals that are used during the various stages of textile processing. Subsequently, substantial quantities of effluents are generated, mostly consisting of spent or unutilized resources, which are not suitable for further usage. These effluents are likely to cause environmental problems if discharged without prior treatment. The wastewater obtained from the textile industry is usually rich in color, chemical oxygen demand (COD), complex chemicals, inorganic salts, total dissolved solids (TDS), pH, temperature, turbidity and salinity (Verma et al., 2012; CPCB, 2007). According to the classification suggested by Environmental Protection Agency (USEPA), textile wastes can be divided into four principal categories, namely the dispersible, hard-to-treat, high-volume, and hazardous and toxic wastes (Foo and Hameed, 2010). Among the various complex constituents present in textile wastewaters, the dyes can be inarguably considered as the most peremptory source of contamination. The direct discharge of the coloured textile effluent into the fresh water bodies adversely affects the aesthetic merit, water transparency and dissolved oxygen content (Duarte et al., 2013; Wang et al., 2009). Besides, these dyes exhibit highly complex structure, high molecular weight and low biodegradability (Verma et al., 2012; ElDefrawy and Shaalan, 2007). This accounts for its toxic effects on flora and fauna present in the water bodies. Further, these dyes are mutagenic and carcinogenic (Wang et al., 2009). The presence of these relatively recalcitrant

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dyes along with inorganic salts, acids, bases and other residual chemicals in the effluent directly discharged into the sewage networks impedes the biological treatment processes (Arslan-Alaton et al., 2008). Also, the chance evaporation of these chemicals in to the air we breathe or adsorption onto human skin is capable of inducing allergic reactions (Khandegar and Saroha, 2013).

Perhaps, the greatest danger to environmental sustainability is posed by the outrageously high amount of primary water consumption by the textile sector, which has, in all probability, resulted in the depletion of available fresh water resources. The deficit in the availability of water can be gauged by the fact the currently the Indian textile industry consumes 0.2 m^3 of water per kg of textiles fabricated (Parvathi et al., 2009), while generating 200–350 m^3 of wastewater per ton of finished product (Ranganathan et al., 2007). According to the recent survey conducted by FICCI Water Mission (2011), the water demand for the industrial sector is likely to witness a rise due to the impending industrial growth as also a significant rise in population; this will probably account for 8.5 and 10.1 per cent of the total freshwater withdrawal in 2025 and 2050 respectively. Thus, a 4 per cent hike from the current 6 per cent level of the total freshwater abstraction by the industries (as per 2010 statistics) is estimated. The dwindling supply of water is hence a concomitant outcome of development of industrial sector, and is bound to bring about a declination in the performance of the textile sector owing to the aggravated paucity of water resources, or deterioration in the quality of water available. These deleterious consequences have compelled the researchers to examine the suitability of the various conventional treatment technologies for treating textile industry wastewater. The sole objective of such investigations is to devise and develop a wastewater treatment technique which is environmentally compatible, cost-effective and at the same time successful in reducing the concentration of various contaminants in the textile effluent to permissible levels, which comply with the current environmental imperatives. The effluent treatment process should also be equally adept in reclaiming the water using in textile processing to a great extent; such an arrangement is indispensable for sustainable development of the industrial sector and of the country as a whole.

