Neoteric approach for mitigation of fouling in membrane bioreactor utilizing green composites

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Received: 20 May 2020 / Accepted: 6 July 2020 / Published online: 14 July 2020
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Abstract

Purification of water is a critical and inevitable process at present to avoid the harmful effect of polluted water and to meet the need for safe drinking water to millions of people in the world. Several methods of water purification exist, but the combination of adsorption and filtration is found to be paramount in the water treatment process owing to the cost-effectiveness and efficacy of the process. The submerged ceramic membrane bioreactor, which includes both bioreactor and filtration system, is one of the most promising technologies effectively employed for water purification. The main hardship in using the membrane bioreactor system is the phenomena called fouling which decreases and gradually ceases the separation capacity of the membrane. The present work focuses on the reduction of fouling, thus increasing the efficacy of the membrane bioreactor system. The two green composite materials, chitosan beads with activated carbon (CH-AC) and cellulose acetate flakes with activated carbon (CA-AC), were used for the first time for reduction of fouling and found to be an excellent aid in the reduction of fouling. The composites synthesized were subjected to characterization using SEM, TEM and BET to study the physical properties of the composites. The optimum dosage of CH-AC and CA-AC for effective reduction of fouling was analysed. Thus, the present work imparts the novel, efficient, economical and eco-friendly solution for fouling reduction and also a significant improvement in the quality of effluent water.

Keywords Water purification · Submerged membrane bioreactor · Ceramic membrane · Chitosan · Cellulose acetate · Activated carbon · Fouling reduction

Introduction

Treatment of wastewater and subjecting the treated water to reuse is the most promising option to decrease groundwater consumption. Impending limitations in conventional water treatment processes have stimulated the need for efficient processes proficient at removing high values of biochemical oxygen demand (BOD), turbidity, suspended solids,

phosphorus, nitrogen and bacteria (Hai et al. 2014; Zhang et al. 2006). The membrane bioreactor (MBR) has evolved as the well-organized cost-effective technology for municipal as well as industrial wastewater treatment (Sutton et al. 2002; Togna and Sutton 2003; Chen and LaPara 2006; Menniti et al. 2011; Hosseinzadeh et al. 2013; Ahmed et al. 2007; Kimura et al. 2005; Xing et al. 2000; Huang et al. 2001; Shimizu et al. 1996; Wang et al. 2008; Shin and Kang 2003).

The MBR system includes lesser footprint and reduced sludge production. MBR process is more advanced and systematic process when compared to conventional activated sludge process (ASP) making it more feasible for extensive use in the wastewater treatment (Gander et al. 2000; Knoblock et al. 1994; Lee et al. 2003; Howell et al. 2004; Hai et al. 2005; Schmidt and Ahring 1996; McCarty and Bae 2011). Among the two configurations of MBR, i.e. side stream and submerged membrane bioreactor (SMBR), submerged membrane bioreactor is more efficient and cost-effective wastewater treatment technique. It requires lesser space, less energy consumption and low sludge production

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(Lee et al. 2001; Sun et al. 2006; Yamamoto et al. 1989; Low et al. 2016; Masse et al. 2006; Rosenberger et al. 2002; Lesjean et al. 2004; Wang et al. 2006).

Employment of ceramic membranes is highly beneficial in membrane bioreactor process due to excellent filtration performance, high chemical resistance, system integrity, ease of cleaning and low operating cost (Pagana et al. 2008; Chiemchaisri et al. 1993; Jeong et al. 2017; Dong et al. 2018; Yue et al. 2015). The predominant disadvantage hindering the utilization of MBRs on a large scale is the process called fouling, which results in a significant reduction of membrane performance and lifespan, leading to the increase in the cost of maintenance and operation of MBR system (Chang et al. 2002; Judd 2008; Iorhemen et al. 2016; Mueller et al. 2010; Reid et al. 2006; Wu and Fane 2012; Shane Trussell et al. 2006; Tatsuki Ueda and Kenji Hata 1999). Fouling is the restriction, occlusion or blocking of membrane pores by suspended particulates solutes, colloids and flocs of sludge which accumulates onto the exterior surface as well as into the pores of the membrane, reducing the flow of permeate water through the membranes (Gkotsis et al. 2014; Lousada-Ferreira et al. 2014; Jin et al. 2013; Chen et al. 2016; Lee et al. 2003; Le-Clech et al. 2006; Jung and Kang 2003; Meng et al. 2006; Zhang et al. 2006).

