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Short Communication

Effect of support material pore size on the filtration behavior of dynamic membrane bioreactor

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ABSTRACT

The effect of support material pore size on the filtration behaviors during start-up and stabilized stages in the dynamic membrane bioreactors (DMBR) was studied. Before the dynamic membrane (DM) was formed, the turbidity at 50-μm could be more than 250 NTU, while it was less than 40 and 10 NTU at 25- and 10-μm, respectively. After the DM was formed, the stabilized stage lasted for 61 days with low transmembrane pressure < 0.6 kPa and the 5-, 10-, and 25-μm filters had similar effluent turbidity (< 1 NTU) and chemical oxygen demand. However, their averaged flux was 66.4, 25.1, and 3.5 $L \cdot m^{-2} \cdot h^{-1}$, respectively, suggesting that the 25-μm filter had significantly lower filtration resistance. Consequently, to avoid unallowable high effluent turbidity during start-up or after membrane cleaning and to achieve high flux with low pressure filtration, a mesh size of ~25 μm is more suitable for DMBR.

1. Introduction

To ensure the membrane bioreactors (MBRs) work properly, complicated operations are needed, e.g., backwashing and chemical cleaning, which lead to significant higher operation cost (Salerno et al., 2017). As a result, the application of MBR is still limited and the new installations of MBRs for large-scale wastewater treatment plant became decreasing since 2010 (except the situation in China) (http://www.thembrsite.com/). Some studies have focused on the development of dynamic membrane bioreactor (DMBR), which replaces the microfiltration or ultrafiltration membranes with cheap materials, e.g., stainless steel grids and polyester mesh (Chu et al., 2010; Hu et al., 2017; Huang et al., 2015). During the operation, an in-situ sludge cake layer or biofilm, named dynamic membrane (DM), will formed on the support material, which can achieve effective solids rejection at low transmembrane pressure (TMP) of 0.01–0.1 m water head loss (Hu et al., 2017). The DMBR has the major advantages of MBR, while it can achieve low pressure gravimetric filtration and the fouled membrane can be easily cleaned.

Previous studies on DMBR mainly focused on support materials with large pore sizes, generally ranging from 30 to 200 μm (Fan and Huang, 2002; Kiso et al., 2000; Li et al., 2012). The large pore size support materials could deteriorate the effluent quality during start-up stage or after membrane cleaning (Chu et al., 2008; Chu and Li, 2006; Fan and Huang, 2002; Kiso et al., 2000; Wang et al., 2012). They also required a relatively longer time, e.g., 0.3–24 h, to form an effective DM (Chu and Li, 2006; Liu et al., 2009; Wang et al., 2012). Due to the high SS in the initial effluent, the filtrate was necessary to be recycled back to the reactor before an effective DM was formed. The DMBR using large-pore support material could also have another problem of unstable effluent quality once the DM was detached. Above-mentioned problems may be resolved by using smaller pore size support materials (1–25 μm), which can possibly achieve both low pressure filtration and low effluent SS before DM is formed.

The objective of this study was to determine the effect of support material pore size (from 1 to 50 μm) on the filtration behaviors and effluent quality during start-up period (DM not formed) and under the stabilized conditions (DM formed).

2. Materials and methods

2.1. Filter design and reactor setup

The filter was made of stainless steel and wrapped with nylon mesh (Fig. 1(a)). Its outer diameter was 25 mm. Five mesh filters with averaged pore sizes of approximately 1, 5, 10, 25, and 50 μm were prepared. The lab-scale reactor (Fig. 1(b)) had five effluent outlets with flanged fitting on the reactor wall. The filters were submerged into the

