World Academy of Science, Engineering and Technology
International Journal of Environmental and Ecological Engineering
Vol:8, No:2, 2014

# An Assessment of the Effects of Microbial Products on the Specific Oxygen Uptake in Submerged Membrane Bioreactor

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***Abstract*—**Sustaining a desired rate of oxygen transfer for microbial activity is a matter of major concern for biological wastewater treatment (MBR). The study reported in the paper was aimed at assessing the effects of microbial products on the specific oxygen uptake rate (SOUR) in a conventional membrane bioreactor (CMBR) and that in a sponge submerged MBR (SSMBR). The production and progressive accumulation of soluble microbial products (SMP) and bound-extracellular polymeric substances (bEPS) were affecting the SOUR of the microorganisms which varied at different stages of operation of the MBR systems depending on the variable concentrations of the SMP/bEPS. The effect of bEPS on the SOUR was stronger in the SSMBR compared to that of the SMP, while relative high concentrations of SMP had adverse effects on the SOUR of the CMBR system. Of the different mathematical correlations analyzed in the study, logarithmic mathematical correlations could be established between SOUR and bEPS in SSMBR, and similar correlations could also be found between SOUR and SMP concentrations in the CMBR.

***Keywords*—**Microbial products, Microbial activity, Specific oxygen uptake rate, Membrane bioreactor.

## I. Introduction

MEMBRANE bioreactor (MBR) has been widely used as a robust option for the biological treatment of wastewater. In the compact configuration of MBR system, modification in biomass activity and viability is more likely [1] principally because of the higher suspended solids' concentration and low solids' retention time. Therefore, maintaining a desired rate of oxygen transfer for microbial activity is critically important for the optimum performance of the MBR system.

The removal of organic matter in a biological wastewater treatment system relies on the oxidative process of utilizing oxygen by microorganism as the terminal acceptor or the use of nitrate under anoxic conditions [2]. Since the adoption of MBR technology for wastewater treatment, significant number of studies was performed to identify factors that might affect the treatment efficiency or contribute to the membrane fouling. However, very limited studies ([3]-[6]) were aimed at assessing the factors that might affect the rate of oxygen transfer and consequently the efficiency of the microbial activities.

Due to the microbial metabolism within the MBR, different types of organic compounds are released and are accumulated within the bioreactor. The role and effects of microbial products have attracted attention of the researchers in this field since those were identified as one of the major contributors of membrane fouling. However, it was also acknowledged by few studies ([6]-[8]) that the soluble microbial products (SMP) and bound-extra polymeric substances (bEPS) might pose inhibitory impacts on microbial activity. The oxygen contained in the air bubbles needs to penetrate the liquid film surrounding the flocs (SMP) to reach the active sites of the bacterial cell membrane, and then diffuse through the floc matrix (EPS) ([6], [9]). Germain et al. [6] identified that the solids' concentration, carbohydrate fraction of the EPS and the COD concentration of the SMP were affecting oxygen transfer coefficient.

As the oxygen uptake by microorganisms is associated with substrate utilization rate [10], the specific oxygen uptake (SOUR) rate is conventionally used as an indicator of microbial activity. The main objective of the study reported in this paper, therefore, was to determine the effect of bEPS and SMPs on SOUR. A conventional aerobic submerged MBR (CMBR) was operated for 59 days and another sponge submerged MBR (SSMBR) was operated up to 90 days. The effects of SMP and bEPS on the microbial activity were assessed for both the aerobic submerged MBR systems.

## II. Experiments and Methods

### A. Experimental Setup

The experiments were conducted using two types of submerged MBR systems, one was a typical aerobic submerged MBR (CMBR) and the other was sponge-submerged MBR (SSMBR). The membrane module used in the experiment was polyethylene hollow fiber with the pore size of 0.2μm and the surface area of 0.1m$^2$ (Tianjing, China). The effective volume of the bioreactor was 8L and the

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filtration rate was maintained at 10L/m$^2$/h. Both the influent and effluent flow rates were controlled by a two channel pump. A pressure gauge was used to measure the trans-membrane pressure (TMP), and a soaker hose air diffuser was used to maintain the air flow rate at 9L/min. Physical cleaning of the membrane was done by applying relaxation of the reactor for one minute in every hour of its operation (59 minutes on and 1 minute off in every hour). The initial mixed liquor suspended solids' (MLSS) concentrations were ~5g/L and ~7g/L in the CMBR and SSMR respectively. The sponges used in the SSMBR were acclimatized with synthetic wastewater for at least 25 days before commencing the experiments. The specification of the sponges was S28-30/45R (density of 28-30 kg/m$^3$ with 45 cells per 25 mm), and each sponge was typically1cm×1cm×1cm, reticulated and porous polyester-urethane sponge (PUS). The fraction of the sponge within the bioreactor was 10% (of bioreactor volume) which was determined according to a critical flux experiment previously done by Guo et al. [11]. The sludge used in the study was taken from a local wastewater treatment plant and was acclimatized with synthetic wastewater.

