Desalination and Water Treatment
www.deswater.com

doi: 10.1080/19443994.2013.833880

52 (2014) 2933–2938
April

Taylor & Francis
Taylor & Francis Group

Performance of membrane bioreactor in presence of flocculants

Niloufar Nouri[a], Mohammad Reza Mehrnia[a,*], Mohammad Hossein Sarrafzadeh[a], Ramin Nabizadeh[b]

[a]*School of Chemical Engineering, College of Engineering, University of Tehran, Tehran 11155-4563, Iran*
Tel. +98 21 61112184; Fax: +982166954041; email: mmehrnia@ut.ac.ir
[b]*Department of Environmental Health Engineering, School of Public Health, Tehran University of Medical Sciences, Tehran 6446-14155, Iran*

Received 3 June 2013; Accepted 4 August 2013

ABSTRACT

This study focused on evaluating the effects of flocculant addition on the performance of membrane bioreactor (MBR). Two different flocculants, aluminum sulfate (alum) and polyaluminum chloride (PACl), were tested and the performance of MBR system in terms of COD removal, membrane fouling, and sludge properties was investigated. Addition of both flocculants resulted in significant reduction of membrane fouling rate and polyaluminum chloride was found more effective than alum. The sustainable filtration time at optimum dosage of alum and PACl was, respectively, 2.5 and 4.2 times more than that in control MBR which had no flocculant. Additionally, sludge oxygen uptake rate (OUR) improved in the presence of both flocculants and average OUR values obtained from flocculant-added membrane bioreactors was about 1.5 times more than that in control MBR. The results also revealed that there were no significant difference in COD removal of flocculant-added MBRs and control MBR and the treatment in all the three MBRs led to high COD removal efficiencies.

Keywords: Flocculant; Fouling; Membrane bioreactor; Trans-membrane pressure

1. Introduction

Membrane bioreactor (MBR) is considered as one of the most promising technologies for wastewater treatment because of many advantages over conventional activated sludge processes. The most important barrier to widespread application of MBR in wastewater treatment is membrane fouling [1]. Membrane fouling increases the capital and operational costs since more frequent backwashing, high aeration rate, and chemical cleaning is required [2]. Recently, various trials have been carried out to minimize the membrane fouling. The researches on membrane fouling can be classified as optimization of operating conditions; improvement of membrane characteristics; and modification of mixed liquor properties [3].

Mixed liquor in MBR can be divided into two phases: solids (flocs) and liquid (supernatant). It was reported that flocs could play a major role in cake resistance [4], so understanding the impact of mixed liquor properties on membrane fouling in MBR system is necessary to develop an effective solution for membrane fouling mitigation.

Coagulation/flocculation of activated sludge by adding chemicals and increasing floc size is a method to minimize membrane fouling [5]. Coagulants can effectively remove the undesirable inorganic and

*Corresponding author.

organic colloids (viruses, protein, polysaccharides with acidic groups in EPS and SMP) by clumping them together into larger flocs which would be rejected by a membrane. As a result, membrane performance with respect to fouling reduction and contaminant removal efficiency may increase [6]. The principal coagulants used in water and wastewater treatment include inorganic metal compounds and synthetic organic polymers. Since the addition of flocculants in MBR could modify the properties of mixed liquor by inducing changes in soluble, colloidal, and solid fraction, it is necessary to investigate the membrane fouling in the flocculant-added MBRs [7]. Wu et al. [8] reported that the addition of Fe^{3+} and Al^{3+} flocculants reduces the trans-membrane pressure (TMP) increase rate. Ji et al. [9] investigated the effects of three typical flocculants (aluminium sulfate, polymeric ferric sulfate, and chitosan) and found improvements in sludge filtration for all filter aids. These were attributed to a lower concentration of macromolecules in supernatant. Lee et al. [10] found that the soluble foulants in MBR were entrapped in sludge flocs through flocculation process. By analyzing the porosity and biovolume of the biofilm formed on the membrane surface, they proved that the addition of a cationic polymer resulted in more porous biofilm and improvement of filtration performance. Study by Ji et al. [7] also indicated that the addition of flocculants had significant impact on sustainable filtration time and in terms of filtration enhancement, polymeric flocculants exceed monomeric flocculants. Despite all these works, comprehensive assessment on the effects of flocculant on performance of MBR needs to be explored more.

