COMBINE EFFECT OF PHYSICAL AND BIOLOGICAL BASED ANTIFOULING STRATEGIES IN LAB SCALE MEMBRANE BIOREACTOR TREATING SYNTHETIC WASTEWATER

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Abstract— Membrane bioreactors (MBRs) have been evolved into state-of-the-art technology in wastewater treatment and reuse. However, fouling associated with the membranes, still remains a major problem that elevates operating and maintenance costs, thereby hampering the spread of MBRs worldwide. Although interrupting the process of the biofilm formation by the action of interspecies quorum quenching (QQ) has received a significant attention since recent years, but it is limited to the control of biofouling only. Whereas, this study demonstrates the combined effect of quorum quenching mechanism and backwashing (distinguished physical technique) in MBR treating synthetic wastewater to control biofouling and membrane pore blockage simultaneously. Three bench-scale MBRs, (i) conventional MBR (C-MBR) (ii) MBR with backwash (MBR-BW) and (iii) MBR with QQ consortium and backwash (MBR-QQ-BW) were set up and operated continuously. MBR with combine effect of backwashing and quorum quenching exhibited 7 and 3 times longer filtration cycle than C-MBR and MBR-BW. Comparatively less cake layer resistance (R_c) and soluble EPS concentrations were observed in MBR-QQ-BW than other two MBRs. Study reveals the novelty of successful application of combined influence of permeate backflushing technique in pore blockage reduction and QQ as an anti-biofouling strategy in MBR and potential use for full scale applications.

Keywords— Wastewater Treatment, Membrane Bioreactor, Fouling Control.

I. INTRODUCTION

Freshwater shortage and stringent environmental regulations are major drivers for introducing advanced water recycling technologies. In recent years, membrane bioreactor (MBR) is widely recognized as a wastewater treatment technology owing to its distinctive advantages, including high treatment efficiency and less sludge production and smaller foot prints, over the conventional activated sludge processes [1, 2]. Further, MBRs can be operated at a longer sludge retention time (SRT), higher mixed liquor suspended solid (MLSS) concentration, and with a much smaller physical footprint. However, membrane fouling is a major impediment that limits the widespread application of MBR due to frequent physical and/or chemical cleaning and high energy demand [3, 4].

Among different types of fouling, biofouling considered as the most difficult one in terms of mitigation. Signal molecules based quorum sensing (QS) with the release of extracellular polymeric substances (EPS) and soluble microbial products (SMP) are considered to be main causing factors of biofouling in MBR [5]. Various fouling control approaches including addition of coagulant, intermittent suction, and backwashing have been developed to reduce the membrane pore blockage as well as organic, and inorganic fouling. Recently, a quorum quenching (QQ) phenomenon has been widely reported to control biofouling in MBR systems at lab as well as pilot scale MBR systems [6-8]. Where, immobilized bacteria releasing QQ enzymes have been introduced into the MBR systems and proved to be effective for biofouling control. However, these techniques are not sustainable to prevent different types of fouling simultaneously in large scale applications. Thus, an integrated strategy, that can retard both membrane biofouling as well as pore blockage, is required to further enhance the performance efficiency of MBR systems.

The study aims to investigate the combine effect of a physical approach i.e. backwash and a biological approach i.e. quorum quenching on the operation and membrane fouling in MBRs. Potential QQ bacteria, immobilized in alginate-polymer solution, was applied in submerged MBR to mineralize various signal molecules whereby reducing the biofilm formation. Monitoring of water quality in terms of organic and nutrients removal rate of MBR with QQ consortium and backwash vs. conventional MBR, was also carried out to assess the performance efficiency of all MBRs.

II. EXPERIMENTAL DETAILS

2.1. Immobilization of antifouling bacteria

Three different strains including*Microbacterium sp.*, *Pseudomonas sp.*, isolated from activated sludge in the authors' lab (the 16S rRNA gene accession number: KR058848 and KR058846 respectively), and *Rhodococcus* RBH4 [7] were selected as a potential antifouling strains. For immobilization, fresh culture of antifouling or QQ bacteria, grown in 10 mL luriabertanni (LB) broth, was centrifuged at 4000 rpm for 30 min and re-suspended in autoclaved water. Polysulfone (5 % w/v dissolved in N-methyl-2-pyrrolidone) was prepared and added drop by drop

into a sterile sodium alginate (2% w/v). Mixture was stirred overnight. Then, 5 mL of bacterial suspension was mixed with sodium alginate-polysulfone and final suspension was dropped into $CaCl_2$ solution (4% w/v) through a nozzle at a rate of 1 mL/min using a peristaltic pump. Finally, the alginate-polymer beads were stirred in calcium chloride solution and for 2-3 hrs and stored in deionized water at 4 ^oC till use.

2.2. Experimental setup

Three bench-scale MBRs, each with a working volume of 4 L, (i) conventional MBR (C-MBR) (ii) MBR with backwash (MBR-BW) and (iii) MBR with QQ consortium and backwash (MBR-QQ-BW) were set up and operated continuously. An optimized filtration (28 min) and backwash mode (2 min) using peristaltic pumps was conducted for MBR-BW and MBR-QQ-BW. Each MBR was immersed with hollow fiber membrane (PVDF) having pore size of 0.05 µm with surface area of 0.06 m^2. Aerobic sludge was acclimatized for one month with synthetic wastewater. Table 1 and 2 show the detailed operational conditions and composition of the synthetic wastewater used in the study, respectively.