### *B. Substrate*

The substrate used in the experiment was synthetic wastewater that was prepared using glucose, ammonium sulphate, potassium dihydrogen phosphate and trace nutrients (compositions of the synthetic wastewater is shown in Table I [12]). The synthetic wastewater had COD of 340-390 mg/L, $NH_4$-N of 15-20 mg/L and $PO_4$-P of 3.5-4.0 mg/L. $NaHCO_3$ or $H_2SO_4$ was used to adjust the pH of the substrate at 7.

TABLE I
CONSTITUENTS OF BIODEGRADABLE SYNTHETIC WASTEWATER

| Compounds | Molecular weight (g/mol) | Concentration (mg/L) |
|---|---|---|
| Organics and nutrients | | |
| Glucose ($C_6H_{12}O_6$) | 180.0 | 280 |
| Ammonium sulphate ($(NH_4)_2SO_4$) | 132.1 | 72 |
| Potassium phosphate ($KH_2PO_4$) | 136.1 | 13.2 |
| Trace nutrients: | | |
| Calcium chloride ($CaCl_2{\cdot}2H_2O$) | 147.0 | 0.368 |
| Magnesium sulphate ($MgSO_4{\cdot}7H_2O$) | 246.5 | 5.07 |
| Magnesium sulphate ($MgSO_4{\cdot}7H_2O$) | 197.9 | 0.275 |
| Zinc sulphate ($ZnSO_4{\cdot}7H_2O$) | 287.5 | 0.44 |
| Ferric chloride anhydrous ($FeCl_3$) | 162.2 | 1.45 |
| Cupric sulphate ($CuSO_4{\cdot}5H_2O$) | 249.7 | 0.391 |
| Cobalt chloride ($CoCl_2{\cdot}6H_2O$) | 237.9 | 0.42 |
| Sodium molybdate dihydrate ($Na_2MoO_4{\cdot}2H_2O$) | 242.0 | 1.26 |
| Yeast extract | | 30 |

### *C. Measurements and Analytical Methods*

The Oxygen uptake rate (OUR) was measured using the YSI 5300 biological oxygen monitor. Specific oxygen uptake rate (SOUR) was then calculated from (1).

$$SOUR = OUR/MLVSS \quad (1)$$

Both the bEPS and the SMP were measured as the combined Polysaccharides (PS) and Protein (PN) in the sample. The bEPS and SMP were extracted from the mixed liquor sample using Cation Exchange Resin (CER) according to [13]. The extracted bEPS and SMP were then analyzed as the combined PS and PN in the sample. PS was analyzed by anthrone method (according to [14] with standard glucose) and the PN was measured by total protein kit (Standard BSA; Micro Lowry, Petersons' modification). The analysis of MLSS and MLVSS were done according to standard methods [15].

## III. RESULTS AND DISCUSSION

### *A. Variation of bEPS and SOUR with Time*

The variation of SOUR with the days of operation as well as the variation (with time) of the concentration of bEPS in the mixed liquor was measured for both the CMBR and SSMBR systems. The measured data are shown in Figs. 1 and 2 for the SSMBR and CMBR system, respectively.

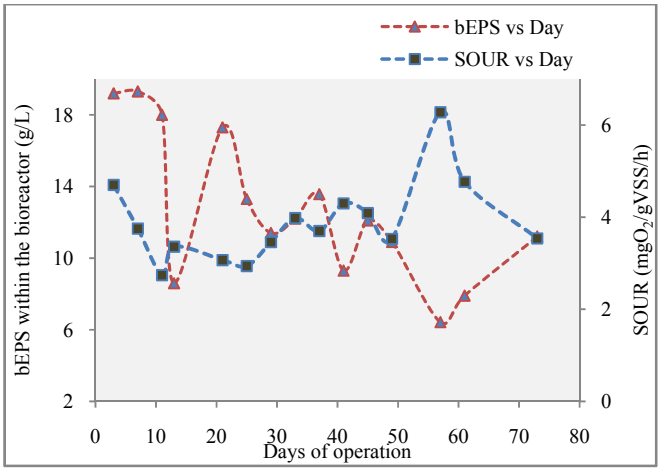


Fig. 1 Variation of bEPS and SOUR with days of operation (SSMBR)