The development of an efficient and sustainable strategy for fouling mitigation in MBRs has been the primary focus of researchers working on MBR technology. The main aim of the present work is the employment of green composite materials in the membrane filtration and to study its effects on the reduction of fouling on ceramic membranes in submerged membrane bioreactor (SMBR). To the best of our knowledge, the efficient and eco-friendly composite materials, i.e. chitosan with activated carbon beads and cellulose acetate with activated carbon flakes, are used for the first time to reduce fouling in the membrane bioreactor. The results obtained show that the composite materials of chitosan and cellulose acetate are found to be very effective in the mitigation of fouling, thus increasing the efficiency of the wastewater treatment in submerged ceramic membrane bioreactor (SCMBR). The present method possesses the potential for replacement of conventional activated sludge process on an industrial scale. The optimum amount of composite materials is determined for chitosan-activated carbon (CH-AC) and cellulose acetate-activated carbon (CA-AC) composites. It is found that the composite materials used are economical as well as sustainable solution for mitigation of fouling in SCMBR. The water quality of the filtrate was tested for various parameters. The tremendous improvement in water quality assures the practicality of the idea proposed.

Materials and methods

Materials

Chitosan (Himedia laboratories, Mumbai, India); cellulose acetate (Loba chemie, Mumbai, India); glutaraldehyde (Rohm Lab reagents, Mumbai, India); meat extract, sodium chloride (NaCl), magnesium sulphate heptahydrate ($\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$), standard potassium dichromate ($\text{K}_2\text{Cr}_2\text{O}_7$), mercuric sulphate (HgSO_4), ferrous ammonium sulphate hexahydrate ($\text{Fe}(\text{NH}_4)_2(\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}$), ferrous ammonium sulphate (FAS), activated carbon (Nice Chemicals, Kochi, India); urea (NH_2CONH_2), calcium chloride dihydrate ($\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$), ferroin indicator, sodium hydroxide (NaOH) (Thomas Baker, Mumbai, India); yeast extract, anhydrous dipotassium hydrogen phosphate (K_2HPO_4), acetone, concentrated sulphuric acid (H_2SO_4), silver sulphate (AgSO_4) (Merck, Sigma-Aldrich, St. Louis, USA); ceramic membrane (procured from BHEL PVT Ltd, Bangalore); all the chemicals used were of analytical reagent (AR) grade. Distilled water was used in the experimental analysis, and tap water was used for the preparation of feed. Activated sludge was obtained from BWSSB (Bangalore Water Supply and Sewage Board) with the permission of Chief Engineer of Waste water management department. The sludge was procured from the BWSSB 75 MLD STP Mylasandra plant, Kengeri.

Synthesis of artificial fermentation feed

Fermentation feed was prepared synthetically in the laboratory according to the procedure followed by Mahesh et al. (2007) for obtaining a high organic content. The feed consists of the following components: yeast extract—160 mg, anhydrous dipotassium hydrogen phosphate—28 mg, calcium chloride dihydrate—4 mg, urea—30 mg, magnesium sulphate heptahydrate—2 mg, sodium chloride—7 mg and meat extract—110 mg dissolved per litre of tap water. 20 L of feed was prepared for every batch of experiments.