The objective of this study is to investigate the effects of metal salt and polymeric flocculant on the performance of MBR in terms of COD removal, membrane fouling, and sludge properties.

2. Experimental

2.1. MBR setup and flocculation

Three submerged MBRs including a control MBR (without flocculant addition) were tested under similar operating conditions. The schematic diagram of MBR system is shown in Fig. 1. The effective volume of each bioreactor was 5 L. A flat sheet membrane module with membrane material of hydrophilic polyvinylidene fluoride and membrane pore size of 0.2 μm was used in each MBR. Each microfiltration system was fed continuously with synthetic wastewater as per the following composition: 1,680 mg/L glucose, 348 mg/L ammonium sulphate, 76.7 mg/L diammonium hydrogen phosphate. The COD: N: P ratio in feed was 100:5:1. In order to provide dissolved oxygen, compressed air was supplied continuously from the diffuser installed at the bottom of the reactors. A peristaltic pump (Heidolph, Germany) was used to obtain the constant permeate flux of 20 L/m^2h. A pressure gauge was employed to measure the TMP. The data of TMP were recorded once every 10 min on the computer. All bioreactors were filled with the activated sludge from the municipal wastewater treatment plant (the activated sludge had been adapted with synthetic wastewater for a month). Same initial mixed liquor suspended solids (MLSS) concentrations (6 gr/L) were kept in three MBRs at time = 0. It should be mentioned that the aeration rate and all other operating parameters were maintained at the same level in all three MBRs.

Two different types of flocculant including aluminum sulfate (alum) and polyaluminum chloride (PACl) were used in this study. In order to determine the optimum dosage of the flocculant, jar test trials were performed in six beakers filled with 500 mL of activated sludge according to standard method [11]. Jar test trials indicate the performance of each flocculant with respect to residual turbidity and hence an optimal dosage of flocculant could be estimated.

Samples were taken from supernatant near the top (1 cm from the top) of the beaker to be able to quantify the efficiency of each flocculant. The turbidity of the supernatants was measured with a spectrophotometer (Merck Co.). The optimal dosage was considered as the flocculant dose which resulted in the lowest turbidity concentration or the lowest dosage above which the decrease of residual turbidity was negligible.

We measured the residual turbidity to determine the optimum dosage of the flocculants because better coagulation results in better settleability and less residual turbidity. As mentioned before, flocs could play a major role in cake resistance and coagulation/flocculation of activated sludge by increasing the floc size is a method to control membrane fouling.

In the next stage of experiments, the optimum dosage of flocculant was used to investigate the performance of MBR in terms of COD and turbidity of permeate, membrane fouling, and sludge properties. In each MBR test, the time when TMP value reaches to 400 mbar was considered as the end of the experiment and all parameters are measured in this duration of time.

2.2. Analytical methods

2.2.1. Sludge properties

MLSS and mixed liquor volatile suspended solids were measured according to standard methods [12].

