Desalination and Water Treatment
www.deswater.com

doi: 10.1080/19443994.2014.932716

56 (2015) 14–23
September

Taylor & Francis
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Suitability of conventional and membrane bioreactor system in textile mill effluent treatment

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Received 19 January 2014; Accepted 1 June 2014

ABSTRACT

Effluents from the industries contaminate surface water, soil and groundwater due to the presence of soluble solids, suspended solids, organic matter, heavy metals and toxic constituents. This necessitates treatment of the discharged wastewater and determination of effluent quality. The situation is very alarming for Tirupur due to textile industries effluent, affecting water consumption pattern around the whole area that generates high stress on groundwater resources as well as agricultural productivity. The present study is based on the general characterization of the quality of effluent before and after installation of conventional effluent treatment plants (CETPs) and membrane bioreactor (MBR) treatment systems. The performance evaluation of CETPs and MBR systems in textile mill effluent treatment was carried out in terms of effluent quality and treatment efficiency. The findings revealed that the CETPs were efficient in removal of total dissolved solids, bicarbonate (HCO_3^-) total major cations and Cd however, the MBR system was more efficient in removal of biochemical oxygen demand, chemical oxygen demand, SO_4^{2-}, Zn, Pb and Cr. On the basis of findings, it can be concluded that the MBR system serve as an effective alternate in treating the industrial wastewater specially for textile effluent treatment with major advantages like less sludge generation, compact and ease in operation and small footprints, in comparison with conventional treatment systems.

Keywords: Textile industry; Effluents; Conventional treatment; Membrane bioreactor; Heavy metals; Textile wastewater; India

1. Introduction

The textile mills are one of the rapidly growing sectors in Indian industrialization. However, as per Ministry of Environment and Forest, textile industry is one of the most polluting industries too. It plays a major role in polluting the water bodies and land by discharging a vast amount of wastewater [1–3]. Textile processing is chemical based with excessive use of different combinations of acids, bases, salts, oxidizing

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and bleaching agents along with complex organic and toxic compounds. Each step is conducted in batches and the water is used only one time for each processing step and then discharged. Which ultimately increase the volume of waste effluent as well as demand of fresh water for the wet processes [2–4]. The chemical nature of textile effluent is very complex having high concentration of dissolved solids, suspended solids, high conductivity and salts along with toxic dye residues.

Tirupur city, which is situated on the bank of Noyyal River, is well known for cotton production. Rapid textile growth of Tirupur is due to good quality of water from Noyyal River, easy availability of cotton, skilled labour, industrial networking and export culture. Now, the Noyyal River is acting for both as a source of water for processing in textile industries as well as sinks for textile mill effluent. As a result, Noyyal River has become much polluted and the river water is not suitable for textile processing. In Tirupur, a high degree of pollution has been accumulated over decades, which further contaminating other environmental spheres [4,5]. Therefore, the proper treatment of textile mill effluent is necessary in order to minimize the environmental pollution and preserve the water quality of river.

In Tirupur, both conventional and MBR treatment systems were installed for the treatment of textile mill effluent. A total of 20 conventional effluent treatment plants (CETPs) have been proposed in Tirupur to achieve zero effluent discharge and reuse of water, however, only 17 CETPs based on conventional treatment systems (16 No.) and MBR technology (1 No.) are in operation. Their designed capacity ranges between 1.6 and 10 million litres per day (MLD). The introduction of MBR-based treatment plant in Tirupur zone is a highlight, mainly due to maximizing reuse of water by follow-up of zero discharge norms. In order to assess the suitability of wastewater treatment systems in reducing the pollution load from water bodies, a comparative study of two different treatment technology-based systems was conducted with following objectives:

(1) To establish the status of the effluent quality of textile mill i.e. before and after treatment.
(2) To compare the treatment efficiency of conventional and MBR treatment systems.

2. Study area

Tirupur town is situated in western part of the Tamil Nadu state, which is a major industrial city and is commonly known as "The Manchester of South India", "Dollar City", "Knit City" and "Cotton City" due to its cotton knitwear industrial hub [6]. It is located on the bank of Noyyal River, a tributary of river Cauvery (Fig. 1). It lies between 11˚10´N to 11˚22´N latitude and 77˚21´E to 77˚50´E longitude [7]. Before 1997, no textile industries had treatment plants. In recent years, efforts have been made to treat the effluents from dyeing and bleaching industries in Tirupur. There are 17 CETPs operated at present in Tirupur and they all are located near the bank of Noyyal River (Fig. 1). The salient features of studied plants are given in Table 1.

3. Materials and methods

Twelve wastewater samples were collected from inlet and outlet stages of five conventional CETPs (activated sludge process based) and one MBR-based CETPs (microfiltration, immersed type) during 2009–2010. The effluents samples were collected in acid washed polypropylene bottles and filtered with 0.45 mm Millipore and preserved by acidification. The unacidified filtered samples were used for the analysis of major anion, whereas, acidified samples were used for the analyses of major cations and trace element.

