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Application of membrane bio-reactor for municipal wastewater treatment: A review

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Abstract
Critical position of total accessible fresh water resources makes non-conventional water resources valuable to meet ever-increasing global water requirement. In this issue, municipal waste water can be a solution to reduce the pressure on fresh water reservoirs in number of nations. But, raw waste water poses serious threats to human health. Over the years, several treatment methods, e.g., constructed wetlands, waste stabilisation pond, vermi-filtration, membrane bio-reactor, up-flow anaerobic sludge blanket reactor have been experimented to treat different types of waste water. The current investigation reviewed the performance of membrane bio-reactor (MBR) for elimination of different physical, chemical and biological contaminants to make the wastewater suitable for irrigation purpose. The worldwide application of MBR suggested that this modern membrane filtration technique alone performed satisfactory for removal of all physical (Total suspended solids, Turbidity), chemical (BOD, COD) and biological (Faecal coliform) impurities from municipal wastewater.

Keywords: BOD, COD, faecal coliform, membrane bio-reactor, municipal wastewater, total suspended solids, turbidity

1. Introduction

The approximate total quantity of accessible water on the earth is around 1.39 × 10^9 km^3 with 2.50% fresh ones. Out of the total freshwater amount, about 30% is groundwater and about 70% is in the form of ice and permanent snow cover in the mountainous, Antarctic and Arctic regions, water in lakes and rivers, atmospheric water, soil moisture and biological water. Out of the total freshwater resources withdrawn (3,906.70 km^3/yr.), about 11% is used for municipal purposes, respectively (FAO-AQUASTAT 2015) [9]. According to the 2011 census report, the world population is about 7 billion and is projected to be about 9.50 billion by the year 2050. Therefore, the rapid population growth in the world is obvious in the future. Such kind of population growth, rapid urbanization, industrialisation and advanced lifestyles will lead to an unprecedented increase in freshwater demand in the future. Therefore, alternative water resources will be very much essential to satisfy the unparalleled freshwater demand. In addition, agriculture is the largest water user worldwide and it is expected that its share would decrease in future to meet the water demands of other sectors, leading to a hasty increase in municipal wastewater. In such a critical situation, treated municipal wastewater can play an important role as an alternative source of water particularly for irrigation.

Municipal wastewater can be defined as the combination of wastewater coming from household connections, institutions and small enterprises. Sometimes, surface water and storm-water are also considered under municipal wastewater category (Ismail *et al*. 2012) [10]. Globally, the total volume of generated municipal waste-water is about 85.85% of the volume of total waste-water produced per year (FAO-AQUASTAT 2015) [9]. According to FAO-AQUASTAT (2015) [9], the worldwide treated municipal wastewater is about 155.41 km^3/yr (about 51.94% of globally produced). About 2%, 1%, 0.0%, 0.0%, 6% and 0.08% of the total volume of produced municipal wastewater is used for irrigation under non-treated condition in Asia, Africa, Europe, Oceania, North America and South America respectively whereas, about 4%, 7%, 1%, 14%, 2% and 6% of the total treated water is used for irrigation in these continents respectively (FAO-AQUASTAT 2015) [9]. The use of untreated waste water for irrigation may results in serious health consequences and its proper treatment is necessary to protect both health and environment. Thus, proper treatment and management of municipal wastewater are required to meet the exceptional freshwater demand of 9830 km^3 yr^{-1} by 2025 in the world.

For the treatment of municipal wastewater, different technologies are practiced in the different parts of the world. These different technologies are activated sludge process (Tandukar *et al*. 2007) [24], coagulation & flocculation process (Ukiwe *et al*. 2014) [25], waste stabilisation pond (Naddafi *et al*. 2009) [19], vermi-filtration (Manyuchi *et al*. 2013) [14], membrane bio-reactor (Zhang *et al*. 2010) [31], up-flow anaerobic sludge blanket reactor (Kasaudhan *et al*. 2013) [13], constructed wetlands (Abou-Elela *et al*. 2012) [2] etc. The performances and intricacies of these technologies in removing different contaminants vary from one to another. Among these different technologies, membrane bio-reactor (MBR) is well structured engineered systems that use the advanced membrane filtration technology to aid in reclamation of wastewater.

With this background, the present study aims to review the performance of MBR for making municipal wastewater suitable for irrigation purpose based on the removal of different physical, chemical and biological impurities from municipal wastewater.

2. Materials and methods

2.1 Physical parameters

The principal physical properties are turbidity, colour, total suspended solids (TSS) and odour. Turbidity is an expression of the optical property that causes scattering and absorption of light by molecules and particles rather than transmission in straight lines through a water sample. It is caused by suspended mineral matter, finely divided organic and inorganic matter, soluble coloured organic compounds, phytoplankton, and zooplankton. It is generally measured by an optical instrument called a turbid meter and expressed by Nephelometric Turbidity Units (NTU). Colour of municipal wastewater generally differs from the true colour of the water due to presence of turbidity. True colour is obtained after removal of turbidity. The TSS includes all suspended particles which cannot pass through a filter. The TSS is measured by spectrophotometer (AbdEL-rahman *et al*. 2015) [1]. It is generally expressed by mg/l. Another common problem with municipal wastewater treatment and application is odour. It is generally characterized by its intensity and hedonic tone (the pleasantness or nastiness). Offensiveness of odour combines intensity and hedonic tone as well as duration and frequency.