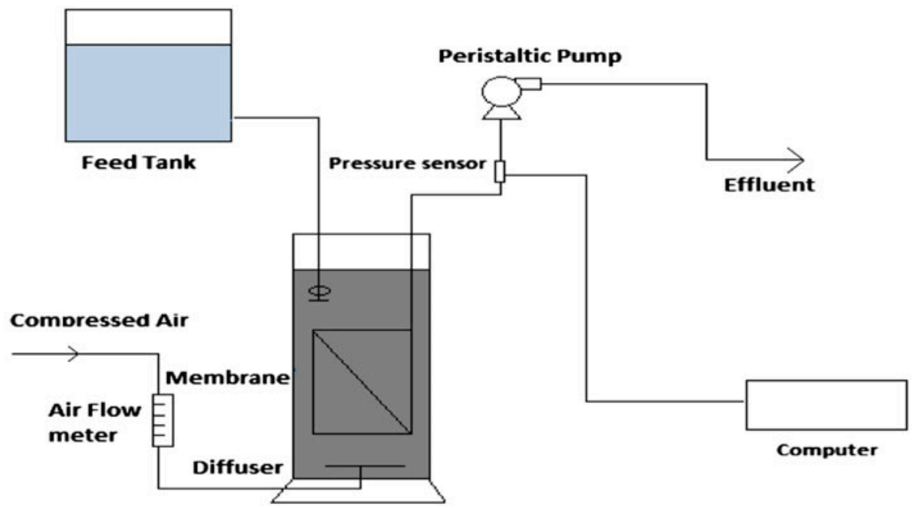

Fig. 1. Schematic diagram of the membrane bioreactor system.

The microbial activity during operation of each MBR was evaluated by measuring the oxygen uptake rate (OUR). A DO sensor (WTW-Multi 340i) was used to measure oxygen consumption in order to assess the sludge activity.

2.2.2. *Analysis of COD and turbidity*

COD was measured by photometric method called Spectroquant cell test (Merck). In order to measure turbidity, spectrophotometer (Spectroquant Multy, Merck Co.) was used. Spectrophotometric turbidity measurements sometimes referred to as absorbtometric or attenuation turbidity are useful to indicate relative values or to monitor changes in turbidity with time. The turbidity results are reported in formazin attenuation units (FAU) [13].

3. Results and discussion

3.1. *Jar test trial results*

The results obtained from jar test trials with alum and PACl are presented in Figs. 2 and 3. The dosage of 250 mg/L and 100 mg/L was considered as the optimal dosage for alum and PACl, respectively. It should be noted that insignificant pH drop was observed in optimum dosages of both flocculant.

3.2. *Effect of flocculant addition on membrane fouling rate*

The filtration performance of three MBRs was investigated at constant flux of 20 L/m^{2}h. Filtration in alum- and PACl-added MBR was conducted at the optimum dosage which was obtained from jar test.

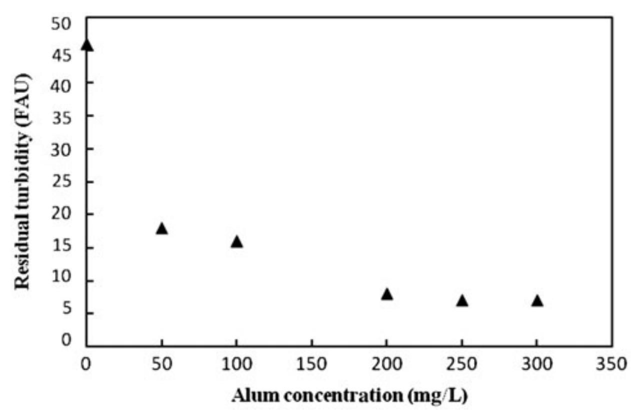

Fig. 2. Residual turbidity in different concentration of alum.

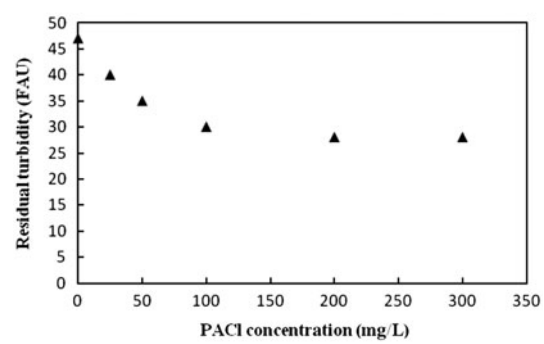

Fig. 3. Residual turbidity in different concentration of PACl.