3.1. Analytical methods and instrument

The pH was measured using a portable pH electrode meter (HACH). Electrical conductivity and total dissolved solids (TDS) were measured using a multiparameter electrode (Sension 4-pole conductivity, HACH). The bicarbonate content was determined by potentiometric titration method. The major ion and metal analyses were done as per the Standard Methods (APHA 2005) using Atomic Absorption Spectrophotometer (Model AA-6800, Shimadzu) {Calcium (Ca^{2+}) and Magnesium (Mg^{2+})}, EEL Flame Photometer {Sodium (Na+) and Potassium (K+)}, Spectrophotometry {Phosphate (PO_4^{3-}), Silica ($H_4SiO_4^-$), Sulphate (SO_4^{2-}) and nitrate (NO_3^-)}. The biochemical oxygen demand (BOD) tests were carried out according to Winkler's method. The chemical oxygen demand (COD) was measured by open reflux method as described in Standard Methods (APHA 2005).

4. Results and discussion

4.1. Performance of conventional CETPs

Table 2 summarizes the results of raw and treated wastewater of CETPs. The high pH in raw wastewater

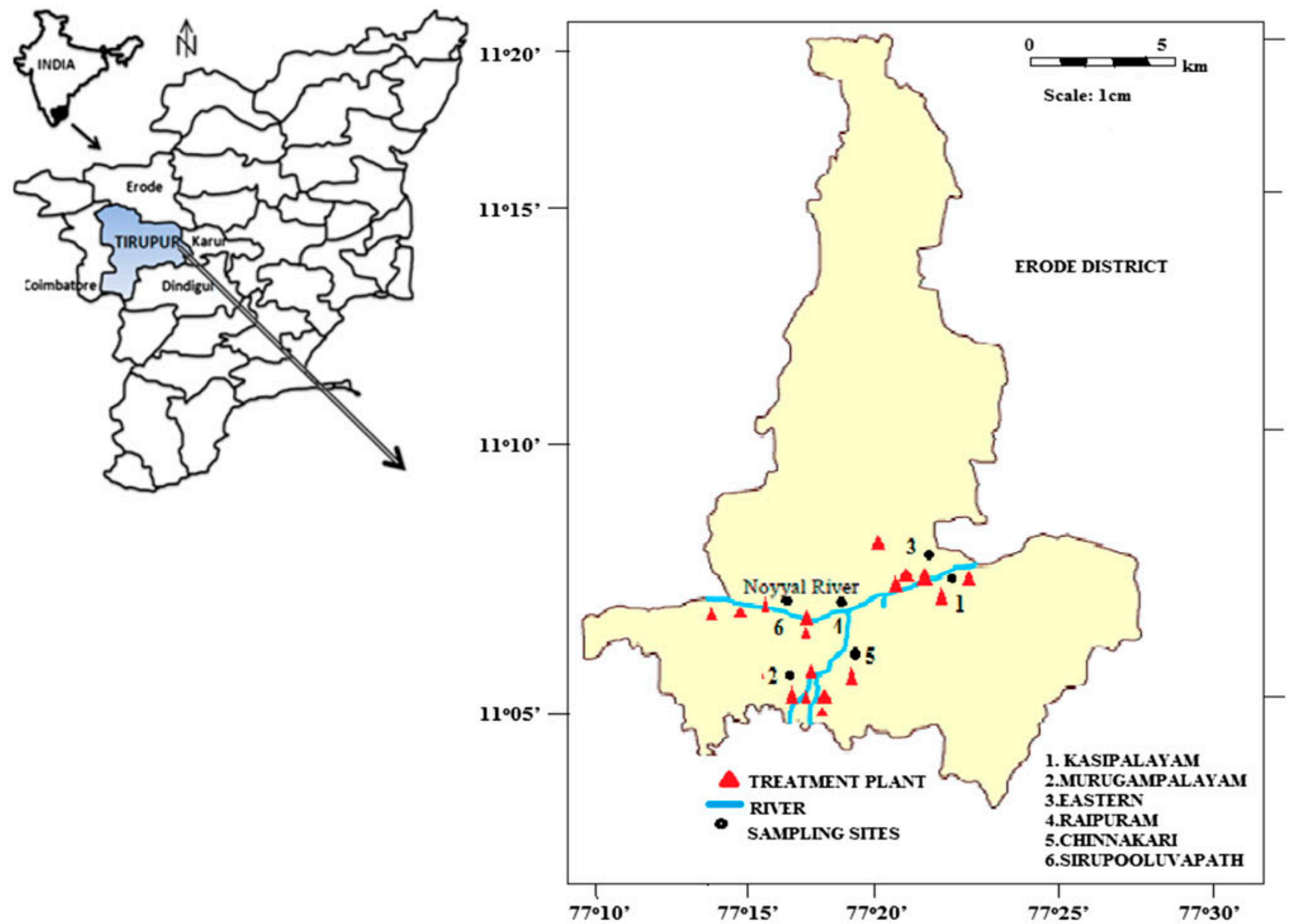

Fig. 1. Location map of CETPs in Tirupur.