2.2 Chemical and Biological parameters

The vital chemical constituents are: hydrogen ion activity (pH), total dissolved solids (TDS), biological oxygen demand (BOD), chemical oxygen demand (COD), ammonium nitrogen (NH_4-N), nitrate (NO_3-N), total nitrogen (TN), ortho-phosphate, total phosphorus (TP), calcium (Ca), sodium (Na), magnesium (Mg), iron (Fe), heavy metals like cadmium (Cd), chromium (Cr), nickel (Ni), copper (Cu), lead (Pb), zinc (Zn), arsenic (As), mercury (Hg) etc., chloride, sulphate, carbonate, bi-carbonate, sodium adsorption ratio (SAR), electrical conductivity (EC) etc. (Zahid *et al*., 2011) [29]. The principal biological impurities of wastewater include fecal coliform (FC), total coliform (TC), fecal streptococci (FS), helminth egg (HE) etc. (Zahid *et al*., 2011) [29].

2.3 Irrigation Standard Quality for physical, chemical and biological parameters

The allowable limits of physical, chemical and biological properties of wastewater for irrigation purpose are discussed in this section. The country-wide variations of standard limit for TSS and turbidity are shown in Fig. 1 and 2 respectively along with the guidelines provided by United States Environmental Protection Agency (USEPA) and Alberta Environment (AE) (AE, 2000) [3]. The standard level of different chemical and biological impurities provided by United States Environmental Protection Agency (USEPA, 2012) [26] and Food and Agricultural Organisation (FAO) are presented in Table 1.