Chitosan-activated carbon composite

The method proposed by Wan Ngah et al. (2002) was followed to synthesize chitosan-activated carbon composite. 250 ml of 1 mol/l NaOH solution was prepared by dissolving the NaOH pellets, and the solution was cooled to room temperature. 1 ml glutaraldehyde was added to the NaOH solution. The cross-linking of chitosan with glutaraldehyde was carried out in order to increase the mechanical strength of the beads. The solution was stirred for uniform composition. Chitosan and the acetic acid solution was prepared by

dissolving 1 g of chitosan into 50 ml of 5% (v/v) acetic acid solution. 0.5 g of activated carbon was added to the chitosan solution, mixed well to obtain a uniform solution. The viscous chitosan-activated carbon solution was added dropwise using a syringe into NaOH and glutaraldehyde mixture to form beads. The addition was carried out slowly to attain beads of uniform shape and size. The beads were left in the solution for about 3 h for hardening. The hardened beads were removed and washed using distilled water to remove NaOH residues.

Cellulose acetate-activated carbon composite

The method proposed by Wu et al. (2005) was followed with further modifications to synthesize the activated carbon-cellulose acetate composite. 1.2 g of cellulose acetate and 10 ml of acetone was mixed well. 0.5 g of activated carbon was added to the mixture and mixed well to get a thick uniform paste. The paste was cast on the glass petri dish, and the composite was subjected to drying for 15 min in the hot air oven for 30 min at 80 °C. The dried sheets were carefully removed from the glass. Each sheet was cut into flakes uniformly.

Experimental procedure

The primary objective of the present work is to treat wastewater by subjecting it to microfiltration in order to improve the quality of the effluent water in terms of the characteristics such as chemical oxygen demand (COD), dissolved oxygen (DO) and turbidity. The submerged membrane reactor was designed and fabricated to handle 20 L of waste water. The schematic representation of the process is as shown in Fig. 1.

The synthetic fermentation feed (20 L) was introduced into the acrylic tank. Activated sludge (5 ml/L) was added to the fermentation feed in order to provide a biological environment. The membrane system containing 4 tubular ceramic membranes was submerged into the feed water and suspended with the help of holder attached at the top of the membrane. The membrane is made up of silicon carbide. The membrane possessed thickness of 2 mm, length 18 cm and diameter 12.5 mm. The external surface area of each membrane is $8.2797 \times 10^{-3} \text{ m}^2$ with a pore size of 1.5 microns. Aeration was provided using the copper-coiled air sparger in order to supply oxygen for the microorganisms present in the MBR. The rate of aeration was maintained at 0.5 m³/h. Aeration also helps in the sustinment of the optimum DO in the water. The vacuum pump, Multivac (Gurgaon, India) of 0.2 HP with speed of 2800 RPM, was used to create a vacuum inside the collection tank for suction of water through the membranes. Solids larger than membrane pores were retained on the

Fig. 1 Process flowchart of the submerged ceramic membrane bioreactor

surface of the membranes. Transmembrane pressure (TMP) was measured with the help of a pressure gauge. Pressure and volume of water collected in the storage tank was noted at equal intervals of time until the water level reaches a constant value. The readings obtained were used to calculate permeate flux. After each run, the feed and effluent were analyzed to determine COD, DO and turbidity of the effluent.

Regeneration of membranes

The membranes were regenerated by the chemical cleaning method. The membranes were washed in tap water and then immersed in 1 wt% H_2SO_4 followed by rinsing in distilled water, further the membranes were immersed in 2 wt% alkaline solution of NaOH for 15 min. After alkaline wash, membranes were cleaned with distilled water. The membranes were subjected to heating at 600 °C to burn the choked carbon material followed by cooling to room temperature.

Results and discussion

Studies on the morphology of the membrane and composite materials were carried out using the scanning electron microscopy (SEM) [Tescan Vega 3]. Transmission electron microscope (TEM) [JOEL, HRTEM] and Brunauer–Emmett–Teller (BET) surface area analyser

(Mirometrix Instruments) were used to study the size and surface area of the membranes. The efficacy of the proposed green composite materials on the reduction of fouling was investigated by carrying out several experiments using the self-designed submerged ceramic membrane bioreactor.