may be due to the addition of sodium salts and caustic soda during the process of dyeing and bleaching [8,9], however, the low pH in treated wastewater may be due to the addition of hydrochloric acid and sulphuric acid at equalization stage. TDS value was found to be high in the raw wastewater is due to the addition of salts at different stages of dyeing and bleaching process [8]. The value of BOD in raw wastewater was very high if compared with the tolerance limit of 30 mg L^{-1}, which indicates the presence of enough biodegradable organic compounds in textile mill effluent [4,10,11]. In treated wastewater, the BOD values were observed below the standard criteria only for Kasipalayam and Murugampalayam CETPs, however, other three CETPs were found unable to achieve the standard BOD value of 30 mg L^{-1} for treated effluent. The COD value was found to be high in raw wastewater was due to the presence of non-biodegradable organic dye components [11]. Similarly, the COD values in treated wastewater were found below the standard criteria only for Kasipalayam and Murugampalayam CETPs, however, other three CETPs were found unable to achieve the standard COD criteria of 250 mg O_2 L^{-1} mg L^{-1} for treated effluent.

The values for chloride (Cl^-) were observed above the permissible limit (1,000 mg L^{-1}) in both untreated and treated wastewater. The high value of Cl^- in raw wastewater was due to the use of high amount of sodium chlorite and sodium hypochlorite in the dyeing and bleaching processes [8,9]. In treated wastewater, the retention of high and excess accumulation of Cl^- concentration was due to the addition of hydrochloric acid for maintaining the alkaline pH of effluent for optimal microbial growth during the biological treatment stage. The high value of SO_4^{2-} in raw wastewater was due to the addition of sodium sulphate and bisulphate during bleaching process [8,9]. The reduction in SO_4^{2-} in conventional CETPs is due to the precipitation and settlement of corresponding salt with sludge.

Table 1
Detailed frame work, hydraulic load and other characteristics of the treatment plants

Treatment plant	Type of treatment	Treatment unit	Capacity (MLD)	Type of industries	Effluent collection	Effluent reuse
Kasipalayam	Conventional effluent treatment plants	Screen + equalization tanks (2) + chemical mixing + clariflocculator + sand filter + activated sludge process based biological reactor and sludge thickener + decanter centrifuge + sludge drying beds for sludge	4	20 Textile bleaching and dyeing	HDPE pipeline	Noyyal River (Orathupalayam dam)
Chinnakarai	Conventional effluent treatment plants	Screen + equalization tanks (2) + chemical mixing + clariflocculator + sand filter + activated sludge process based biological reactor and sludge thickener + decanter centrifuge + sludge drying beds for sludge	5	31 Textile bleaching and dyeing	HDPE pipeline	Odai Canal
Sirupooluvapatti	Membrane bioreactor (MBR) systems	Screen + equalization tank + oil & grease removal + flash mixer + anaerobic tank + aerobic (activated sludge process type) + membrane + MBR treated water + ACF + RO system + evaporator	2	–	–	Noyyal River

The high concentration of Na% in raw wastewater was due to the addition of sodium salts during the textiles processing. The enhancement of Na% in treated wastewater was due to high quantity of sodium salts, lime and ferrous sulphate used in primary treatment units [7,12]. The use of pigments like iron blue (a dye) in textile processing contributed to the iron (Fe) in raw wastewater [13]. However, the presence of Fe in treated effluent was contributed by the addition of ferrous sulphate and ferric chloride in the treatment process for removing the contaminants load by coagulation and precipitation.

The presence of copper (Cu) in raw wastewater was contributed by the wide use of metals like Cu, Pb, Cd and Cr for the production of colour pigments in textile dyes. The lower concentration of Cu in treated wastewater may be due to the utilization of the Cu by microbes as a nutrient during biological treatment stage. The zinc (Zn) concentration in treated wastewater was below detection limit (5 mg L^{-1}). The low concentration of Zn in treated wastewater may be due to the utilization by microbes as a trace nutrient during biological treatment step.