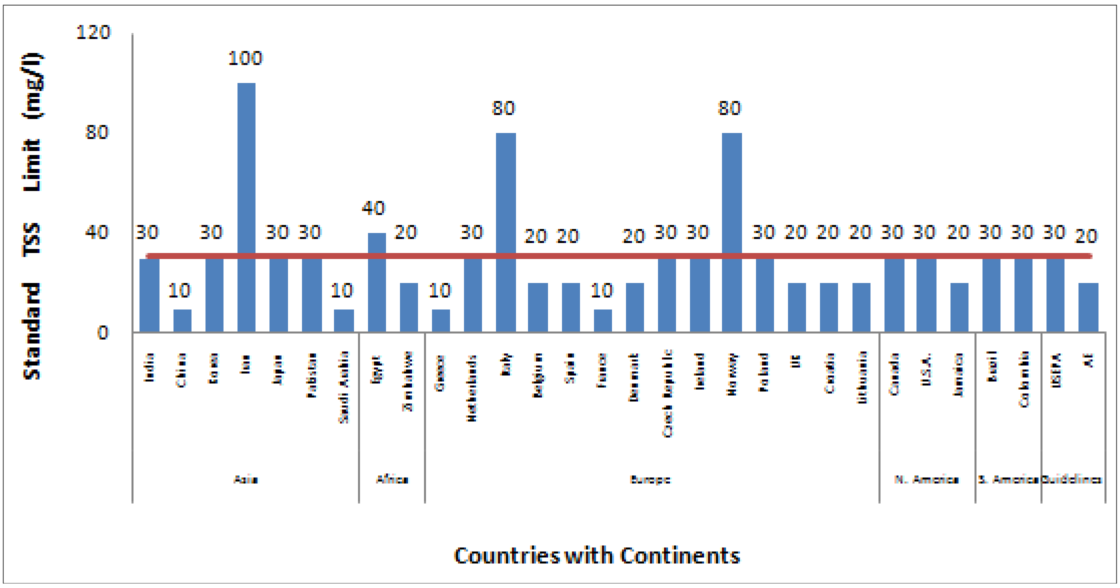

Fig 1: Standard limits of TSS (mg/l) in water for Irrigation purpose

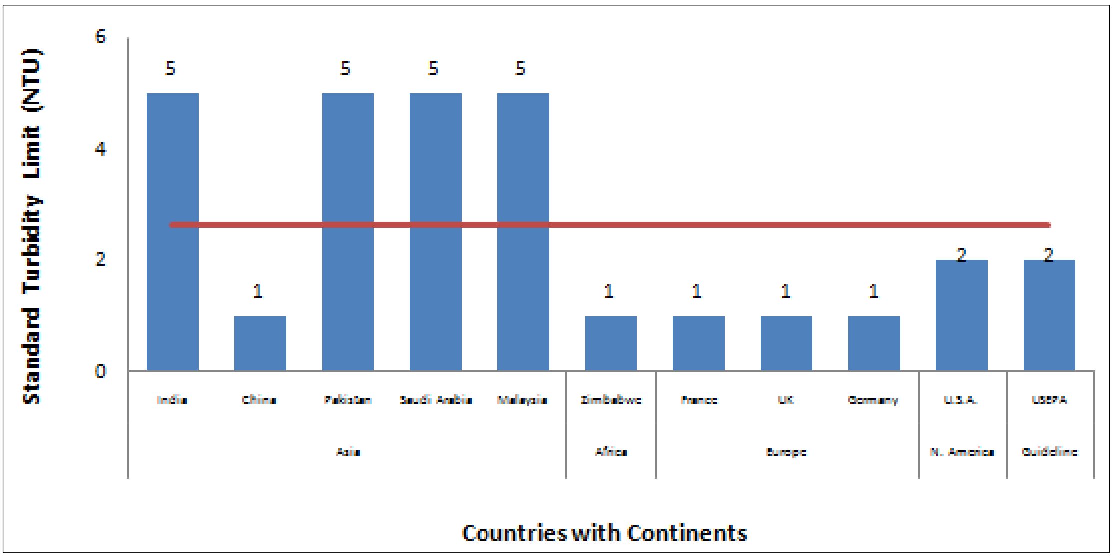

Fig 2 Standard limits of Turbidity (NTU) in water for Irrigation purpose.

Table 1: Water quality standard according to USEPA and FAO guidelines

Serial No.	Chemical and Biological Parameters	Unit	Guidelines	
			USEPA	**FAO**
1.	pH	*	6.50-8.40	6.50-8.50
2.	TDS	mg/l	<450	2000
3.	BOD	mg/l	10	*
4.	COD	mg/l	*	*
5.	NH_4-N	mg/l	*	0-5
6.	Nitrite	mg/l	*	*
7.	Nitrate (NO_3-N)	mg/l	<5	0-10
8.	Total Nitrogen (TN)	mg/l	*	30
9.	Phosphate-P	mg/l	*	0-2
10.	Total Phosphorus (TP)	mg/l	*	*
11.	Potassium (K)	mg/l	*	0-2
12.	Calcium (Ca)	mg/l	*	400
13.	Magnesium (Mg)	mg/l	*	60
14.	Sodium (Na)	meq/l	<3	900
15.	Manganese (Mn)	mg/l	0.20	0.20
16.	Iron (Fe)	mg/l	5.00	5.00
17.	Cadmium (Cd)	mg/l	0.01	0.01
18.	Cromium (Cr)	mg/l	0.10	0.10
19.	Zinc (Zn)	mg/l	2.00	*
20.	Lead (Pb)	mg/l	5.00	2.00
21.	Nickel (Ni)	mg/l	0.20	5.00
22.	Boron (B)	mg/l	0.75	0-2
23.	Chloride	mg/l	<70	1100
24.	Sulphate (SO_4)	mg/l	*	1000
25	Carbonate (CO_3)	mg/l	*	0-100
26.	Bicarbonate (HCO_3)	mg/l	<150	600
27.	SAR	*	<3	15
28.	Electrical Conductivity	dS/m	<0.70	3.00
29.	Copper (Cu)	mg/l	0.20	0.10
30.	Aluminium (Al)	mg/l	5.00	*
31.	Cobalt	mg/l	0.05	0.05
32.	Fluoride	mg/l	1.00	*
33.	Arsenic	mg/l	0.10	*
34.	Beryllium	mg/l	0.10	*
35.	Molybdenum	mg/l	0.01	*
36.	Vanadium	mg/l	0.10	*
37.	Selenium	mg/l	0.02	*
38.	Lithium	mg/l	2.50	*
39.	Fecal Coliform	-	23/100 ml	< 200/100 ml

* indicates data unavailability

2.4 Membrane bio-reactor (MBR) method

2.4.1 General Information

Membrane bioreactor (MBR) is an innovative approach for wastewater treatment. It is a biochemical engineering process. It involves the action of both a suspended growth bioreactor and a membrane separator (Radjenovic *et al*. 2008; Wang *et al*. 2009) [22, 27].

The MBR is generally categorized into two groups: (i) integrated and (ii) recirculated. Generally, outer skin membranes are involved in the first group. Under this category, the operational force is obtained by the formation of negative force on the permeate face (Rosenberger *et al*. 2002; Cicek 2003) [23, 7]. In the second group, mixed liquor recirculation takes place. In this case, the pressure formed by high cross flow velocity develops the driving force for operation (Urbain *et al*. 1998; Cicek 2003) [7].