Characteristics of the influent water

To investigate the quality of the water to be treated, the influent water sample was subjected to the examination of various parameters as per IS standards, as shown in Table 1. It can be noted that water quality testing of the influent sample shows that the quality of the water was not good. It possessed disagreeable odour and it was highly turbid with high organic content. The presence of oil and grease was noted, and *E coli*/100 ml of the sample was present in the influent. Thus the influent water was found to be polluted and not fit for use. As the polluted water harms the health of human-kind, it is necessary to treat the water using a practical and feasible method. In the present work, the self-designed submerged ceramic membrane bioreactor with antifouling aids were used to treat the influent feed water effectively.

Filtration studies

The study of permeate flux is an essential aspect of membrane filtration. It is calculated using the formula shown in Eq. (1)

$$\text{Permeate flux} = \frac{\text{volume of water collected}}{\text{surface area of membranes} \times \text{Time of the collection}} \quad (1)$$

Table 1 Characteristics of water samples

Sl no.	Parameter	Tested method	Results	
			Influent water	Effluent water
1	Colour (Hz unit)	IS 3025 (Part-4):1983	30	< 5
2	Odour	IS 3025 (Part-5):2018	Disagreeable	Agreeable
3	pH	IS 3025 (Part-11):1983	7.84	7.2
4	Oil and grease (mg/L)	IS 3025 (Part-39):1991	106	Not detected
5	Turbidity	IS : 3025 Part-10 1984	162	0.7
6	Dissolved oxygen	Winkler test	5.6	15
7	Total suspended solids (mg/L)	IS 3025 (Part-17):1984	140	7
9	Total nitrogen (mg/L)	IS 3025 (Part-34):1988	739	Not detected
10	Free ammonia (mg/L)	IS 3025 (Part-34):1988	897	Not detected
11	Biological oxygen demand (mg/L)	IS 3025 (Part-44):1993	175	2
12	Chemical oxygen demand (mg/L)	IS 3025 (Part-58):2006	302	7.8
13	Total phosphates (as PO_4) (mg/L)	IS 3025 (Part-31):1988	12.8	1.0
15	Lead (as Pb) (mg/L)	IS 3025 (Part-2):2004	BDL	BDL
16	Cadmium (as Cd) (mg/L)	IS 3025 (Part-2):2004	BDL	BDL
17	Total arsenic (as As)	IS 3025 (Part-2):2004	BDL	BDL
18	Mercury (as Hg)	IS 3025 (Part-2):2004	BDL	BDL
19	<i>E coli</i> /100 ml	IS 1622:1981	Present	Absent

BDL: below detectable limit

The permeate flux is dependent on the membrane resistance, the hydrodynamic state of the membrane, the liquid interface and the operational conditions and the fouling of the membrane. The efficiency of the membrane process was analysed based on permeate flux. Permeate flux ($\text{L}/\text{m}^2 \text{ h}$) was investigated by plotting the flux with respect to time. Figure 2 shows the plot of permeate flux against time for the feed water with the characteristics reported in Table 1. The flux was initially at $100 \text{ L}/\text{m}^2 \text{ h}$, which gradually decreased and reached to a constant value at 150 min which indicates that the fouling has gradually increased and reached to a constant value at 150 min. The fouling of the membranes may be due to the concentration of various organic and inorganic compounds on the surface of the membrane. It often leads to the formation of a gel layer that hinders the penetration of water through the membrane surface, thus decreasing the flux rates.