The nickel (Ni) concentration in raw and treated wastewater was found within the regulatory limit of 3 mg L^{-1}, which may be due to precipitation of Ni as metal sulphite due to anoxic condition and alkaline pH condition in biological oxidation pond. The concentration of cadmium (Cd) in both raw and treated wastewater was observed within the regulatory limit (2 mg L^{-1}). Lead (Pb) concentration was above the regulatory limit (0.1 mg L^{-1}) in raw wastewater, which may be due to the use of lead containing dyes in the textile processing [5,14,15] the low concentration of Pb in treated effluent was due to the removal of Pb and other heavy metals by the addition of alum in the treatment process. The concentration of Cr in raw and treated wastewater was below detection limit (2 mg L^{-1}). The source of Cr in raw wastewater may be due to the use of Cr in oxidation process in cotton dyeing and for chemical fixation in wool dyeing [16] and due to the use of metal-based dyes in the textile industry, which mainly contains chromium. The low concentration of Cr in treated effluent was due to the conversion of soluble form (Cr^{6+}) into insoluble form (Cr^{3+}), which further precipitates as hydroxide and got adsorbed on dead biomass.

4.2. Performance of MBR process

Table 3 summarizes the results of raw and treated wastewater of MBR. The variation in pH values in raw wastewater could be attributed to the presence of different dyes, caustic soda, bleaching powder,

Table 2
Effluent quality before and after conventional treatment system

Locations		Kasipalayam		Murugampalayam		Eastern		Raipuram		Chinnakarai	
Parameter	Tolerance limit**	Before	After	Before	After	Before	After	Before	After	Before	After
pH	5.5–9.0	9.3	7	9.2	7.5	7.64	7.07	9.1	7.7	9.8	7.6
TDS	2,100	5,250	4,960	8,240	6,950	5,556	4,457	11,237	10,378	7,544	5,234
BOD	30	452	16	410	19	475	43	300	42	330	110
COD	250	1,730	194	800	113	848	346	1,975	243	1,056	330
Cl^-	1,000	2,622	2,149	3,170	3,199	2,612	2,403	5,283	5,292	3,778	2,136
SO_4^{2-}	1,000	832	536	765	671	1,183	946	2,917	2,457	864	416
Na%	60%	67	86	86	93	78	86	75	85	82	89
Fe	3	0.87	1.28	1.93	0.66	0.91	1.13	0.17	0.83	0.78	1.03
Cu	3	0.55	0.45	1.02	0.77	0.73	0.27	0.02	bdl	0.92	bdl
Zn	5	0.02	bdl	0.56	0.02	0.24	0.08	2.19	0.93	0.82	0.33
Ni	3	1.62	0.78	0.04	0.02	0.28	0.05	1.83	0.74	0.08	0.02
Cd	2	0.04	0.02	0.01	0.01	0.03	0.01	0.18	0.07	0.42	0.04
Pb	0.1	0.73	0.05	0.03	0.01	0.04	bdl	0.56	0.55	0.11	0.02
Cr	2	0.87	0.65	bdl	bdl	0.81	0.30	0.77	0.33	0.67	0.52

Notes: All values are in $mg\,L^{-1}$ except pH and Na%; bdl: Below detection limit.
**Source: TNPCB 2008.

sodium bisulphate, hydrochloric acid and hydrogen peroxide. The low pH in treated effluent was contributed by the addition of acid in equalization tank in order to neutralize the wastewater for biological treatment.

The TDS values in treated wastewater were found to surpassed the regulatory limit of 2,100 $mg\,L^{-1}$. High level of TDS in raw wastewater was due to the use of various salts of Na, K, Ca and Mg in the textile process, however, the high TDS concentration in treated wastewater may be due to the use of chemicals in the primary treatment units [17]. Such low efficiency in TDS removal is not common for this type of treatment that hints at some irregularities like low membrane quality, membrane fouling, low rejection rate and ill-managed RO systems. This may also be attributed to low chloride removal as observed in this study.

The BOD value in treated wastewater was below tolerance limit (30 $mg\,L^{-1}$). It suggests that MBR system has high potential to reduce the BOD significantly due to presence of anaerobic tank. High concentration of biomass in MBR contributed to better degradation of organic pollutants. COD value was high in raw wastewater due to the non-biodegradable nature of organics present in the dye material [16]. A substantially low COD in treated wastewater was due to the systematic degradation of organic matter in anaerobic as well as aerobic chambers of MBR.

The high value of chloride (Cl^-) in raw wastewater was due to the addition of sodium salts of chloride, chlorite and hypochlorite during textile processing [8,9]. On the other hand, a slight reduction in Cl^- level in treated wastewater was due to the addition of hydrochloric acid in the treatment processes. Concentration of sulphate (SO_4^{2-}) was high in raw wastewater may be due to the addition of sodium sulphate and bisulphates in the bleaching processes [8,9]. There is significant reduction of SO_4^{2-} concentration in treated wastewater was due to the precipitation and settling of corresponding salts with sludge.