2.4.2 Working Principle

The MBR combines the conventional activated sludge (CAS) process and membrane filtration technique for removal of hazardous impurities from wastewater. The CAS process consists of different treatment stages. These are: (i) making of a mixed liquor by mixing the activated sludge with the wastewater to be treated, (ii) aeration and agitation of this mixed liquor for the certain duration, (iii) separation of the activated sludge from the mixed liquor in the final clarification process, (iv) return of the proper amount of activated sludge for mixing with the wastewater and (v) disposal of the excess activated sludge. The performance of CAS process depends on some important factors such as temperature, return rates, amount of available oxygen, amount of available organic matter, pH, waste rates, time of aeration and wastewater toxicity. During MBR process (Fig 3), liquid-solid separation is accomplished by ultrafiltration or micro-filtration membranes. Sometimes, pre-treatment step is required to remove unwanted solids from raw wastewater. Membrane fouling is a major limitation in MBR operation. Generally, fouling indicates the deposition and accumulation of solids and biomass on membranes (Meng *et al*., 2009; Zahid *et al*., 2011) [17, 29]. It is formed due to two major incidents: (i) pore blocking caused by colloidal materials and (ii) formation of cake by suspended solids (Juang *et al*., 2007; Zahid *et al*., 2011) [11, 29]. The treatment process through this technology is shown by flow diagram in Fig 3.