As shown in Fig. 4, adding flocculant had significant impact on membrane fouling rate. In alum-added MBR, it takes 239 h for TMP to reach to 400 mbar. But in control MBR, TMP reaches to

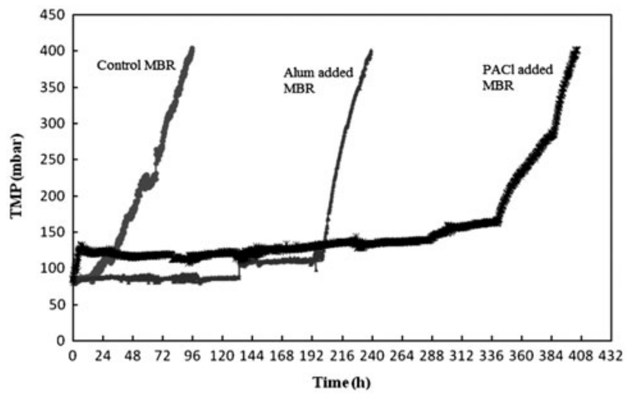

Fig. 4. TMP profile of control and flocculant-added MBRs.

400 mbar after 95.5 h. So the sustainable filtration time was nearly 2.5 times more than that in control MBR. The longest sustainable filtration time was observed in the PACl-added MBR in which TMP value reaches to 400 mbar after 403.5 h. So, the polymeric flocculant resulted in lower fouling rates as compared to the metal salt. It can be concluded that the addition of alum and PACl can reduce the membrane fouling tendency because flocculants lead to make bigger flocs and more porous cake layer on the surface of membrane. Mitigation of membrane fouling in the presence of flocculant is also due to the disappearance of some small particles and colloids from the mixed liquor [14,15]. Colloids contribute to membrane fouling by various mechanisms including pore blocking, pore constriction, or cake formation depending on their size relative to the membrane pore size [16]. In a similar experimental study by Ji et al. [9], the flux enhancement in MBRs with the addition of three kinds of filter aids was investigated. They reported that the addition of flocculants (alum, PFS, and chitosan) in MBRs could lead to the reduction of the fouling rate for both short-term operation conducted at 40 L/m^2 h and long-term operation conducted at 20 L/m^2 h. Their results of GPC, FTIR, and batch experiments demonstrated that the fouling from pore blocking, gel layer, and cake layer were all reduced in the filter aids added MBRs. Gue et al. [14] also investigated the effects of three flocculants including PACl on the membrane fouling rate in a submerged MBR and they reported that the inorganic polymeric flocculants had better ability of mitigating membrane fouling. Their results also revealed that the flocculant addition reduces some small particles, colloids, and SMP (soluble microbial product) in mixed liquor resulting in the enhancement of filterability. The results of a recent experiment conducted by Mehrnia et al. [17] also showed that the presence of cations in MBR removes colloids, soluble biopolymers, and induces bioflocculability of activated sludge resulting in fouling mitigation in MBRs.

3.3. The performance of MBR in terms of COD removal

COD removal was compared with and without flocculant addition. (Influent COD = 1,800 mg/L). Fig. 5 shows COD removal efficiencies in flocculant-added and control MBR. As can be seen from the results, there is only little difference between the removals with and without adding alum and PACl.

3.4. The role of membrane in COD removal by measuring the ratio of permeate COD to supernatant COD

In Fig. 6, the ratios of permeate COD to supernatant COD were compared in control and flocculant-added MBRs. The samples were taken from the outlet and supernatant of each MBR at the same time. We expected that permeate COD values are lower than supernatant COD values because the presence of microorganisms on the membrane surface can cause a little COD removal. So membrane also plays a role in COD removal. As shown in Fig. 6, the ratio of permeate COD to supernatant COD is less than one in three MBRs. So in all MBRs, the biofilm which exists on the membrane surface has also a role in COD removal. Mafirad et al. [18] also investigated the contribution of biofilm (formed on membrane) in COD removal. This research was conducted in submerged MBR for micro- and ultra-filtration of oily wastewater. Their results showed that the biofilm formed on membrane surface plays a significant role in COD removal.