High level of Na% in raw wastewater was due to the addition of sodium salts in the dyeing and bleaching processes [8,15]. The further increment of Na% in treated wastewater may be due to the use of large quantity of sodium salts and lime in treatment units.T. The iron (Fe) concentration in both raw and treated wastewater was below the regulatory limit of 3 $mg\,L^{-1}$. A slight increase in Fe concentration in treated wastewater was due to the addition of lime and ferrous sulphate during primary treatment for reducing the organic load from the textile wastewater [11]. The concentration of Cu

Table 3
Effluent quality before and after MBR treatment system

MBR (at Sirupooluvapatti)			
Parameters	Tolerance limit**	Before	After
pH	5.5–9.0	9.3	8
TDS	2,100	10,280	9,590
BOD	30	436	12
COD	250	528	92
Cl	1,000	2,941	2,387
SO_4	1,000	1,093	232
Na%	60	86	89
Fe	3	1.11	1.15
Cu	2	1.02	bdl
Zn	5	2.16	0.084
Ni	2	0.18	bdl
Cd	2	0.57	0.10
Pb	0.1	0.93	0.01
Cr	2	0.078	0.003

Notes: All values are in mg L^{-1} except pH and Na%; bdl: before detection limit.
**Source: TNPCB 2008.

and Zn in both raw and treated wastewater was found within the permissible limit. The presence of Cu in raw wastewater was due to the use of Cu containing dye like HRV5 and azo dye, which is used as a dyeing agent in textile industries [13]. In raw wastewater, the presence of Zn was due to the use of pigment like zinc yellow in the dyeing processes [13]. The low concentration of Cu and Zn in treated wastewater was due to the uptake of metals by microbes as a nutrient during biological treatment.

The concentration of Ni in raw and treated wastewater was below detection limit (2 mg L^{-1}). The presence of Ni in raw wastewater was due to the use of Ni-containing dyes like Ni-phthalocyanine complex used in the textile industries [13]. The concentrations of Cd in raw and treated wastewater were below detection limit (2 mg L^{-1}). The value of Pb in treated effluent was below tolerance limit of 0.1 mg L^{-1}. The Cr concentration in raw and treated wastewater was below detection limit (2 mg L^{-1}). The lower concentration of Cr may be due to the conversion of soluble hexavalent chromium (Cr^{6+}) to insoluble chromic form (Cr^{3+}), and then it precipitates as hydroxide followed by removal as sludge [16]. The metals like Ni, Cd, Cr and Pb in raw wastewater come from their corresponding dyes used in the textile industries [18,19]. The reduction of metal ion concentration in treated effluent may be contributed by several factors like precipitation of metals by alkaline condition, microbial degradation and uptake, adsorption on sludge flocs and filtration through biomembrane [14,20–22].

4.3. Comparison between the effluent quality of CETPs and MBR system

The physicochemical quality of treated water from CETPs and MBR system is depicted in Figs. 2((A)–(J)) and 3((A)–(B)). The pH values in treated effluent of CETPs and MBR i were observed to falls within the regulatory limit. Thus, keeping in view the pH value, the treated water was suitable to discharge in surface water bodies or can be used for irrigational purpose. However, the TDS concentration in effluent from CETPs and MBR was found to surpass the standard criteria.

The CETPs Eastern, Chinnakarai and Raipuram could not attain the regulatory limit for BOD. However, MBR system was found capable to bringing down the BOD values below the standard limit. Treated water from three conventional CETPs (Eastern, Chinnakarai and Raipuram) was not found suitable to discharge into the water body or on land. This makes discharge of water from conventional treatment system doubtful in terms of BOD standard criteria. In terms of COD, the Eastern and Chinnakarai CETPs were found incapable to achieve the COD standard disposal criteria; since the effluent from other three CETPs fulfil the standard COD discharge criteria. Among the wastewater treatment systems studied, the lowest COD value was found in the effluent discharged from MBR system. This suggests that MBR system is more robust in removing the organic pollutants in comparison of conventional wastewater treatment systems [21,22].

The chloride (Cl^-) concentration in the effluent from both conventional and in MBR systems was found above the regulatory limit. The effluent sulphate concentration from conventional CETPs except Raipuram and MBR system was found within the regulatory limit. Thus, with respect to sulphate concentration, the effluent discharge from both the treatment systems is safe for the water bodies. Moreover, the high Na% in the effluent of conventional and MBR systems shows that both types of treatment do not play significant role in the efficient removal of Na%.

The concentration of all the studied heavy metals in the raw and treated wastewater was observed to falls significantly below the regulatory limits in both the conventional CETPs and MBR system, except the high Pb concentration in treated effluent from Raipuram and Kasipalayam CETPs. Overall, the discharge of the treated water from both conventional and MBR treatment system is safe to the environment. The efficient removal of Pb and other heavy metals was contributed to the alum addition during the chemical treatment, and the optimum alum dose for effective heavy metal removal was 10 mg L^{-1} at pH 7.8.