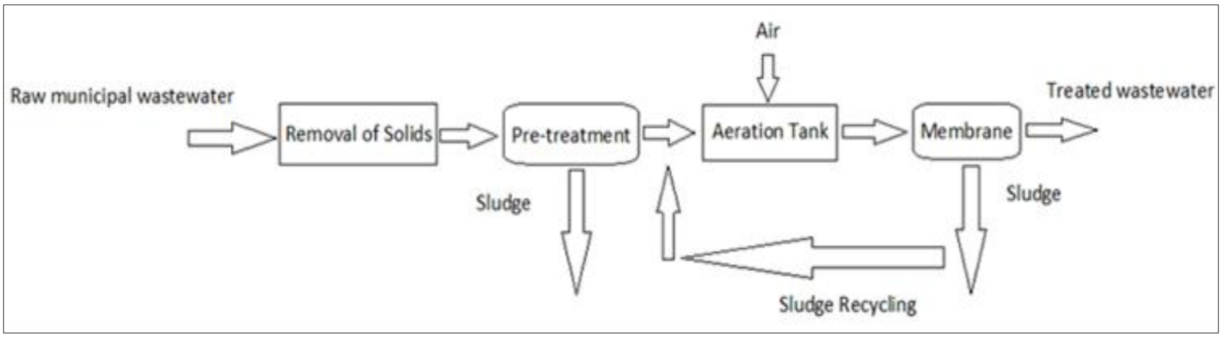

Fig 3: Flow diagram of MBR treatment processes

3. Results and discussions

3.1 Removal of physical impurities from municipal wastewater through MBR

Cote *et al*. (1997) [8] investigated the performance of the integrated system made by the coupling of microfiltration hollow fibres with bioreactor. Two pilot studies were accomplished at Valley Sanitary District, California for the duration of 5 months. In this integrated system, membranes were effectively utilized with a certain flux (< critical value) and low pressure value. Highly effective performance (100% TSS removal efficiency as shown in Fig. 4) with minimum membrane fouling was obtained from such an integrated system in this study. The principle advantage of this system was that it did not require chemical cleaning process or membrane modules handling operation. It needed only 0.30 kWh energy for filtration of one m^3 volume of wastewater. It was reported that advantages of membrane filtration (like compactness, security and superiority) were obtained through this technique without accounting for its usual drawbacks (like necessity of frequent cleaning, utilization of high energy). Therefore, this process was recommended as an advanced suitable one for rural areas. Chang *et al*. (2001) [4] experimented with submerged MBR where low-cost membranes (non-woven poly-propylene of 3 μm pore size and traditional polysulfone) were utilized. In each reactor, two plate and frame membrane modules (each with 0.24 m^2 surface area) were used. The pressure during feeding was maintained at 6kPa. In this study, all membranes showed good performance in term of turbidity removal efficiency (99%). The performance of non-woven polypropylene (NWPP) microfiltration membrane made MBR was found as comparable with the MBR utilizing polysulfone. The stabilized flux, obtained through NWPP was found as 1.50 times of that of traditional membrane. The capital cost of NWPP membrane made MBR for treatment of unit volume of wastewater was expected to be about half of that of traditional polysulfone made MBR. Pollice *et al*. (2004) [20] investigated the utility of membrane filtered municipal wastewater in agricultural irrigation purpose. The filtration unit used hollow fibre submerged system. Each hollow fibre (0.03 μm nominal pore size) had 1.00 mm internal and 1.90 mm external diameter. Total surface area of the membrane module was 23.50 m^2. The filtration unit produced treated water at the rate of 0.70 m^3/h. This study was carried out for 2 years with two crops (tomato and fennel). After completion of treatment process, the satisfactory performance was obtained (96.93% TSS removal efficiency as shown in Fig. 4) from such an advanced method and the treated effluent was recommended for irrigation purpose. But, this research work did not obtain any significant difference between the impacts of treated wastewater and traditional groundwater on soil and crop parameters. Chu *et al*. (2006) [6] built a MBR with an industrial cloth-filter. The reactor had 660 cm^2 effective membrane module areas. TSS and turbidity of raw wastewater was found as 48-136 mg/l and 186-378 NTU respectively. The primary sludge concentration was obtained as 2900 mg/l. The HRT and sludge retention time (SRT) was followed as 5.90-7.90 h and 46-56 d respectively. Temperature fluctuation was observed as 9-13 ºC during this study. The study revealed that the filter cloth had the capability to separate activated sludge successfully. The treated water turbidity was observed as less than 35 NTU for mixed liquor suspended solids (MLSS) of lower than 5500 mg/l and 15 NTU for 8000 mg/l MLSS. During the most of operation period, turbidity of the effluent was lower than 9 NTU and TSS was almost zero (Fig. 4). But, the treated water quality was found as little poor as that of the traditional MBR due to the enhanced level of SS density in the effluent. The reason behind the increased SS level was reported as the fast formation and steady growth of dynamic membrane on filter-cloth because of high sludge density. The study indicated the formation of cake layer as the chief resistance during the operation. The overall resistance of dynamic membrane was obtained as 2-3 numeral classes lower than that of the microfiltration/ultrafiltration membrane. Zhang *et al*. (2007) [30] compared the performance of MBR with the conventional activated sludge (CAS) process. Three separate pilot-scale MBRs were operated in parallel with average flux of 34 L/(m^2 h). MBR unit had a permeate cycle of 10 mins. and a backpulse cycle of 30s. Excellent TSS removal efficiency (> 99%) (Fig. 4) was obtained in the both cases. Turbidity was observed as 0.10 NTU in MBR treated water whereas CAS (in combination with tertiary and chlorination stage) produced treated effluent with almost zero turbidity value. Treated water from the both methods was found as suitable for potential reuse. But, the results of the study suggested that better treatment performance was obtained through MBR in comparatively few steps than the combined method of traditional activated sludge process and advanced tertiary treatment technique. Chu *et al*. (2008) [5] investigated the features of bio-diatomite dynamic membrane technique for municipal wastewater treatment in laboratory scale. Dynamic membrane generally possesses capability to produce low TSS effluent. Diatomite consists of amorphous SiO_2 and it has the special features of high porosity, well hydrophilicity and good chemical stability. The bio-diatomite reactor is able to produce good quality effluent. This study utilized the advantages of both the bio-diatomite reactor and dynamic membrane for treatment purpose. SRT and HRT was 87 d and 7 h respectively during the experiment. Designed flux was 8.60-130.00 L/(m^2 h). After completion of treatment, TSS level was brought down from 20.50-360.50 mg/l to almost zero value (Fig. 4) and turbidity was reduced to 0.392-0.726 NTU. Therefore, such reactor having the advantages of short pre-coating time, high filtration flux and easy backwash showed very efficient performance in terms of removal of physical impurities. Pollice *et al*. (2008) [21] examined the possible effect of SRT on the MBR performance. Different SRTs (ranging between 20 days) were adopted during the research work. A submerged MBR was utilized in this study for 4 years. Zenon hollow fibre membrane module (0.047 m^2 surface area) was used in this MBR. The overall performance of this system was shown in Fig. 4. The study suggested that the MBRs could be effectively operated at the SRTs of higher than 40 days without having any limitations in the form of filterability, biological activity and cleaning requirements. Zahid *et al*. (2011) [29] investigated the performances of different textile materials (Acrylate, Polyester and Nylon) as filter media in MBR for treatment purpose. Three MBRs (R1, R2 and R3) were operated for 60 d. The actual HRT was followed as 8.60, 8.90 and 8.00 h for R1, R2 and R3 respectively. Each treatment unit consisted of aeration tank (with attached float valve to control feed raw wastewater), aeration device, membrane module (3024 cm^2 filtration area of each module), suction pump, pressure measurement device and receiving chamber for treated effluent. During the operation, the best turbidity and TSS removal efficiency (99%) (Fig. 4) were obtained at 5.30-5.50 g/l MLSS and 28.30 d SRT. Significant differences between the performances of (i) R2 and R3; (ii) R1 and R3 were identified in this study. R2 treated water contained comparatively lower values of TSS and turbidity. More times of mechanical cleaning made the performance of R2 better than the others. The use of such kind of textile materials as filter media was also appreciated because of their operational simplicity and non-requirement of chemical cleaning, resulting the reduction of the operational and capital cost of the reactors. This study recommended the treated effluent for restricted irrigation purpose.