Various treatment techniques are in use to mitigate the contaminant levels of textile wastewaters. Table 1 provides a broad overview of the various conventional as well as recently engineered treatment processes employed to bring about the treatment of textile effluents. However, these methods suffer from certain serious handicaps. For instance, the otherwise eco-friendly biological processes, such as the conventional activated sludge systems (Lotito et al., 2012b, 2011) or anaerobic textile waste bioremediation processes (Türgay et al., 2011) often lack flexibility; their respective efficiencies are adversely affected by the biologically persistent constitution of the pollutants present in the textile wastewater as well as by the diurnal fluctuation in the problem environment in terms of variation in wastewater pH, temperature or concentration of contaminants in the textile wastewaters (Kapdan et al., 2000; Oller et al., 2011). Additionally, these biological treatment methods do not bring about complete mineralization of the target dye contaminants. Hence, the toxicity of the discharged effluent is often exacerbated by the chance regeneration of the primary organic constituents of the textile dyes. This drawback severely impedes the scale-up of the biological treatment technique due to the resulting reactor instability (ElDefrawy and Shaalan, 2007; Robinson et al., 2001). The complex rheology of the textile discharge therefore entails either singular or combined application of the physicochemical methods, such as chlorination, coagulation–flocculation (Al-Ani and Li, 2012; Gao et al., 2007; Yang et al., 2013), adsorption (Mezohegyi et al., 2012) and advanced oxidation processes, such as, ozonation (Somensi et al., 2010), Fenton treatments (Karthikeyan et al., 2011), electro-Fenton methods (Yu et al., 2013), photo-Fenton oxidation processes (Punzi et al., 2012), and photoelectrocatalytic reaction (Sapkal et al., 2012), for complete degradation of the toxic textile wastewater components (Álvarez et al., 2013; Lotito et al., 2012a; Oller et al., 2011; Torrades and García-Montaño, 2014). The potential of the adsorption technology remains largely untapped due to the limitations posed by environment-friendly disposal of spent adsorbents, difficulty in regeneration of spent adsorbents, reduction in reactivated adsorbent efficiencies, high costs of the adsorbents and the maintenance expenses involved (Robinson et al.,

Table 1
Overview of various conventional as well as recently engineered physicochemical, biological and membrane based treatment processes employed to bring about the treatment of textile effluents.

Process adopted	Effluents characteristics	Reference
Catalytic degradation (biosynthesized silver Nanocatalysts)	Methyl orange, methylene blue and eosin Y	Vidhu and Philip, 2014
Adsorption (PES/PEI nanofibrous Membrane)	Anionic dyes, Sunset Yellow FCF, Fast Green FCF, Amaranth	Min et al., 2012
Catalytic ozonation (activated carbon, ceria catalysts)	One acid azo dye, CI Acid Blue 113, two reactive dyes, CI Reactive Yellow 3 CI Reactive Blue 5.	Faria et al., 2009
Adsorption (activated carbon)	Raw textile effluent obtained from a cotton textile mill	Ahmad and Hameed, 2009
Biodegradation (facultative Staphylococcus arlettae Bacterium)	Textile azo dyes: CI Reactive Yellow 107, CI Reactive Black 5, CI Reactive Red 198, and CI Direct Blue 71	Elisangela et al., 2009
Electrolysis (anode materials: $Ti/Ru_{0.3}Ti_{0.7}O_2$; $Ti/Ir_{0.3}Ti_{0.7}O_2$; $Ti/Ru_XSn_{1-X}O_2$, with $X = 0.1$, 0.2 or 0.3)	Real textile effluent	Malpass et al., 2008
Electrolysis ($Ti/Ru_{0.3}Ti_{0.7}O_2$ DSA® type electrode)	Real textile effluent	Malpass et al., 2007
Electro-Fenton process	Synthetic textile wastewater (Reactive Blue 49 dye (RB49) and Polyvinyl Alcohol (PVA))	Yu et al., 2013
Photo-Fenton oxidation (Solar and UV-C irradiation, Zero-valent iron (ZVI) catalyst)	Synthetic wastewater (azo dye, C.I. Reactive Black 1 (RB1))	Grčić et al., 2012
Photodegradation (TiO_2/H_2O_2 and Sunlight)	Real textile effluents	Garcia et al., 2009
Photocatalyzed degradation (UV-C/TiO_2, UV-C/H_2O_2 and UV-C/TiO_2/H_2O_2)	Azo-dye Reactive Orange 16	Egerton and Purnama, 2014
Ozonation (Semi-batch reactor)	Remazol Red RB Remazol Turquoise Remazol Black RL Remazol golden Yellow RNL	Tabrizi et al., 2011
Ozonation (Batch reactor)	Persistent anthraquinone dye C.I. Reactive Blue 19.	Tehrani-Bagha et al., 2010
Coagulation/flocculation (CF)/ Microfiltration (MF), CF/ULtrafiltration (UF) and CF/Powdered Activated Carbon (PAC)	Simple textile effluent (dyeing processes) complex global effluents(dyeing, bleaching and washing outlets)	Harrelkas et al., 2009