*Desalination and Water Treatment*
www.deswater.com
1944-3994 / 1944-3986
doi: 10.5004/dwt.2010.1773

18 (2010) 212–216
June

# A hybrid system combining self-forming dynamic membrane bioreactor with coagulation process for advanced treatment of bleaching effluent from straw pulping process

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Received 31 May 2009; Accepted 10 December 2009

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**ABSTRACT**

An innovative hybrid system combining self-forming dynamic membrane bioreactor (SFDMBR) with coagulation process was developed to treat bleaching wastewater from pulping process. Pilot-scale experimental results showed that the average removal efficiencies of chemical oxygen (COD) demand and lignin by the SFDMBR were over 80% and 51%, respectively. The fairly good treatment performances can be attributed partly to the high biomass concentration (i.e. –10 g/L) maintained in the SFDMBR and partly to the more efficient solid-liquid separation achieved by the self-forming dynamic membranes. It was found that the self-forming dynamic membranes can be quickly created, normally less than 60 min, during the initial stage of SFDMBR operation. Effluent turbidity was lower than 5 NTU in most cases. Membrane fouling can be effectively controlled via [illegible]min online air backwashing at an intensity of 3.2 $m^3 \cdot m^{-2} \cdot h^{-1}$, and the separation capacity can be restored within 30 min. The effluent of SFDMBR was subsequently treated by coagulation process with polyaluminum chloride (PAC) to further enhance effluent quality. According to batch test results, the optimal dosage of PAC was determined to be 0.54 g/L. The mean effluent concentrations of COD and lignin were measured to be 117 and 63 mg/L, respectively.

***Keywords:*** Self-forming dynamic membrane bioreactor (SFDMBR); Polyaluminium chloride (PAC); Bleaching effluent; wastewater treatment

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## 1. Introduction

China has by far the fastest growing paper industry in the world. The majority of virgin pulps are based on non-wood sources (e.g. rice straw, wheat straw, reed). At present, effluent chemical oxygen demand (COD) from straw pulping and papermaking process, mainly bleaching process, accounted for 40–45% of total COD discharge in China. In view of this, numerous research efforts have been devoted to reducing and minimizing bleaching effluent COD in straw pulping and papermaking industries. Because of its poor biodegradability, bleaching effluent can not be adequately treated by conventional biological process in most cases. This makes it difficult to meet the increasingly stringent discharge standard [1] and consequently induce serious potential contamination of the receiving water body. It is, therefore, of great importance to develop more efficient and

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effective treatment systems to minimize the adverse environmental impacts caused by bleaching effluent.

A new process, termed self-forming dynamic membrane bioreactor (SFDMBR), has recently emerged as a promising technology and attracted many researchers' attention [2–5]. In an SFDMBR, solid-liquid separation is achieved by a sludge layer self-formed on coarse materials. The sludge layer is thus termed self-forming dynamic membrane as that proposed by Fan and Huang [2]. As a modification of conventional membrane bioreactor (MBR), an SFDMBR possesses a lot of advantages including high biomass concentration, low excess sludge production, excellent effluent quality and so on. Moreover, the capital cost of SFDMBR is much lower than that of MBR owing to the use of cheap coarse materials instead of micro/ultra-filtration membranes. The relatively small filtration resistance of self-forming dynamic membrane, on the other hand, greatly reduces the energy consumption and thus the operational cost of SFDMBR.

In earlier studies, mesh materials (e.g. industrial filter cloth, dacron and stainless steel) were employed as filter media where self-forming dynamic membranes were formed to obtain the same separation efficiency as that of commercial microfiltration membranes [2–5]. More recently, non-woven fabrics were applied as new filter media on which faster formation of self-forming dynamic membranes can be achieved [6–8]. Regardless of which material was utilized as filter media, previous SFDMBR studies mainly focused on synthetic or real municipal wastewater treatment. Few efforts have been made to investigate the performance of SFDMBR with real industrial wastewaters which are usually more challenging for emerging treatment processes.