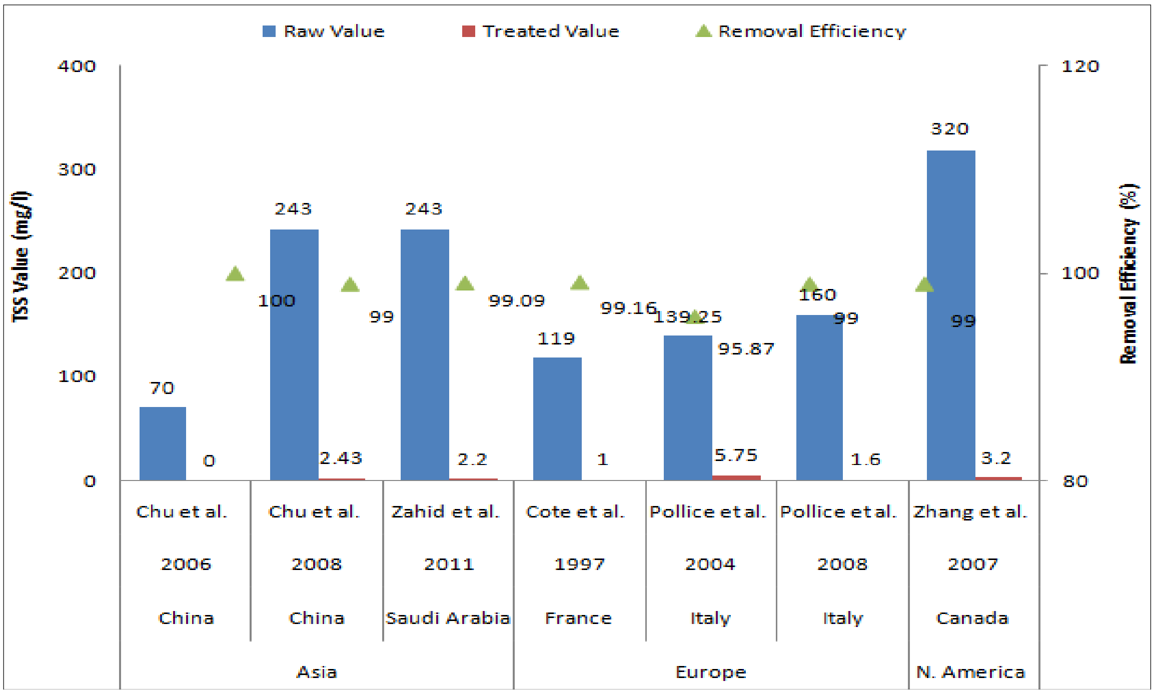

Fig 4: TSS concentration in raw and treated water along with TSS removal efficiency for MBR