The plot of flux v/s time reveals that the permeate volume increased with an increase in time and after specific time there was no further increase in the volume which was due to the process of fouling. In order to reduce the fouling two composite materials, namely chitosan-activated carbon and cellulose acetate-activated carbon was employed as antifouling aids for reduction of fouling and increasing the efficiency of the filtration process. The composite materials act as adsorbent as well as filtering aids and assist in increasing the flux. The main factor influencing the filtration process in the present scenario is the cake layer growing on the surface of the membrane which is reduced by the addition of chitosan-activated carbon beads and cellulose acetate-activated carbon flakes as the composite materials which are excellent adsorbents.

Chitosan-activated carbon (CH-AC) as the filtration aid

Chitosan has been employed for adsorption of metal ion, pesticides, endocrine disruptors, drugs, tincture agents, dyes and pigments (Krajewska 2005). Chitosan is also found to be non-toxic and biodegradable (Boributh et al. 2009; Hamzah et al. 2012). The eco-friendly biopolymer sorbent possesses improved phase separation and acts as very useful and excellent material for treating wastewater (Le Roux et al. 2005). When chitosan along with activated carbon is employed in submerged ceramic membrane bioreactor aids in the mitigation of fouling and assist in increasing the efficacy of the process.

The microbes and particles present in the waste water tend to get adsorbed on the beads, thus reducing the number of particles clogging to the membrane surface. The clogging can be reduced by using the antifouling aid (CH-AC), which decreases the cake layer growth on membrane surface thus increasing the efficacy of the filtration process. It was found that with the increase in the dosage of the chitosan-activated carbon beads, the volume of water collected increased and the fouling decreased. Experiments were conducted by varying dosages of the fouling reductant, i.e. 1 g CH–0.5 g AC, 3 g CH–0.5 g AC, 5 g CH–0.5 g AC, 7 g CH–0.5 g AC. The graph of permeate flux v/s time is as shown in Figs. 3, 4, 5 and 6 for the 1 g CH–0.5 g AC, 3 g CH–0.5 g AC, 5 g CH–0.5 g AC, 7 g CH–0.5 g AC, respectively. The feed influent with 1 g CH–0.5 g AC clogged at 210 min. The feed influent with 3 g CH–0.5 g AC clogged at 300 min. The feed with 5 g CH–0.5 g AC clogged at 345 min. The feed treated with 7 g CH–0.5 g clogged at 450 min. With the increase in the dosage of chitosan, the efficiency of the reactor increased. Maximum bioreactor efficacy was observed with the dosage of 7 g of CH–0.5 g AC beads. Figure 6 shows the permeate flux versus time data for the feed water

Fig. 2 Variation of permeate flux with the time of operation of feed water

Fig. 3 Variation of permeate flux with time of operation [fermentation feed and 1 g CH-AC]

Fig. 4 Variation of permeate flux with time of operation [fermentation feed and 3 g CH-AC]

Fig. 5 Variation of permeate flux with time of operation [fermentation feed and 5 g CH-AC]

Fig. 6 Variation of permeate flux with time of operation [fermentation feed and 7 g CH-AC]

containing 7 g of chitosan–0.5 activated carbon beads. The adsorption of foulants onto CH-AC composite hinders the accumulation of foulants onto the membrane, thus decreasing the fouling process in the membrane.

Cellulose acetate-activated carbon (CA-AC) as the filtration aid

Cellulose acetate flakes can be used in various applications such as enzymes immobilization, adsorbent, for controlled releasing of active pharmaceutical ingredient and as the medium for separation (Fischer et al. 2008). In the present work, cellulose acetate along with activated carbon were used as fouling reductant in submerged ceramic membrane bioreactor in order to increase the efficiency of the filtration

process. The main reason for the reduction of fouling and increase in the efficiency of the treatment process is due to the adsorption of foulants on the green composite material instead of getting accumulated on the membrane surface. Adoption of cellulose acetate and activated carbon as antifouling aids results in an increase in efficiency of the submerged ceramic membrane bioreactor. The employment of CA-AC resulted in an increase in the volume of water collected due to reduction in fouling.