In this paper, an innovative hybrid treatment system was designed, constructed and employed successfully to remove the contaminants in bleaching effluent discharged from straw pulping process. It combined an SFDMBR with a coagulation process in which polyaluminium chloride (PAC) was used as coagulants. Pilot-scale experiments were conducted to investigate the removal efficiencies of COD and lignin achieved by the SFDMBR and the coagulation treatment process, respectively. In addition, particular efforts were made to optimize the filtration performance of self-forming dynamic membranes. The optimum PAC dosage for cost-effective post-treatment of bleaching effluent was also investigated.

## 2. Materials and methods

### 2.1. Experiments

The schematic diagram of the SFDMBR with the filtration device submerging in is shown in Fig. 1. The working volume of the reactor was 10 L and the effective filtration area of each self-forming dynamic membrane module was 0.045 m². A baffle which divided the SFDMBR into two parts was installed in the middle of the device. An aeration unit serving for the activated sludge aeration by an air pump and generating turbulence in the mixed liquid was placed at the bottom of the reactor (mainly onto the left side). In the reactor there stood two self-forming dynamic membrane modules that were manually prepared by polyvinyl chloride profiles, wire netting and nylon mesh cloth with the nominal pore size of 100 μm. The filtration was driven by the pressure difference between the water level and the outlet of the SFDMBR. Back-washing was carried out when the self-forming dynamic membrane was severely fouled. At the same time, another aeration diffuser was turned on in order to clean out the foulants absorbed on the surface of the mesh cloth. In other words, when back-washing course was started, valves 1# and 3# were dismissed and valve 2# was switched on, air flowed into the modules simultaneously to destroy the bio-layer and to eliminate the clogs adhering on the self-forming dynamic membrane. After cleaning, valve 1# and 3# was turned on and valve 2# was shifted down again to restart normal operation.

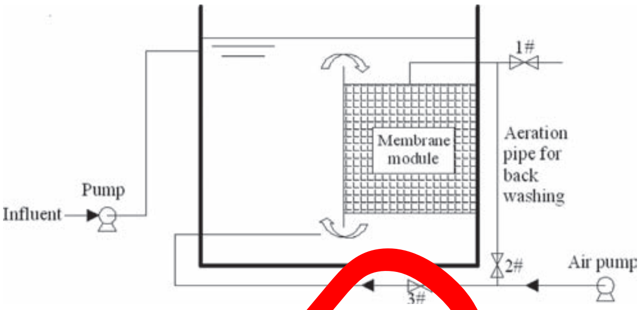

Fig. 1. Schematic diagram of the SFDMBR.

### 2.2. Bleaching wastewater and operation conditions

Raw bleaching wastewater supplied into the bioreactor was taken from a straw-based pulp and paper mill locating in Shandong province. The water quality is listed in Table 1. The effluent treatment method employed by

Table 1
Water quality of the raw effluent.

| COD (mg/L) | $BOD_5$ (mg/L) | Lignin (mg/L) | pH |
|---|---|---|---|
| 1100–1600 | 250 | 380–400 | 7.5–8.5 |

this enterprise was BIOLACK process and the COD in the final effluent was lower than 450 mg/L according with the standard of GB3544-2001. Activated sludge samples that injected into the bioreactor were derived from the secondary clarifier in the same paper mill. The MLSS concentration in the reactor was 10 g/L with the HRT of 24 h and flux rate of 4.6 L·m$^{-2}$·h$^{-1}$. During the operation period no excess sludge was discharged. The effluent was then treated by adding the flocculant PAC intermittently once a day.

### 2.3. Analyses

Besides the MLSS concentration, the influent and effluent COD, lignin, pH and dissolved oxygen (DO) of the SFDMBR were measured. COD and MLSS were determined according to Chinese NEPA Standard Methods [9], while lignin was conducted by the procedure in the reference [10]. The pH and DO was monitored by model MP220 pH meter and MC-7W DO analytic instrument, respectively.

The optimum dosage of PAC was investigated in a beaker by the following steps: 350 ml water sample was impregnated into the container with volume of 500 ml, then was mixed round in various proportions with PAC by a stirrer at the rate of 120 r/min; 1 min later, the stirring rate declined to 30 r/min and kept for 20 min; COD and lignin in the supernatant which was gotten through the sedimentation of mixed liquid in 15 min were properly and carefully acquired.