3.2 Removal of chemical and biological impurities from municipal wastewater through MBR

The MBR is considered as an advanced wastewater treatment technology (Melin *et al*., 2006) [16]. This method allows biological treatment of waste matters followed by membrane filtration (Cicek 2003; Zahid *et al*. 2011) [7, 29]. Generally membranes consist of about 0.20-0.25 μm thick skin which is supported by 100 μm thick porous structure. Commercial membranes are generally in form of tube, flat sheets and fine hollow fibres. The operational behaviour of this method is similar to that of the ASP. But, it does not consider any kind of secondary clarification and tertiary treatment phase like sand filtration etc. which are followed in the CAS. The major advantages of such modern technique include high treatment efficiency for high strength wastewater, lower susceptibility to the extreme level of impurities, most consistent quality of treated effluent (Judd and Jefferson 2003; Zahid *et al*. 2011) [12, 29], lower amount of produced sludge (Yang *et al*. 2009; Zahid *et al*. 2011) [28, 29], independent choice of SRT and HRT and small reactor volume. Successful performance of this method in terms of organic and inorganic material removal is expected (Cicek 2003) [7]. In spite of having such kind of positive points, this method holds also few drawbacks: high cost involvement in construction and operation, membrane fouling, frequent monitoring of membrane and maintenance, limitations associated with pressure and temperature and low oxygen transfer efficiency. In MBR system, membrane fouling is a very common problem. Such type of fouling took place due to some factors: membrane type, structure of module, presence of compounds with higher molecular weight and hydrodynamic condition. As a result of fouling, flux generally decreases at the time of filtration. Two major divisions of MBR include submerged membranes and external circulation respectively. Cote *et al*. (1997) [8] worked with immersed membrane activated sludge process where microfiltration hollow fibres were used for effective performance. High degree of treatment in terms of chemical (organic matter) and biological impurities (fecal coliform and bacteriophages) was obtained in this study. The rate of sludge production was found to be 50% lower than that of conventional activated sludge (CAS). This study found out some important advantages of this method: no requirement of chemical cleaning for membrane modules, low requirement of filtration energy (0.30 kW-h/m^3 of treated water), high effluent quality, compactness and security. According to Pollice *et al*. (2004) [20], there was no significant difference between the utilization of tertiary filtered water and well water in irrigation in terms of soil and crop microbiological quality. The study was conducted with two crops (tomato and fennel) for the duration of 2 years. The treatment performance of this technique in terms of bacteria removal was also very good. Ultimately, the filtered water was recommended ideal alternative for irrigation. Chu *et al*. (2006) [6] built a MBR with industrial filter-cloth material which was used in quick formation of dynamic membrane in this study. Such kind of material showed less resistance during operation than the traditional ultra-filtration and microfiltration membrane. The treatment efficiency of this process (6.90 h HRT and 9-13^{0}C operatonal temperature) was 72-89% and 60-94% in terms of total COD and ammonia removal respectively. According to Zhang *et al*. (2007) [30], MBR showed better performance than the conventional treatment in terms of pathogen removal. Variations in trend of somatic coliphages and F-specific coliphages concentration were similar as that of flow rate. It was far better than any biological treatment method and disinfection process or effluent polishing was not needed in MBR operation. MBR treated effluent was suitable for any unrestricted reuse practice. Pollice *et al*. (2008) [21] examined the effect of solid retention time (SRT) on MBR performance for different values of HRTs (0-20 days). The study revealed the logarithmic improvement of the average biomass concentration with SRT increased. Finally, it was concluded that MBR operation could be possible at an elevated SRT level in spite of limitations related to bio-degradation activities. Chu *et al*. (2008) [5] investigated the features of bio-dynamite dynamic membranes for municipal wastewater treatment. The combination of bio-diatomite, anoxic and aerobic processes is designated as bio-diatomite reactor. Such kind of combination showed stable performance during operation. The incorporation of dynamic membrane with bio-diatomite reactor removed the problems associated with MBR application. Wastewater temperature was 16-33^{0}C during this study (HRT 7 hrs., SRT 87 days). The high efficiency of such technology is shown in Fig. 5-6. Such kind of reactor showed small pre-coating duration (25 mins.), high filtration flux and easy backwash in this study. Martinez-Sosa *et al*. (2011) 15] used anaerobic submerged membrane bio-reactor (AnSMBR) for their study. Anaerobic process depends mainly on operational temperature. Such anaerobic treatment technique performs successfully under tropical climatic condition. Chief advantages of such anaerobic process includes production of biogas (energy source), 20 times less production of sludge compared with aerobic process and presence of inorganic nutrients like nitrogen, phosphorus in treated effluents. In this study, operation continued for 100 days. AnSMBR consisted of two containers like anaerobic reactor and membrane container. The total volume of reactor was 350 litres. A flat sheet polythene sulfone ultra-filtration membrane (mean pore size 38nm) was used and total membrane surface area was 3.50 m^2. Operation was accomplished in four steps: feeding, filtration, relaxation and backwashing. Mesophilic condition (35^0 C) prevailed in first 69 days. After that, transition period lasted for 10 days. After 79 days, the operation was done in psychrophilic condition (20^{0}C). The overall performance of this reactor is shown in Fig 5-6 and Table 2. The study suggested that the final effluent was suitable for irrigation purpose. Monclus *et al*. (2010) [18] studied on the applicability of MBR in municipal wastewater treatment for biological phosphorus removal. Biological nutrient removal was found to be high from the start of the operation and finally 92% removal efficiency was obtained at the end of the study. Zhang *et al*. (2010) [31] also worked on anaerobic dynamic MBR with high flux (65 l/m^2-h). The operation continued for 100 days. Removal of particulate COD was the principle role of dynamic membrane. Dynamic membrane of AnMBR could not retain soluble COD effectively. Effluent pH was 7.20-7.60. Ultimately, further downstream treatment was recommended for soluble COD removal. Zahid *et al*. (2011) [29] used cloth media filter in MBR technology for treatment of municipal wastewater. The performance of this method in terms of COD removal is shown in Fig 6. Four log of faecal reduction was observed in this study. Therefore, this method can be considered as ideal alternative over the traditional activated sludge process because of high biomass concentration resulting better elimination of nutrients as well as improved preservation capacity of slow growing microorganisms like nitrifiers. Finally, the treated effluent was found suitable for restricted irrigation purpose.

The performance of the MBR for deduction of both chemical and biological impurities from municipal wastewater was evaluated and shown in Fig 5-6, and Table 2.