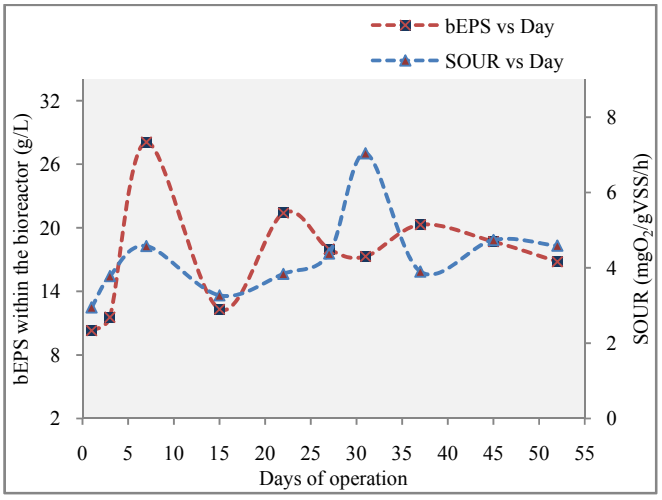


Fig. 2 Variation of bEPS and SOUR with days of operation (CMBR)

The concentration of bEPS in the mixed liquor of the SSMBR was generally decreasing with the days of operation

of the MBR. Relatively higher concentrations of bEPS were measured during the first 20 days of operation of the SSMBR, while reasonably stable concentrations of bEPS were found between 25 and 50 days of operation followed by lower concentrations of bEPS after 50 days. While the development of foulants on the membrane surface was negligible during the observed period of time, the decreasing concentrations of bEPS in the mixed liquor might be due to the fact that the bEPS were mainly getting attached on the surface or inside the sponges.

The concentration of the bEPS in the mixed liquor of the CMBR was generally high as compared to that found in the mixed liquor of the SSMBR. An opposite trend of the concentration of bEPS in the mixed liquor of CMBR was observed in the CMBR, and generally increased concentration of the bEPS was found with increasing days of operation of the MBR. There was abrupt increase or decrease of the concentration of bEPS within up to 20 days of operation of the CMBR which became more or less stable between 20 and 49 days.

There are contradictory findings reported in the literature about the effects of the EPS on the microbial activity. Germain et al. [6] found that the EPS was beneficial for oxygen transfer in pilot and full-scale MBR whereas Rojas et al. [16] reported about faster growth of microorganisms with less production of the EPS. The experimental results of the study on the SSMBR suggest that there exists a relationship between the concentration of microbial products and microbial activity subject to the beneficial effects of the sponges attaching the bEPS with them. Selected data of SOUR plotted against the respective concentrations of bEPS (Fig. 3) shows that the microbial activity decreases logarithmically with the increased concentration of bEPS in the mixed liquor of the bioreactor. The logarithmic mathematical relationship between the SOUR and the concentration of the bEPS within the bioreactor of the SSMBR can be expressed by the following mathematical relationship with reasonably good correlation coefficient ($R^2$= 0.72).

$$SOUR = -2.564\ln (bEPS) + 10.04 \quad (2)$$

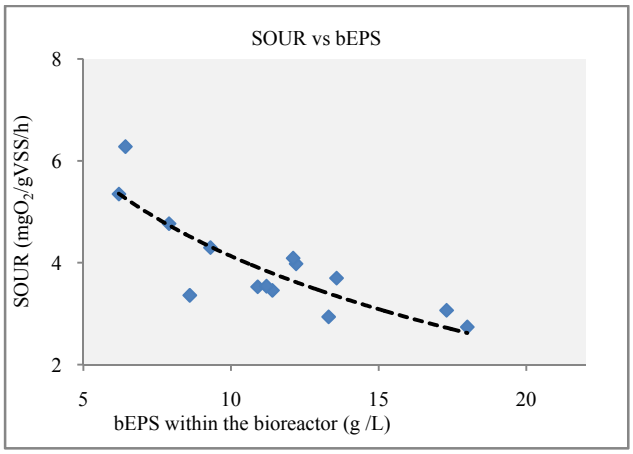


Fig. 3 SOUR vs. bEPS of the SSMBR system

The SOUR in the CMBR was also affected by the bEPS within the bioreactor although the effect was not as significant as it was in the SSMBR. However, no defined correlation could be established between the SOUR and the concentration of the bEPS (Fig. 4) in the CMBR. The microbial activities enhanced near the middle stage of operation of the CMBR when the concentrations of bEPS were higher (within the range between 17 and 22 mg/L).