## 3. Results and discussion

### 3.1. The formation of the self-forming dynamic membrane

Effluent turbidity was continuously measured in the present study to assess the solid-liquid separation efficiency of the self-forming dynamic membrane. As shown in Fig. 2, effluent turbidity was extremely high (986 NTU) at the very beginning and gradually declined due to the progressively build-up of the self-forming dynamic membrane. The effluent turbidity decreased to 5.2 NTU within 60 min and remained stable thereafter, indicating that the self-forming dynamic membrane was successfully created. Fuchs et al. [4] reported that dynamic membrane can be self-formed within 12 h at the MLSS concentration of 4 g/L, whereas Chu and Li [5] observed that dynamic membrane was self-formed within 3 h at the MLSS concentration of 6 g/L. In our study, the formation of self-forming dynamic membrane was completed more quickly (i.e. within 1 h). This implies that higher MLSS concentration (i.e. 10 g/L) could accelerate the formation of self-forming dynamic membranes, since more sludge flocs were in contact with the surface of the mesh material.

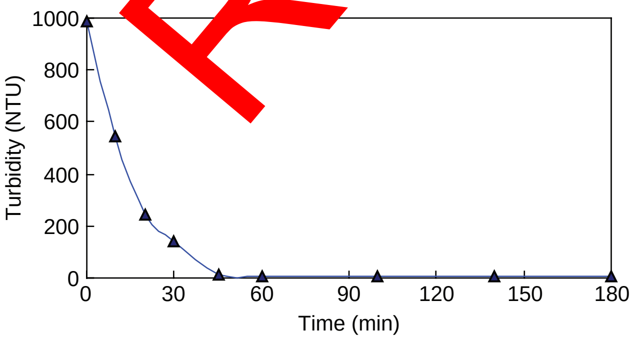

Fig. 2. Turbidity variation of the SFDMBR effluent at the initial period.

### 3.2. Treatment effects of the SFDMBR-Flocculation method

#### 3.2.1. COD and lignin removal performance of the SFDMBR

Figures 3 and 4 describe the removal efficiency of the SFDMBR for COD and lignin, respectively.

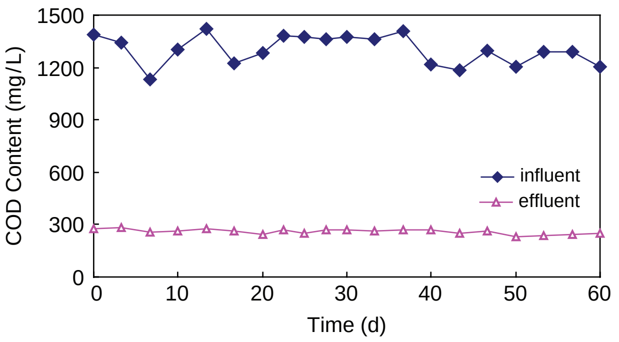

Fig. 3. COD removal effect of the SFDMBR.

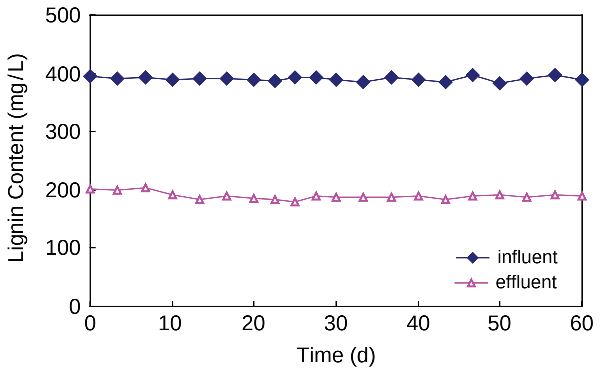

Fig. 4. Lignin removal effect of the SFDMBR.

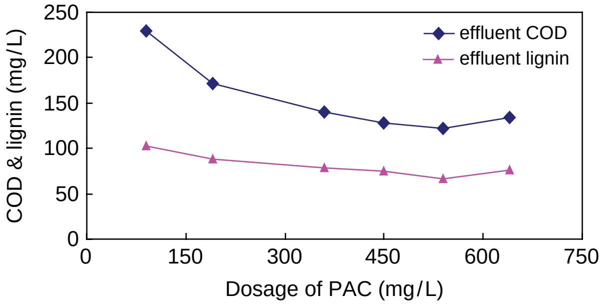

Fig. 5. The influence of the PAC dosage on the COD and lignin removal.