3.5. Effect of flocculants on the permeate turbidity

Fig. 7 shows the permeate turbidity of control and flocculant-added MBRs presented at FAU. Turbidity,

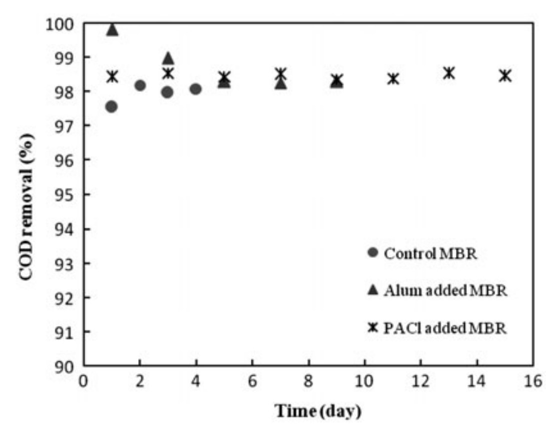

Fig. 5. COD removal in control and flocculant-added MBR.

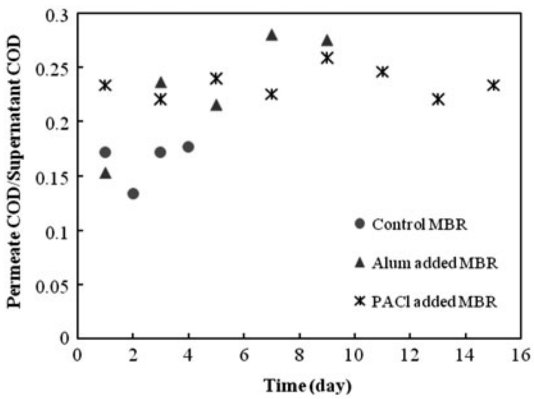

Fig. 6. Permeate COD to supernatant COD ratio in three MBRs.

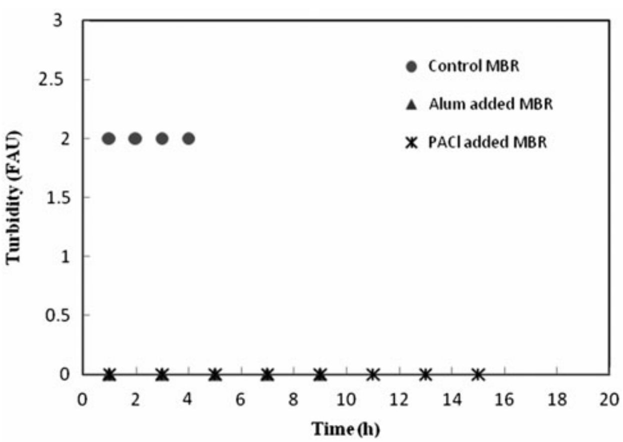

Fig. 7. Permeate turbidity in three MBRs during their operations.

which can make water appear cloudy, is caused by the presence of suspended and dissolved matter such as colloids [13]. Colloidal matter is defined as small non-settleable particles with size ranging from 1 nm to 1 μm [16]. The application of flocculants can decrease the concentration of colloidal matter through its formation of larger flocs which can't pass through microfiltration membrane. The results showed that the permeate turbidity in control MBR is 2 FAU. This amount of turbidity is mainly due to the presence of small particles or colloids in activated sludge mixture. In other experimental studies [19], similar values for permeate turbidity in microfiltration was reported and according to their results, the turbidity of water after filtration with 0.1 μm pore-sized membrane was reduced to 2 FAU.

The results of our experiments also revealed that, in the presence of alum and PACl, the permeate turbidity was reduced significantly because flocculants clump the small particles together into larger flocs which are not able to pass through membrane.

It should be mentioned that the turbidity was measured by spectrophotometric turbidity instrument which reports the result at FAU (formazing attenuated unit) [13].

3.6. Effect of flocculant addition on activated sludge properties

3.6.1. Sludge activity

Tests of activated sludge have been conducted using WTW-multi 340i. Fig. 8 shows OUR values during operating time in control and flocculant-added MBRs.