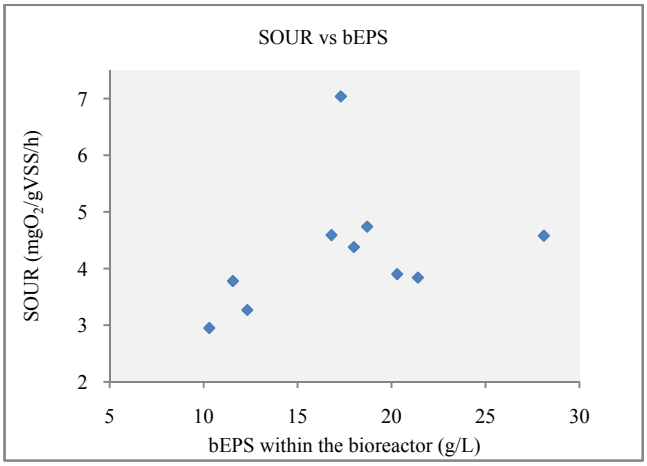


Fig. 4 SOUR vs. bEPS of the CMBR system

No definite trend of the variation of the SOUR with time was observed for either of the MBR system. The SOUR profile in Fig. 1 shows that microbial activity was relatively stable between 30 and 50 days of operation of the SSMBR. In the initial stage of operation of the SSMBR, the microbial activity was low which might be due to the inhibition by the increased concentration of bEPS in the mixed liquor. The microbial activity increased in the following days with the decreased concentration of the bEPS in the mixed liquor.

### *B. Variation of SMP and SOUR with Time*

The concentrations of SMP in the mixed liquor of the bioreactors at different days of operations of the SSMBR and CMBR systems are shown in Figs. 5 and 6 respectively. The figures also show the SOUR profile with time. The concentration of SMP in the SSMBR varied in the range between 1-9mg/L while in the CMBR system, the concentration of SMP was higher and was in the range between 1 and 25mg/L. Unlike the concentration of bEPS in the SSMBR, the variations of SMP concentrations in the MBR systems were unstable. The concentration of SMP in the SSMBR was varying in an unstable manner even up to 50 days of operation of the system, and it was steadily increasing after 50 days of operation of the system. In the CMBR system, the concentration of SMP in the mixed liquor significantly decreased with time perhaps due to its increased accumulation and attachment tomembrane surface. Similar to the effects of bEPS on the SOUR, it was observed in both the MBR systems that the microbial activity increased with reduced concentration of SMP in the mixed liquor of the bioreactors.

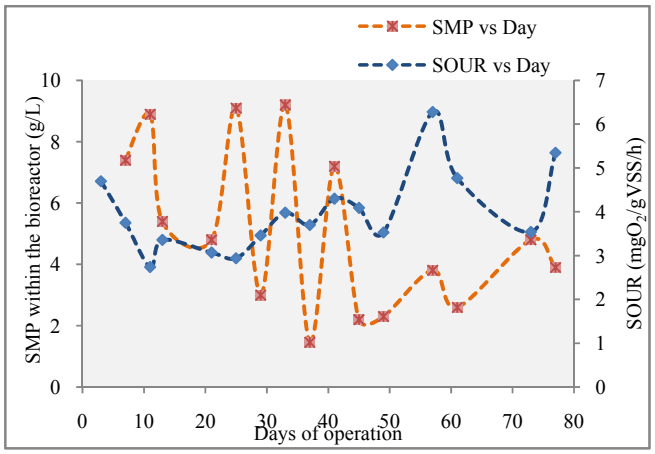


Fig. 5 Variation of SMP and SOUR with days of operation (SSMBR)