Experiments were conducted by varying the amount of CA-AC flakes, i.e. 1.2 g CA–0.5 g AC, 3.6 g CA–0.5 g AC, 6 g CA–0.5 g AC, 8.4 g CA–0.5 g AC (Figs. 7, 8, 9, 10). The filtration in the bioreactor was more prominent with the addition of the cellulose acetate and activated carbon flakes compared to the plain feed. The feed influent with

Fig. 7 Variation of permeate flux with time of operation [fermentation feed and 1.2 g CA-AC]

Fig. 8 Variation of permeate flux with time of operation [fermentation feed and 3.6 g CA-AC]

Fig. 9 Variation of permeate flux with time of operation [fermentation feed and 6 g CA-AC]

Fig. 10 Variation of permeate flux with time of operation [fermentation feed and 8.4 g CA-AC]

1.2 g CA–0.5 g AC clogged at 210 min. The feed influent with 3.6 g CA–0.5 g AC clogged at 300 min. The feed with 6 g CA–0.5 g AC clogged at 360 min. The feed treated with 8.4 g CA–0.5 g AC clogged at 450 min. With the increase in the dosage of CA-AC, the efficacy of the reactor tends to increase. Maximum bioreactor efficacy was observed with the dosage of 8.4 g of CA–0.5 g AC beads. Figure 10 represents the permeate flux versus time data for the feed water containing 8.4 g of CA–0.5 AC.

Characterization

Characterization of membranes

The surface of the membranes was analysed using SEM analysis. Surface analysis of the clean and fouled membranes was performed to study the morphology of the surface. The SEM images of clean/regenerated membrane and fouled membranes are as shown in Fig. 11a and b, respectively. Figure 11a reveals that the pores of the unfouled membranes are larger and precise, which would facilitate the passage of the water through the membrane. The pore size of fouled membranes reduces, and the blocking of the pores through the foulants as depicted in Fig. 11b leads to clogging of membrane pores which would hinder the penetration of water through the membrane surface, thus enhancing the fouling in the membrane.

In order to reduce fouling and increase the efficacy of filtration, the composite materials, chitosan and activated carbon beads and cellulose acetate and activated carbon flakes were synthesized, and subjected to characterization using SEM. The SEM images of the chitosan-activated carbon beads before usage as antifouling aids and chitosan-activated carbon beads after use as antifouling aids are as shown in Fig. 11c and d, respectively. It is observed that there is a deposition of various organic matters on the surface of the beads after using it as antifouling aid. The results reveal good adsorption characteristics of the beads. Due to the deposition of the foulants on the beads, the fouling on the membrane was significantly reduced.

The SEM image of fresh cellulose acetate-activated carbon flakes and cellulose acetate-activated carbon flakes after using in fouling reduction in the reactor is depicted in Fig. 11e and f, respectively. Scattered bacterial and other microbial colonies on the fouled cellulose acetate-activated carbon flakes can be observed from Fig. 11f. The cellulose acetate-activated carbon is a good adsorbent material, and hence, it can be effectively used as antifouling aid in a submerged ceramic membrane bioreactor.

Figure 12a and b represent the transmission electron microscope (TEM) image of the unfouled membrane (left) and fouled membrane (right). The TEM images obtained

from membranes before fouling show the particles of uniform shape.

The smaller particles observed in the fouled membrane Fig. 12b can be attributed to the various organic and inorganic matters adhered to the membrane in the process of fouling. We observe the decrease in pore size, which is the main criteria for the decline in flux and hence reduction of filtration.

The BET analysis reveals that the surface area of the membrane is found to be 0.1557 m²/g, the micropore area is 4.8696 m²/g, and micropore volume is 0.002012 cm³/g.