Table 1: Membrane characteristics and operational conditions of MBR

Membrane material	Polyvinylideneflouride (PVDF)
Membrane configuration	Hollow fiber
Membrane area Flux	0.05 µm 15 LMH
HRT	6 h
SRT	30 d
MLSS Immobilized beads to volume ratio	6-8 g/L 2 %

Table 2: Synthetic wastewater composition

Chemicals	Quantity mg/L
$C_6H_{12}O_6$	500
NH_4Cl	190
KH_2PO_4 $CaCl_2$	55.6 5.5
$MgSO_4.7H_2O$	5.7
$FeCl_3$	1.5
$MnCl_2$	1
$NaHCO_3$	To adjust pH

2.3. Measurement of filtration resistance

Simple resistance in series model was used to evaluate the filtration potential of membranes [9]:

$$R = \frac{\Delta P}{J\mu}$$

Where R = hydraulic resistance (1/m),
ΔP = TMP rise (Pa)
J = Operational flux ($m^3/m^2/s$)
μ = Permeate dynamic viscosity (Pa.s).
Where, following equation was used to calculate the total hydraulic resistance (R_t), intrinsic membrane resistance (R_m), pore blockage resistance (R_p) and cake layer resistance(R_c).

$$R_t = R_m + R_p + R_c$$

Initial R_m was calculates by filtering deionized (DI) water through new membrane; while R_t was recorded at the end of the operation by measuring flux and trans membrane pressure (TMP). Cake layer was removed and membrane was submerged again in DI water to calculate R_m+R_p.

2.4. Sludge characterization

For extraction of extra cellular polymeric substances (EPS), major components like soluble EPS (S-EPS), loosely bound EPS (LB-EPS) and tightly bound EPS (TB-EPS) were measured using heat method. riefly, 50 mL sludge sample, collected from MBR, was centrifuged (4000 rpm for 30 min at 4 ^oC) and supernatant was stored as soluble EPS. Folin-ciocalteu phenolic reagent was used [10] for protein analysis and absorption was measured at 750 nm via spectrophotometer (T60UV, PG Instrument, Britain). Whereas, phenol sulphuric acid method was used for the quantification of polysaccharides (PS), and absorption was measured at 490 [11].
Further, mixed liquor suspended solids (MLSS) and mixed liquor volatile suspended solid (MLVSS), sludge volume index (SVI), dissolved oxygen (DO) and soluble oxygen uptake rate (SOUR) were monitored as described in Standard Methods [12]. Sludge dewaterability was evaluated in terms of capillary suction time (CST) using CST apparatus (Triton, Canada).

2.5. Monitoring of water quality

Chemical Oxygen Demand (COD), Phosphate, ($P-PO_4^-$) and ammonium nitrogen (NH_4-N) were measured regularly to monitor permeate quality, using Standard Methods [12].

III. RESULTS AND DISCUSSION

3.1. Evaluation of trans-membrane pressure (TMP)

All MBRs were seeded with the same activated sludge keeping the MLSS concentration of 6-8 g/L. This study was attempted to control biofouling and pore blockage via quorum quenching and backwash respectively. TMP, considered as an important indicator for membrane filterability and have direct relation with membrane fouling, was critically evaluated for all MBRs as shown in Fig. 1. Average membrane fouling rate ($\Delta P/\Delta t$) in C-MBR, MBR-BW and MBR-QQ-BW was found to be 6, 2.3 and 0.83 kPa/day respectively. Previous studies already reported the contribution of biofilm formation over the membrane surface and membrane pore blockage due to continuous suction in membrane fouling [9, 13]. Results indicate the significant contribution of backwashing where 100 % delayed in TMP buildup was observed in MBR-BW than C-MBR. Further, a great potential shown by QQ bacterial consortium,

immobilized in alginate-polymer mixture, in terms of biofouling inhibition ensures MBR as more acceptable technology. Enzymes, including acylase or lactonase [14], released by QQ consortium may successfully degraded signal molecules resulted into reduction in biofilm formation, therefore, MBR with combine effect of backwashing and quorum quenching exhibited 7 and 3 times longer filtration cycle than C-MBR and MBR-BW.

3.2. Extra cellular polymeric substances (EPS) distribution in mixed liquor

Considering the importance of EPS in membrane biofouling, three major categories including soluble EPS (S-EPS), loosely bound (LB)-EPS and tightly bound (TB)-EPS were measured (Fig. 2). At the time of fouling, a continuous rise in S-EPS concentration from 155 to 180 mg/L and 193 mg/L in case of C-MBR and MBR-BW was witnessed. Whereas, MBR-QQ-BW showed a reduction in S-EPS concentration till day 20. Increase in S-EPS value from day 20 till 35 could be directly linked with TMP build up. No significant change in bound EPS concentration was observed for C-MBR and MBR-BW, whereas a slight increase, from 110 to 147 mg/g.VSS, was indicated by MBR-QQ-BW. It can be anticipated that the effect of S-EPS concentration is more pronounced in TMP build up than bound EPS. Further, QQ mechanism affects the EPS dissemination in mixed liquor whereas, physical strategy i.e. backwash did not contribute to reduction in EPS concentration. Thus, it could be inferred that the filtration duration prolonged in the MBR-QQ-BW due to reduction in EPS.