OUR values indicated that the flocculant addition led to the improvement in sludge activity. The average OUR value in control MBR is 20 mg/L.h, but this value in alum- and PACl-added MBR is 33 and 29.7 mg/L.h, respectively. So, it can be said that the sludge adaptation to wastewater improved in the presence of both flocculants. Gue et al. [14] also investigated the impact of flocculants on microbial activity in SMBR and they reported that regarding to OUR, all three different flocculants (chitosan, PACl and $FeCl_3$) showed significant improvements and the highest OURs was observed with chitosan.

3.6.2. MLSS production rate

Changes of MLSS concentration in three MBRs are shown in Fig. 9. These results indicated that there was no significant difference in MLSS production rate of three MBRs. It can be said that the flocculant addition had no negative influence on the growth of activated sludge.

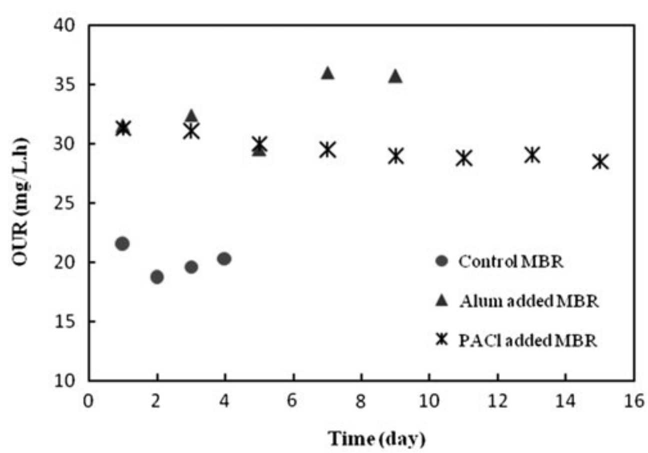

Fig. 8. Activated sludge OUR in control and flocculant-added MBRs.

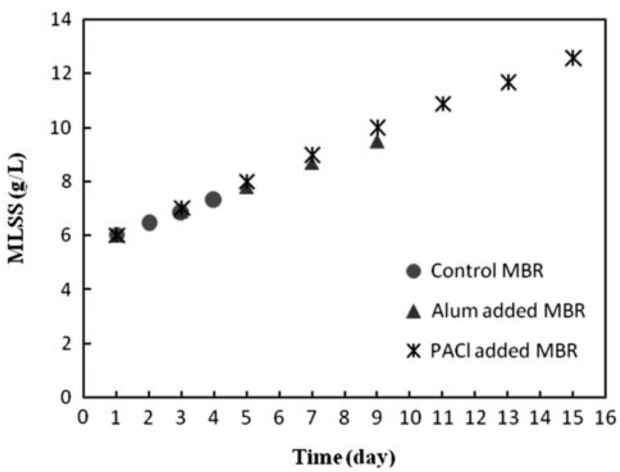

Fig. 9. MLSS concentration in control and flocculant-added MBRs.

4. Conclusions

The study evaluated the effect of aluminum Sulfate and polyaluminum chloride on the performance of MBR. The results indicated that:

(1) Addition of flocculants had significant impact on sustainable filtration time and reduced membrane fouling tendency. The sustainable filtration time at optimum dosage of alum and PACl was, respectively, 2.5 and 4.2 times more than that in control MBR. Therefore, in this study polymeric flocculant resulted in lower fouling rates as compared to metal salt.

(2) There was only marginal difference in COD removal in flocculant-added MBRs and control MBR and all three experiments resulted in high COD removal efficiencies.

(3) The permeate turbidity of flocculant-added MBR was lower than that of control MBR, because flocculation leads to decrease the concentration of colloidal matter by clumping them into larger flocs.

(4) Flocculant addition led to an increase in OUR which shows the improvement of microbial activity. The average OUR values in flocculant-added MBRs were approximately 1.5 times more than that in control MBR.

Acknowledgments

Authors would like to acknowledge the support of the University of Tehran for this research and also express their profound gratitude toward Hamed Azami & Farshid Shariati Pajoum for their technical contributions.