4.4. Efficiency of conventional and MBR treatment systems

Based on various parameters of effluent quality, the efficiencies of the conventional CETPs and MBR systems were calculated by using the following formula:

$$\%\ \text{efficiency} = 100 - \frac{\text{AT effluent quality} \times 100}{\text{BT effluent quality}}$$

Table 4 and Fig. 4 show the treatment efficiency of conventional CETPs and MBR system. In the MBR

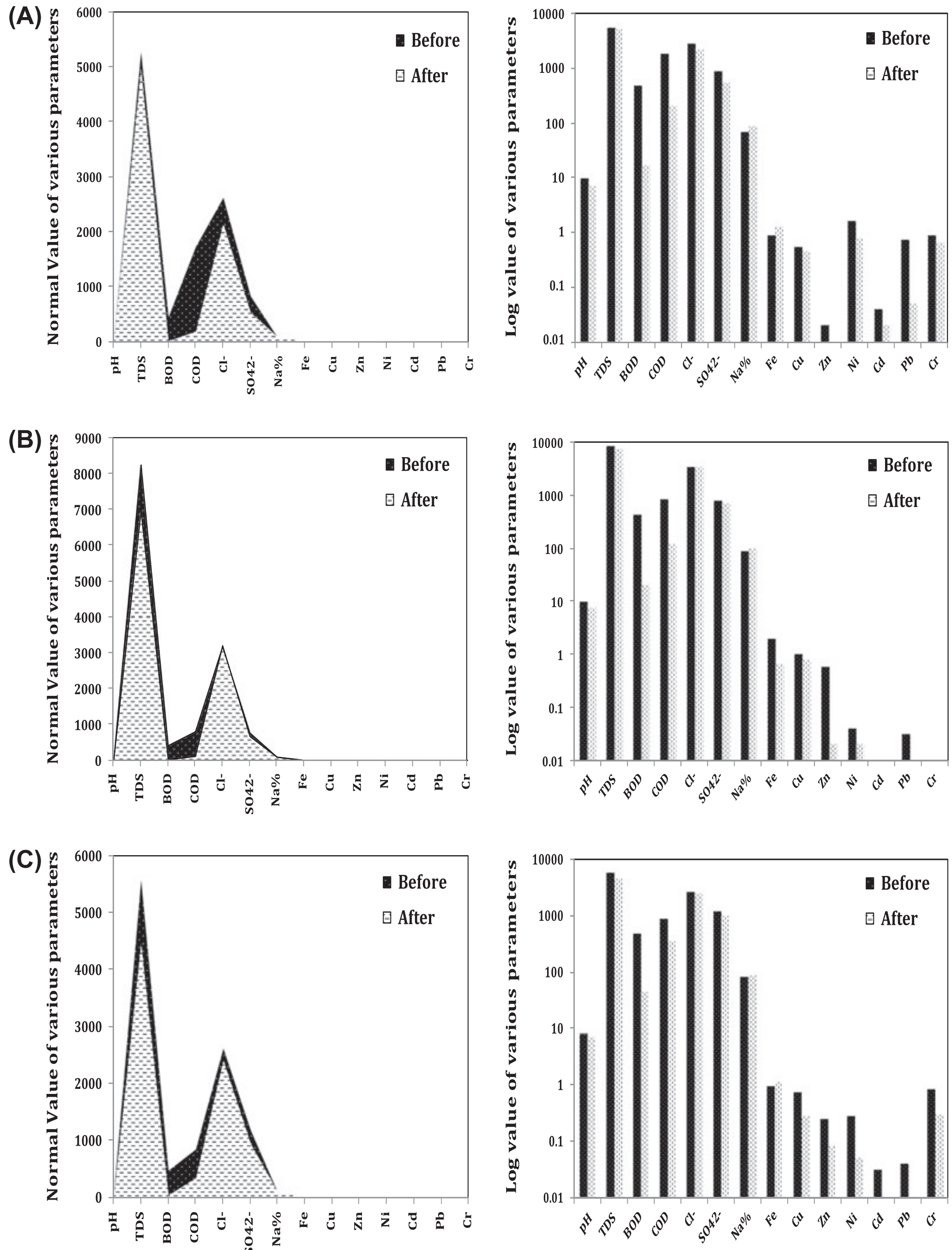

Fig. 2. ((A)–(E)) The quality of effluent before and after conventional treatment plants (CETP) of (A) Kasipalayam CETP, (B) Murugampalayam CETP, (C) Eastern CETP, (D) Raipuram CETP, and (E) Chinnakarai CETP.