Variation of chemical oxygen demand (COD)

COD is the amount of oxygen consumed in the course of degradation of organic matter and oxidation of inorganic chemicals present in the water. A SPECTROQUANT TR 320 COD digester was used for digesting the influent and effluent samples. COD was measured as a standardized laboratory assay in which a closed water sample was incubated with a strong chemical oxidant under specific conditions of temperature and for a particular period of time.

From Fig. 13a and b, it is observed that the COD of the influent fermentation feed was very high around 300 ppm, while the average COD of the effluent sample collected from the effluent tank after every run was found to be around 5.6 ppm. High COD value indicates that inadequate oxygen was available in the sample, which means a large quantity of oxidizable organic material was present, which would reduce dissolved oxygen (DO). Reduced level of DO indicates anaerobic conditions, which is highly harmful to the various aquatic animals. The maximum value of COD of the effluent sample was 7.7 ppm which is well below the permissible limit of COD of tap water which is about 10 ppm. Figure 13a shows the reduction of COD when chitosan and activated carbon were used, and Fig. 13b shows the reduction of COD when cellulose acetate-activated carbon was used as aids to reduce fouling.

Variation of dissolved oxygen (DO)

DO level decreases when the BOD of the wastewater increases as the surplus bacteria and other microbes leading to high BOD consume the DO in water. Dissolved oxygen availability affects the ecology of fishes and many other organisms (Kramer 1987). Hence, it becomes an important parameter of water quality. Different organisms have different preferred DO concentrations, but, in general, DO concentration of about 7–11 mg/L is considered to be a perfect condition for the survival of aquatic life. The dissolved oxygen in the water below 5.0 mg/l leads to the potential threat on aquatic life. In the present work irrespective of the dosage, dissolved oxygen levels have

Fig. 11 **a** SEM image of the regenerated membrane, **b** SEM image of the fouled membrane, **c** SEM image of chitosan-activated carbon beads, **d** SEM image of fouled chitosan-activated carbon beads, **e**

SEM images of cellulose acetate-activated carbon flakes and **f** SEM image of fouled cellulose acetate-activated carbon flakes

Fig. 12 **a** TEM image of the unfouled membrane, **b** TEM image of the fouled membrane

Fig. 13 **a** Variation of COD of influent and effluent employing chitosan-activated carbon bead, **b** variation of COD of influent and effluent employing cellulose acetate-activated carbon

increased tremendously from the range of 5–6 ppm to 14–15 ppm. Figure 14a and b shows the increase in DO levels when chitosan-activated carbon and cellulose acetate-activated carbon composites were used in the reactor. Thus, the usage of the two green composite materials

proposed is found to be beneficial in increasing the quality of effluent water.

Fig. 14 **a** Variation of DO of influent and effluent (chitosan-activated carbon), **b** variation of DO of influent and effluent (cellulose acetate-activated carbon)

Variation of turbidity

Water with a turbidity of less than 5 NTU is generally the acceptable limit for consumption. Turbidity must be low to have efficient disinfection as particulates help in protecting microorganisms from the effects of disinfection. Low turbidity values indicate high water clarity. Systronics 132 digital nephelo-turbidity metre was used throughout this work for measuring the turbidity of influent and effluent water. From Fig. 15a and b, it can be noted that the turbidity of the effluent sample has drastically reduced to an average of 0.4 NTU in comparison with the turbidity of the influent. High turbidity results in the reduction of dissolved oxygen. Various organic and inorganic matters such as clay, algae, silt, soluble coloured compounds, plankton and other microscopic organism result in turbidity of water. High turbidity in drinking water is unpleasing and also forewarns about the possible health hazard. Turbidity facilitates the growth of various pathogens which causes several waterborne diseases, including gastroenteritis. The maximum value of turbidity of the effluent sample is 0.7 NTU which is well below the permissible limit of turbidity of tap water which is about 5 NTU.

The trends of turbidity when chitosan and cellulose acetate were used are as shown in Fig. 15a and b, respectively.