COD and lignin fluctuated in the range of 1100–1600 mg/L, 380–440 mg/L in the influent fed into the SFDMBR with the mean value of 1344 and 390 mg/L, respectively. However, there occurred a more remarkable decrease about COD (220–270 mg/L, average 260 mg/L) than lignin (182–210 mg/L, average 192.4 mg/L) in the effluent as observed. Due to high MLSS concentration as well as long sludge age in the SFDMBR, the mean removal efficiency of COD could reach even more than 80%. Moreover, lignin could be removed to the extent of 51%.

### 3.2.2. *Effect of flocculation process*

The addition of PAC serving as a filter aid enhanced adsorption and biodegradation of organic substances. Besides these functions mentioned as above, rejection and flocculation were occurred to remove organic contents and lignin that were difficult to be eliminated only through biodegradation. The effect of PAC dosage on COD and lignin removal efficiency is expressed by Fig. 5. The total amount of COD and lignin minimized as the PAC dosage gradually increased, then they would raised unavoidably due to backflocing phenomenon that the deposited suspended solids in the bottom of the reactor returned to the supernatant again. As plotted in Fig. 5, the optimum addition dosage of PAC was 0.54 g/L which can not only efficiently remove the pollutants in the wastewater but also save flocculant that costs a lot in the practice application.

As proved by the experiment above, the water quality that treated by PAC at the dosage of 0.54 g/L was given in Figs. 6 and 7. COD decreased considerably from 260 to 117 mg/L while lignin from 192 mg/L in the influent to 63 mg/L in the effluent. Interestingly, the removal efficiency of lignin (33%) was remarkable higher than COD (11%) after the coagulation process. The total COD removal efficiency as well as lignin was 91% and 84%, respectively.

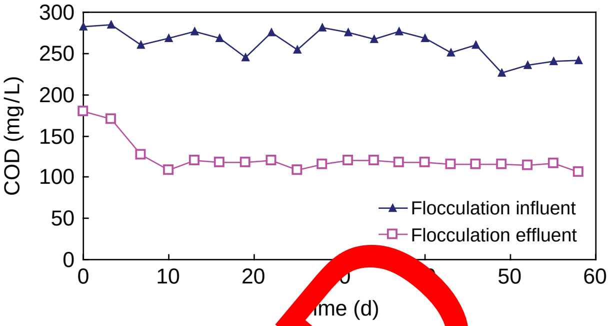

Fig. 6. COD removal efficiency of the flocculation process.

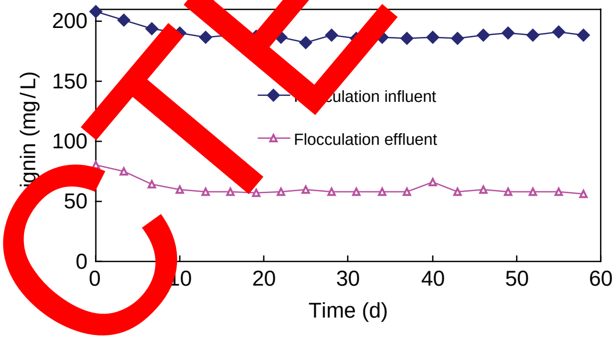

Fig. 7. Lignin removal efficiency of the flocculation process.

### 3.3. *Membrane fouling and control method*

Colloids existing in the wastewater and metabolic products of the microorganism in the sludge accumulated massively on the surface of the mesh cloth clogged the membrane, which resulted in a severe flux reduction. Once the cake layer was thick enough to elevate the water head drop, therefore the transfer pressure began to climb up rapidly, and the water level reached to the highest, SFDMBR needed backwashing to solve this bothersome issue of membrane fouling.