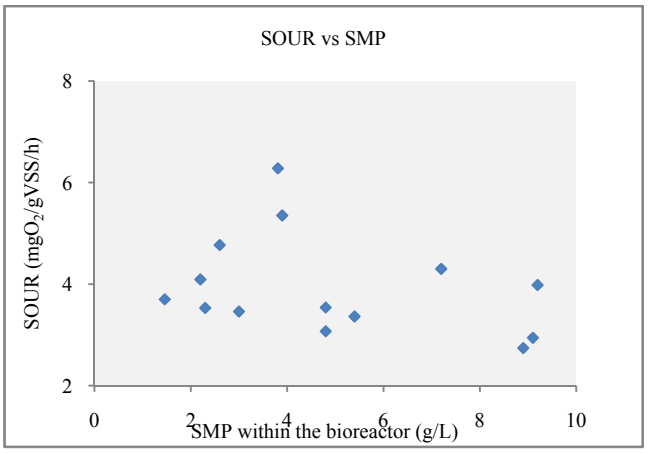


Fig. 7 SOUR vs. SMP of the SSMBR system

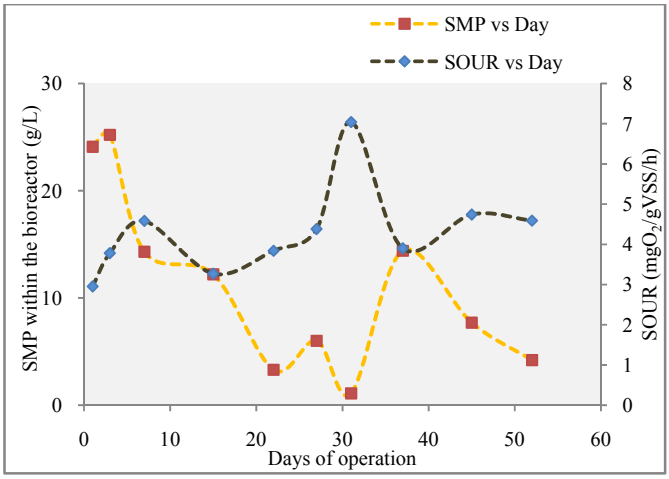


Fig. 6 Variation of SMP and SOUR with days of operation (CMBR)

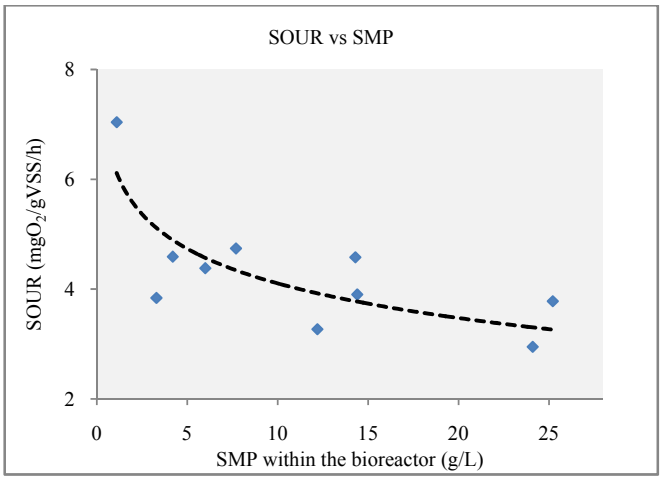


Fig. 8 SOUR vs. SMP of the CMBR system

It may be observed in Figs. 6 and 8 that the variations of the concentrations of the SMP in the bioreactor affected inversely the oxygen uptake rate of the microorganisms. With relative lower concentration of SMP in the SSMBR system and also due to the sponges attaching some SMP fractions with them, the effects of SMP on the SOUR is not evident in Figs. 5 and 7. The logarithmic mathematical relationship between the SOUR and the concentration of the SMP in the CMBR can be given by the following mathematical relationship with reasonably good correlation coefficient ($R^2$= 0.63).

$$SOUR = -0.911\ln(SMP) + 6.20 \quad (3)$$

## IV. Conclusions

This paper presents different experimental results and analyses to assess the effects of microbial products on the oxygen uptake of microorganisms in two different types of submerged MBR systems. The specific oxygen uptake rate (SOUR) by microorganisms was measured at different times of operation of the MBR systems, and the SOUR was used as an indicator parameter of the microbial activities. The measured data of the SOUR were correlated with the respective concentrations of the bound-EPS and SMP in the mixed liquor of the bioreactors. The findings of the study indicate that the production and accumulation of bEPS/SMPs within the bioreactor affected microbial activities in the MBR treatment systems. The bEPS in the sponge submerged MBR system significantly affected the SOUR while relative higher concentration of SMP in the conventional MBR system had adverse effects on the SOUR. The role of sponge in the MBR was found beneficial as it could possibly attach the SMP/bEPS on its surface or within the pores, and thereby reducing the inhibitory effects of microbial products on the SOUR. Logarithmic mathematical expressions with reasonably good correlation coefficients could be used to explain the

relationship between SOUR and bEPS of the SSMBR, and that between SOUR and SMPs of the CMBR as well.

## ACKNOWLEDGMENT

This study was funded by Australian Research Council (ARC) Industry Linkage Grant (LP0882089).

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