Variation of pH

Water with a low pH value (<6.5) may be acidic and corrosive. Therefore, the water with low pH could contain a high quantity of toxic metals. On the other hand, water with a pH > 8.5 is hard water. Hard water does not cause a health risk on its own but has an affinity to pose problems. It is seen that the pH of the permeate is reduced and maintained, nearing the neutral value of pH 7. Figure 16a and b shows the trend lines in pH for influent and effluent for the various runs when chitosan-activated carbon and cellulose acetate-activated carbon were used in the reactor.

Effluent water quality

The quality of effluent obtained from the treatment process plays a key role in determining the efficacy of the process. The water treated using submerged ceramic membrane bio-reactor was subjected to water quality testing, and the results are depicted in Table 1. The water quality testing (Table 1)

Fig. 15 **a** Variation of turbidity of influent and effluent (chitosan-activated carbon), **b** variation of Turbidity of influent and effluent (cellulose acetate-activated carbon)

shows the influent water had disagreeable odour and highly turbid with high organic content. The effluent water has agreeable odour with increased dissolved oxygen, decreased COD, turbidity, and BOD. The oil and grease, free ammonia and E coli/100 ml of the sample were absent in the effluent. The decrease in total nitrogen and total phosphate was noted. Thus, the water treated is found to be of good quality which emphasis the proposed process efficiency.

Conclusions

The current investigation focuses on the novel approach to mitigate membrane fouling by using green composite materials such as chitosan-activated carbon and cellulose acetate-activated carbon. The filtration in the bioreactor is more prominent with the addition of the proposed green composites (CH-AC and CA-AC) compared to the plain feed. By using the composite materials, it was possible to increase the efficiency of the submerged ceramic membrane bioreactor substantially. Fermentation feed

without the addition of composite materials had a run time of about 150 min. The feed with 1 g CH-0.5 g AC clogged at 210 min. With the increase in the dosage of chitosan, the run time of the reactor increased with 7 g CH-0.5 g AC, and the reactor clogged at 450 min. Feed water with 1.2 g CAH-0.5 g AC clogged at 210 min and 8.4 g CAH-0.5 g AC clogged at 450 min. The main reason for the reduction of fouling and increase in the efficiency of the treatment process may be due to the adsorption of foulants on the green composite material. The adsorption of foulants onto CH-AC and CA-AC composite hinders the accumulation of foulants onto the membrane, thus decreasing the fouling process in the membrane. The efficiency of the process is enhanced due to a reduction in fouling. The quality of effluent obtained by the process is of excellent quality. COD of the influent fermentation feed is very high around 300 ppm, while the average COD of the effluent sample collected after treatment was found to be around 5.6 ppm. Irrespective of the dosage, dissolved oxygen levels have increased tremendously from the range of 5–6 ppm to 14–15 ppm. It is observed that the pH of

Fig. 16 **a** variation of pH of influent and effluent (chitosan-activated carbon), **b** Variation of pH of influent and effluent (cellulose acetate-activated carbon)

permeate is reduced and maintained, nearing the neutral value of pH 7. The turbidity of the effluent sample has drastically reduced to an average of 0.4 NTU. In conclusion, the water obtained by SCMBR was of high purity, and the employment of composite materials has a significant influence on fouling reduction as well as improving the quality of effluent water.

Acknowledgements The authors would express their profound thankfulness to WOS-A, Department of Science and Technology for financial support. The authors would like to acknowledge VTU Belgaum for the kind motivation. The authors are thankful to BWSSB for providing the activated sludge.

Author contributions SSR was involved in funding acquisition, visualization, conceptualization, investigation, validation, formal analysis, writing—original draft preparation. MGM contributed to methodology, writing—review and editing, supervision, project administration. Dr. MCD helped in resources.

Funding The present work was funded by Department of Science and Technology under Women Scientist Scheme, Grant No. SR/WOS-A/ET-20/2017.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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