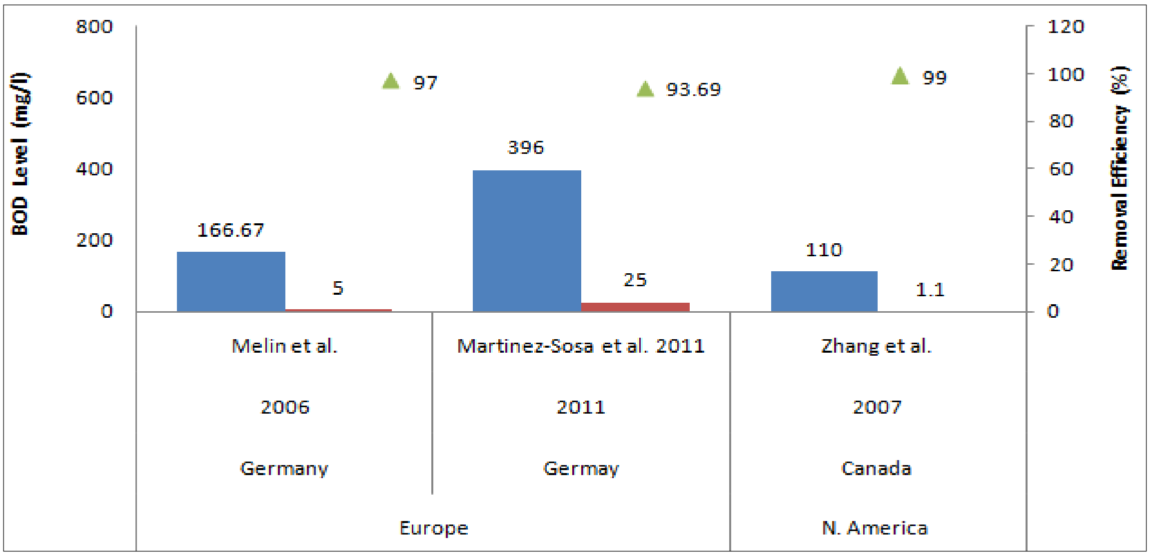

Fig 5: BOD concentration in raw and treated water along with removal efficiency for MBR

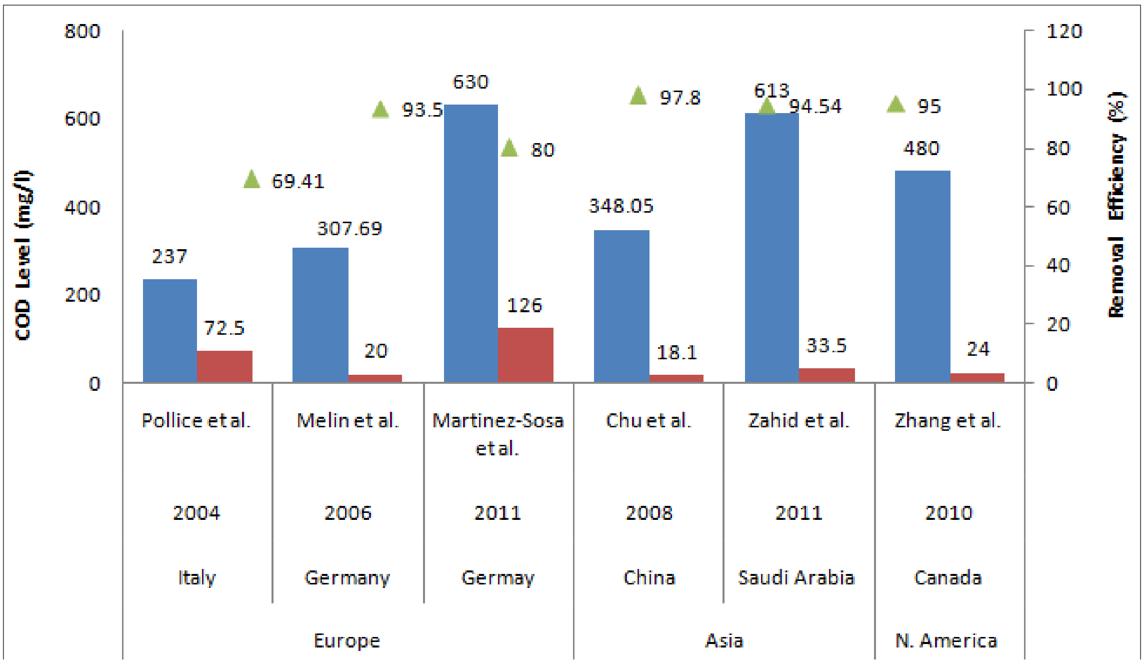

Fig 6: COD concentration in raw and treated water along with removal efficiency for MBR

Table 2: Performance of MBR treatment method for removal of FC

Parameters	References	Year	Treatment Methods	Country	Raw Value	Treated Value	Removal Performance
Faecal Coliform (FC)	Martinez-Sosa *et al.*	2011 [15]	AnSMBR	Germany	4.30*10^6 CFU/ 100 ml	49	5 log
	Zahid *et al.*	2011 [29]	MBR	Saudi Arabia	-	-	4 log

CFU indicates colony-forming unit

4. Conclusions

This literature survey was conducted with MBR technology for removal of several physical, chemical and biological impurities from municipal wastewater. Based on the review of this wastewater reclamation method, the following conclusions can be drawn.

- TSS removal efficiency was found to vary from 95 to 100%.
- BOD removal efficiency was found to vary from 94 to 99%.
- COD removal efficiency was found to vary from 69 to 98%.
- Average worldwide performance of MBR for removal of biological contaminants was also found as satisfactory.

Therefore, this survey revealed the worldwide satisfactory performance of MBR for removal of physical, chemical and biological impurities. Hence, the study suggested that MBR treated municipal waste water could be applicable for irrigation purpose.

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