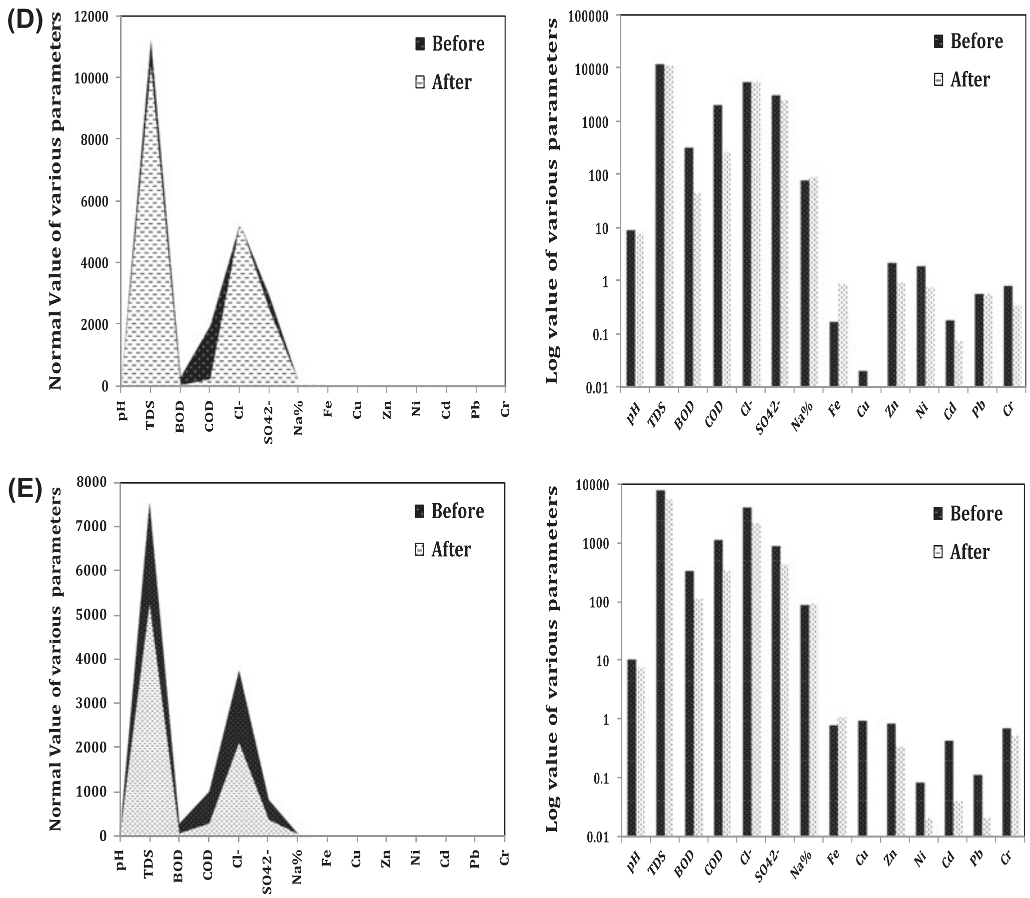

Fig. 2. (*Continued*)

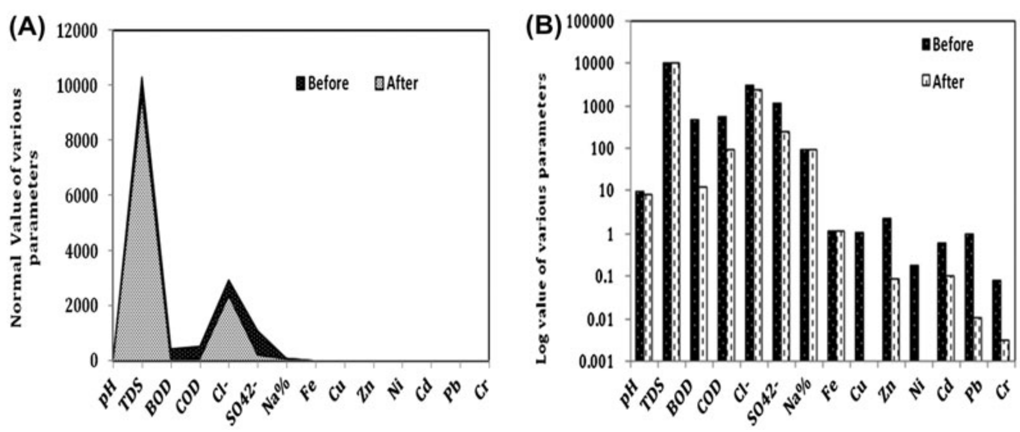

Fig. 3. Representing the quality of effluent before and after MBR treatment system at Sirupooluvapatti.

system, the average removal of BOD and COD was 97.2 and 82.6%, respectively. However, in the conventional CETPs, the average removal of BOD and COD ranges from 66.7 to 96.5% and 88.8 to 59.2%, respectively. This can be attributed to the fact that most of the dye stuffs were non-biodegradable, which renders conventional biological treatment ineffective or less efficient than MBR system. High TDS content of textile mill effluent retarded the biological growth thus, the efficiency of the treatment systems for BOD removal