### 3.3.1. *Regeneration of the self-forming dynamic membrane*

Backwashing was found adequate for sloughing off all foulants sticking to the rough cloth and transporting back to the solution. The flux can be improved remarkably though the water quality discharged from the reactor was a little lower in the recovery process of self-forming dynamic membrane. Thus, the operation conditions of backwashing had powerful and vital impacts on the performance and the removal efficiency of the SFDMBR.

The maximal water head drop maintained at 15 cm while the aeration intensity was kept at the rate of

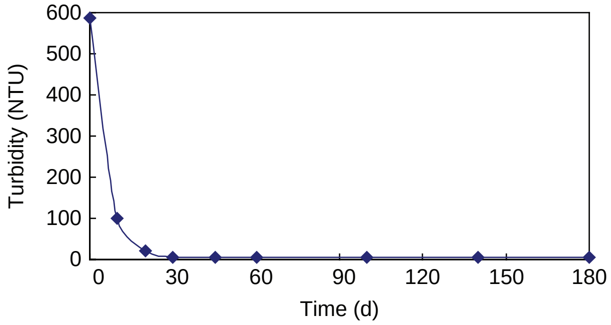

Fig. 8. Turbidity variation of the SFDMBR effluent after back-washing.

$3.2\ m^3 \cdot m^{-2} \cdot h^{-1}$, the time spent for cleaning was 5 min in case that long time aeration would destroy the self-forming dynamic membrane and the foulants would be removed uncompleted within short time. Figure 8 identifies the turbidity alterability along with time in the regeneration process of the self-forming dynamic membrane after backwashing. As shown in Fig. 8, the turbidity in the effluent reached to 586 NTU so that the water was with awful colors. As the filtration proceeded, the turbidity fell off slowly to 5.26 NTU in 30 min. Conclusively, the self-forming dynamic membrane could complete the recovery course within 30 min.

### 3.3.2. Back-washing interval

Figure 9 presents the interrelation between the back-washing interval and its frequency. 36 times of back-washing were preformed in two months operation. It should be noted that the SFDMBR was operated at a constant flux of $4.6\ L \cdot m^{-2} \cdot h^{-1}$ over the entire experimental period. Back-washing was carried out when the self-forming dynamic membrane was severely fouled (i.e. the hydraulic head went beyond [illegible] cm $H_2O$). It can be seen from Fig. 9 that the back-washing interval significantly decreased from the initial [illegible]3 to 2[illegible] h at the end of the operation. This suggests that the self-forming dynamic membrane became more prone to fouling as operation proceeded, probably due to the progressive deterioration of the mesh material.

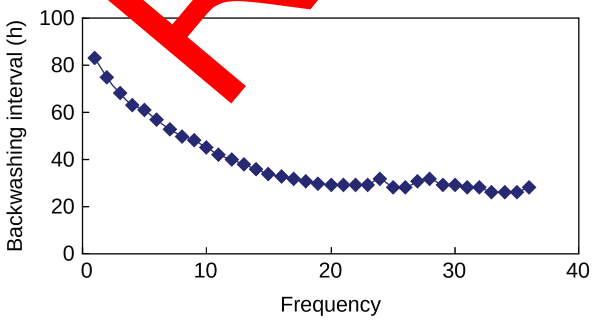

Fig. 9. The interrelation between the back-washing period and frequency.

## 4. Conclusions

The following conclusions can be drawn from the presented study.

1. The self-forming dynamic membrane formed gradually on the surface of the supporting materials after the SFDMBR ran normally in 60 min. With mixed liquid suspended solids (MLSS) concentration of 10 g/L and hydraulic retention time of 24 h, COD decreased obviously from 1344 mg/L in the influent to 260 mg/L in the effluent and lignin from 390 to 192 mg/L.
2. By adding PAC to improve the water quality of the effluent discharged from the SFDMBR, average COD and lignin dropped to 117 and 63 mg/L, respectively, at the PAC dosage of 0.54 g/L of wastewater.
3. The self-forming dynamic membrane could be recovered in 30 min. The regeneration of self-forming dynamic membrane was extraordinarily easy and SFDMBR could perform two months with a circulation period of 29 h.

## Acknowledgement

This work was supported by the National Water Special Project (2009ZX07210-009) and Graduate Independent Innovation Foundation of Shandong University (2009JQ009).

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