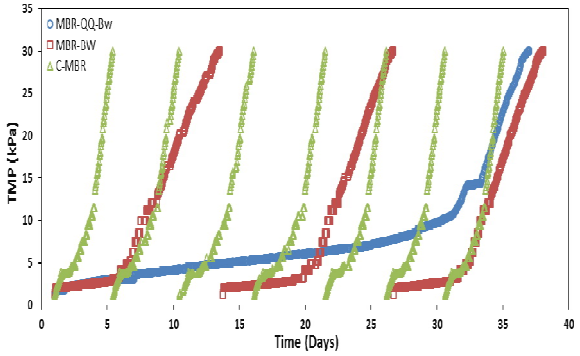

Fig. 1. Trans-membrane pressure trends in three MBRs

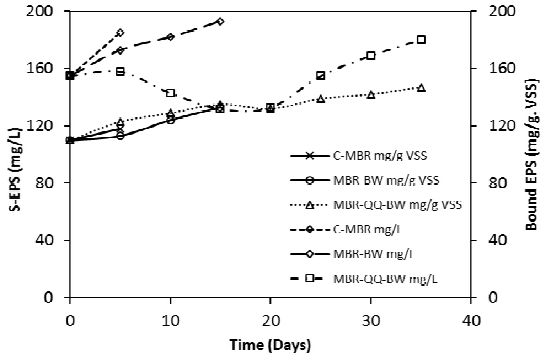

Fig. 2. EPS distribution in mixed liquor of MBRs

3.3. Measurement of the membrane resistivity

The membrane resistances are reported in Table 3 including total hydraulic resistance (Rt), cake layer resistance (Rc), pore block resistance (Rp) and intrinsic membrane resistance (Rm). Overall, contribution of Rc was 67, 48 and 29 % in C-MBR, MBR-BW and MBR-QQ-BW respectively. Rp was comparatively less in MBR-BW indicating the role of backwashing in reduction of pore blockage. Whereas, more Rp in MBR-QQ-BW than MBR-BW could be due to the prolonged filtration cycle of up to 36 days. Since QQ membrane exhibited lower Rc due to significant reduction in cake layer formation through quorum quenching activity, Rm contributed the major share of Rt in MBR-QQ-BW.

3.4. Sludge characteristics and effluent quality

Higher CST in C-MBR could be the result of increased concentration of soluble matter including soluble EPS because of which filterability deteriorated and vice versa for QQ-MBR [9]. Furthermore, QQ activity decreased the polysaccharides (PS) concentration which contributes to increase in flocs hydrophobicity due to which CST was found to below in MBR-QQ-BW as compared to C-MBR. Organic removal efficiencies of both MBRs were found to be excellent in terms of COD, ammonium-nitrogen and phosphate-phosphorous concentrations as reported in Table 4. Microbial activity in terms of SOUR was found to be more or less similar indicating the no significant impact of physical and biological strategy on the performance efficiency of MBR.

Table 3: Membrane resistivity measurements through resistance in series model

	C-MBR (x 10^{12})	MBR-BW (x 10^{12})	MBR-QQ-BW (x 10^{12})
R_t (m^{-1})	12.534	7.23	4.599
$R_m + R_p$ (m^{-1})	4.532	3.99	3.3676
R_m (m^{-1})	1.845	2.69	1.963
Rc (m^{-1})	8.323	3.445	1.3126
R_p (m^{-1})	2.712	1.3	1.334
R_m / R_t (%)	14.7	37.2	42.6
Rc / R_t (%)	66.5	47.6	28.5
R_p / R_t (%)	21.6	17.9	29.0

Table 4: Sludge characterization and performance efficiency

Parameters (Units)	C-MBR	MBR-BW	MBR-QQ-BW
DO (mg/L)	3-4	3-4	3-4
SOUR (mg/hr/g)	32.5	34.6	38.95
CST (s)	22	19	13
MLSS g/L	6-8	6-8	6-8
PSA (µm)	88.5	90.3	62.45
COD removal (%)	93	90	92
PO_4^{-3} removal (%)	49	51	47
NH^{+4}-N removal (%)	66	58	56

CONCLUSIONS

Impact of physical (backwash) and biological (quorum quenching) based mechanisms, on the performance efficiency and fouling retardation of MBR, was evaluated. Combine effect of backwashing and quorum quenching lessened the EPS concentration, reduced the biofilm formation and pore blockage, prolonged the duration of filtration and delayed the TMP rise up to 7 times.

ACKNOWLEDGEMENTS

Authors greatly acknowledge the National University of Sciences and Technology (NUST), Pakistan for providing the research grant.

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