Table 4
Comparison of treatment efficiency of conventional and MBR treatment systems

	Kasipalayam CETP	Murugampalayam CETP	Eastern CETP	Raipuram CETP	Chinnakarai CETP	Sirupooluvapatti MBR
Parameters (in mg L^{-1})	% Efficiency	% Efficiency	% Efficiency	% Efficiency	% Efficiency	% Efficiency
TDS	5.53	15.6	19.8	7.64	30.6	6.71
BOD	96.5	95.4	90.9	86	66.7	97.2
COD	88.8	85.9	59.1	87.7	68.7	82.5
HCO_3^-	35.9	32.4	68.0	8.16	36.2	10.4
Cl^-	18.0	NG	8.01	NG	43.4	18.8
SO_4^{2-}	35.5	12.3	20.1	15.8	51.9	78.7
Na^+	NG	NG	4.42	14.8	19.5	1.69
K^+	32.6	19.4	20.2	78.9	36.0	15.0
Ca^{++}	61.1	65.5	69.3	47.7	44.0	39.0
Mg^{++}	82.0	78.6	25.9	54.4	69.0	5.57
Fe	NG	66.0	NG	NG	NG	NG
Cu	18.3	24.5	62.4	ND	ND	ND
Zn	ND	96.8	67.9	57.8	60.1	96.1
Ni	51.9	35.1	81.2	59.7	74.7	ND
Cd	61.4	29.7	71.4	60.6	90.6	NG
Pb	92.7	75.6	ND	1.95	74.8	99.1
Cr	25.6	ND	63.5	57.5	23.3	95.9

Note: ND—Not defined; NG—Negative.

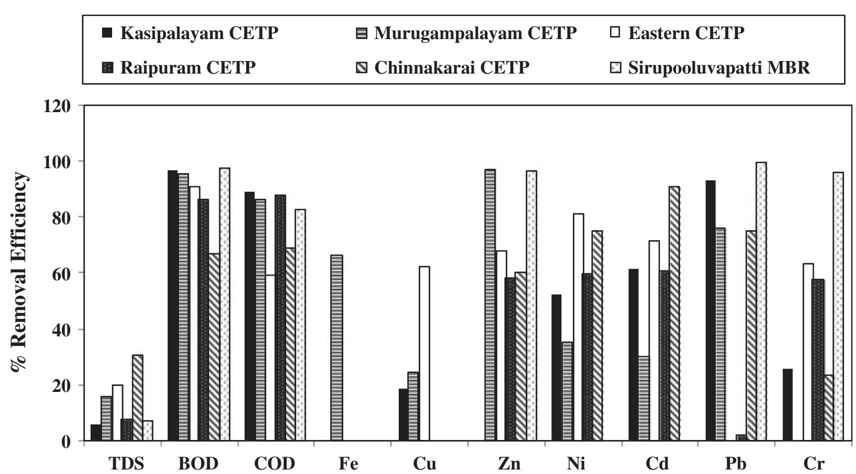

Fig. 4. Percentage efficiency of conventional as well as MBR treatment systems.

was adversely affected. For HCO_3^-, Cl^-, SO_4^{2-}, Na, K, Ca and Mg the MBR system shows the removal efficiency of 10.4, 18.8, 78.7, 1.60, 1.77, 39.0 and 5.57%, respectively, which was more effective than those achieved by conventional CETPs. In case of heavy metal removal efficiency, it can be said that the MBR system can remove the metals more effectively if compared with conventional CETPs.

Based on the removal efficiency of various parameters like BOD, COD, SO_4^{2-} and heavy metals, the MBR system was found much efficient than conventional wastewater treatment systems. Nevertheless, conventional treatment system showed good treatment efficiency for the removal of TDS, bicarbonate, chloride, % sodium, zinc and cadmium. Thus, the treated water may be used for irrigation as it is expected not to have any detrimental effect even in the groundwater recharge zones of the study area [23].

5. Conclusion

The overall results show that the MBR-based CETP showed comparatively better textile effluent treatment potential than conventional systems. Thus, the membrane-based separation process or application of membrane filtration processes will not only achieve high pollutant removal efficiencies, but also allows the reuse of wastewater and some of the valuable constituents from wastewater. In the present study, some of the reuse criteria provided as tolerance limit are not fulfilled due to improper maintenance though. In an industrial area like Tirupur, implementation of the MBR wastewater treatment technology can effectively fulfil the idea of zero discharge strategy, and subsequently help to minimize the harmful impacts of the textile effluents on water resources.

Acknowledgements

First author wants to thank Dr K. Dhanapal, Managing Director, MBR treatment facility, Sirupooluvapatti. She also acknowledges the institutional fellowship received from University Grant Commission (UGC), India.

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