References

[1] W. Yang, N. Cicek, J. Ilg, Stage-of-art of membrane bioreactors: Worldwide research and commercial application in North America, J. Membr. Sci. 270 (2006) 201–211.
[2] T.O. Leiknes, H. Odegaard, The development of a biofilm membrane bioreactor, Desalination 202 (2007) 135–143.
[3] P. Le-Clech, V. Chen, A.G. Fane, Fouling in membrane bioreactors used in wastewater treatment, J. Membr. Sci. 284 (2006) 17–53.
[4] L. Deferance, M.Y. Jaffrin, B. Gupta, P. Paulier, V. Geaugey, Contribution of various constituents of activated sludge to membrane bioreactor fouling, Bioresour. Technol. 73 (2000) 105–112.
[5] H. Koseoglu, N.O. Yigit, V. Iversen, A. Drews, M. Kitis, B. Lesjean, M. Kraume, Effects of several different flux enhancing chemicals on filterability and fouling reduction of membrane bioreactor (MBR) mixed liquors, J. Membr. Sci. 320 (2008) 57–64.
[6] S.H. Yoon, J.H. Collins, D. Musale, S. Sundararajan, S.P. Tsai, G.A. Hallsby, J.F. Kong, J. Koppes, P. Cachia, Effects of flux enhancing polymer on the characteristics of sludge in membrane bioreactor process, Water Sci. Technol. 51 (2005) 151–157.
[7] J. Ji, J. Qiu, N. Wai, F.S. Wong, Y. Li, Influence of organic and inorganic flocculants on physical-chemical properties of biomass and membrane-fouling rate, Water Res. 44 (2010) 1627–1635.
[8] J. Wu, F. Chen, X. Huang, W. Geng, X. When, Using inorganic coagulants to control membrane fouling in a submerged membrane bioreactor, Desalination 197 (2006) 124–136.
[9] J. Ji, J. Qiu, F.S. Wong, Y. Li, Enhancement of filterability in MBR achieved by improvement of supernatant and floc characteristics via filter aids addition, Water Res. 42 (2008) 3611–3622.
[10] W.N. Lee, I.S. Chang, B.K. Hwang, P.K. Park, C.H. Lee, X. Huang, Changes in biofilm architecture with addition of membrane fouling reducer in a membrane bioreactor, Process Biochem. 42 (2007) 655–661.
[11] AWWA, Microfiltration and Ultrafiltration Membranes for Drinking Water, 1st ed., American Water Works Association, Denver, CO, 2005.
[12] APHA, AWWA, WEF, Standard Methods for the Examination of Water and Wastewater, 20th ed., American Public Health Association, Washington, DC, 1998.
[13] W.A. Chauncy, National Field Manual for the Collection of Water – Quality Data, (Chapter A6, 2005). Available from: http://water.usgs.gov/owq/FieldManual/Chapter6/Section 6.7_v2.1.pdf.
[14] W. Gue, H.H. Ngo, S. Vigneswaran, F. Dharmawan, T.T. Nguyen, R. Aryal, Effect of different flocculants on short-term performance of submerged membrane bioreactor, Sep. Purif. Technol. 70 (2010) 274–279.
[15] F. Meng, H. Zhang, F. Yang, S. Zhang, Y. Li, Y. Zhang, Identification of activated sludge properties affecting membrane fouling in submerged membrane bioreactors, Sep. Purif. Technol. 51 (2006) 95–103.
[16] H. Huang, K. Schwab, J.G. Jacangelo, Pretreatment for low pressure membranes in water treatment: A review, Environ. Sci. Technol. 43 (2009) 3011–3019.
[17] M.R. Mehrnia, H. Azami, M.H. Sarrafzadeh, Fouling mitigation in membrane bioreactors using multivalent cations, Colloids Surf., B 109 (2013) 90–96.
[18] S. Mafirad, M.R. Mehrnia, H. Azami, M.H. Sarrafzadeh, Effects of biofilm formation on membrane performance in submerged membrane bioreactors, J. Bioadhes. Biofilm Res. 27 (2011) 477–485.
[19] K. Fukushi, F. Kurisu, K. Oguma, H. Furumai, P. Fontanos, Southeast Asian Water Environment 4, IWA, London, 2010, pp. 153–158.