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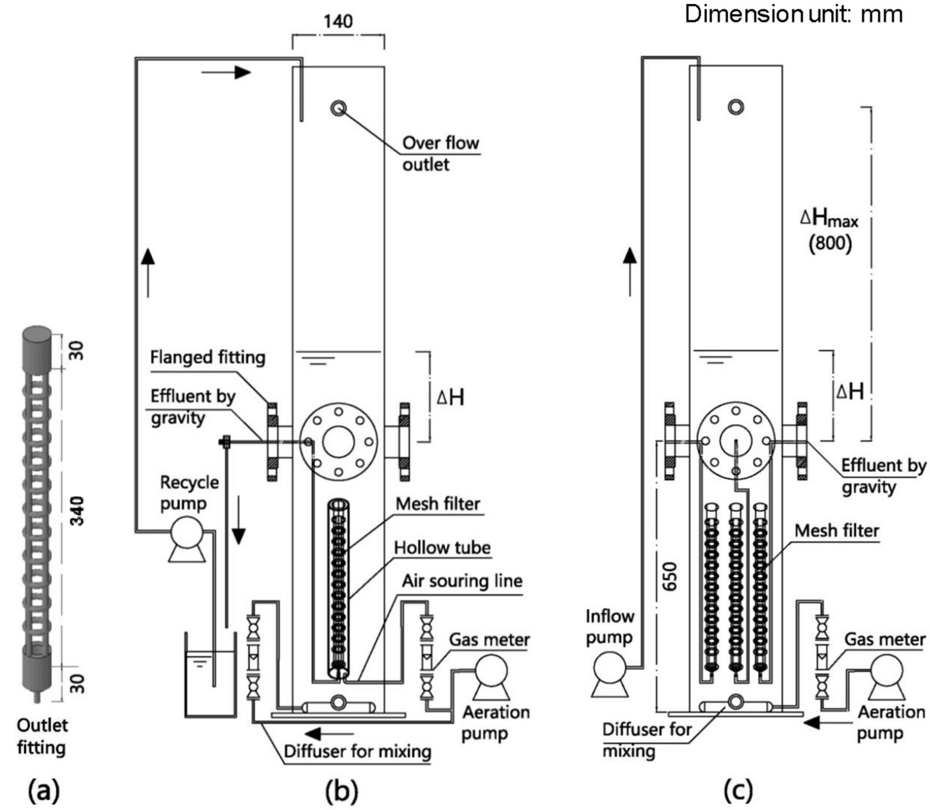

Fig. 1. (a) Frame of the mesh filter, (b) reactor setup for the screening test, and (c) reactor setup for the long-term test.

bioreactor and connected to the inner side of effluent outlet. The filtration process was driven by the water head loss between the bioreactor water level and the outlet (ΔH).

2.2. Screening test

A screening test was carried out to quickly evaluate the effect of pore size on the filter behavior during DM forming stage. As shown in Fig. 1(b), the mesh filter was inserted into an organic glass tube with inner diameter of 36 mm. At the bottom side of the hollow tube, there was an air tube outlet. This setting allowed the air scouring to be controlled more accurately and effectively. The five filters were installed into the reactor at the same level and connected to the five reactor effluent outlets with flanged fitting, respectively. So the performance of each filter could be evaluated independently under the same conditions.

A fresh activated sludge sample collected from a local municipal wastewater treatment plant was used for the screening test. Once the sludge sample was loaded, the effluent flow rate and turbidity from each filter were monitored with time. The effluent was returned back to the reactor immediately to maintain a constant water head loss of 5 cm. In this test, the MLSS was 3000 mg/L, the air scouring strength was 400 mL/min, and the temperature and pH were approximately 23 °C and 7–7.5, respectively.

2.3. Long-term test

According to the screening test results, the 5-, 10-, and 25-μm mesh filters were selected for the long-term test. The reactor setup was shown in Fig. 1(c). Once the reactor was seeded, it was fed continuously with synthetic wastewater at a constant flow rate of approximately 42 mL/min, which contained chemical oxygen demand (COD) and ammonia nitrogen (NH_3-N) concentrations of 180 mg/L and 33 mg-N/L, respectively. The COD and ammonia in the influent were provided with glucose and ammonium bicarbonate, respectively. Trace elements were added into the influent as well (Liu and Wang, 2015). The water temperature varied at 20–25 °C and DO was greater than 2 mg/L. The solids retention time (SRT) was controlled at approximately 40 days through daily biomass discharge.

The outflow rate and the turbidity from each filter and the water head loss were monitored daily. The effluent concentrations of COD and ammonia and the MLSS in the reactor were measured regularly. Along with membrane fouling, the water level in the reactor would increase to provide a greater TMP. Once the operation pressure reached 7.84 kPa, the long-term test ceased. Analytical methods for MLSS, COD and ammonia were described previously (Liu and Wang, 2012).

3. Results and discussion

3.1. Screening test results

During the screening test, the initial flux (the averaged flux in the first 0.5 h) for the 10-, 25-, and 50-μm filters were approximately 600 $L{\cdot}m^{-2}{\cdot}h^{-1}$ (Fig. 2(a)). For the 1- and 5-μm filters, however, the initial flux was only approximately 75 and 55 $L{\cdot}m^{-2}{\cdot}h^{-1}$, respectively. This suggested that when the pore size decreased from 10 to 5 μm, the filtration resistance increased dramatically. As shown in Fig. 2(b), the initial turbidity (the averaged effluent turbidity in the first 0.5 h) for the 50-μm filter was approximately 260 NTU. According to the correlation of SS and turbidity (SS = 1.463 × turbidity) (Fuchs et al., 2005), the initial SS was 380 mg/L. For the 25-μm filter, the initial effluent turbidity was only about 38 NTU. For the 10-, 5-, and 1-μm filters, very low initial turbidity of less than 10 NTU was detected, indicating that most of the particulates in the wastewater could be rejected at pore size below 10 μm without the formation of DM. With a pore size of 50 μm, however, the DM was needed to achieve effective solids rejection.

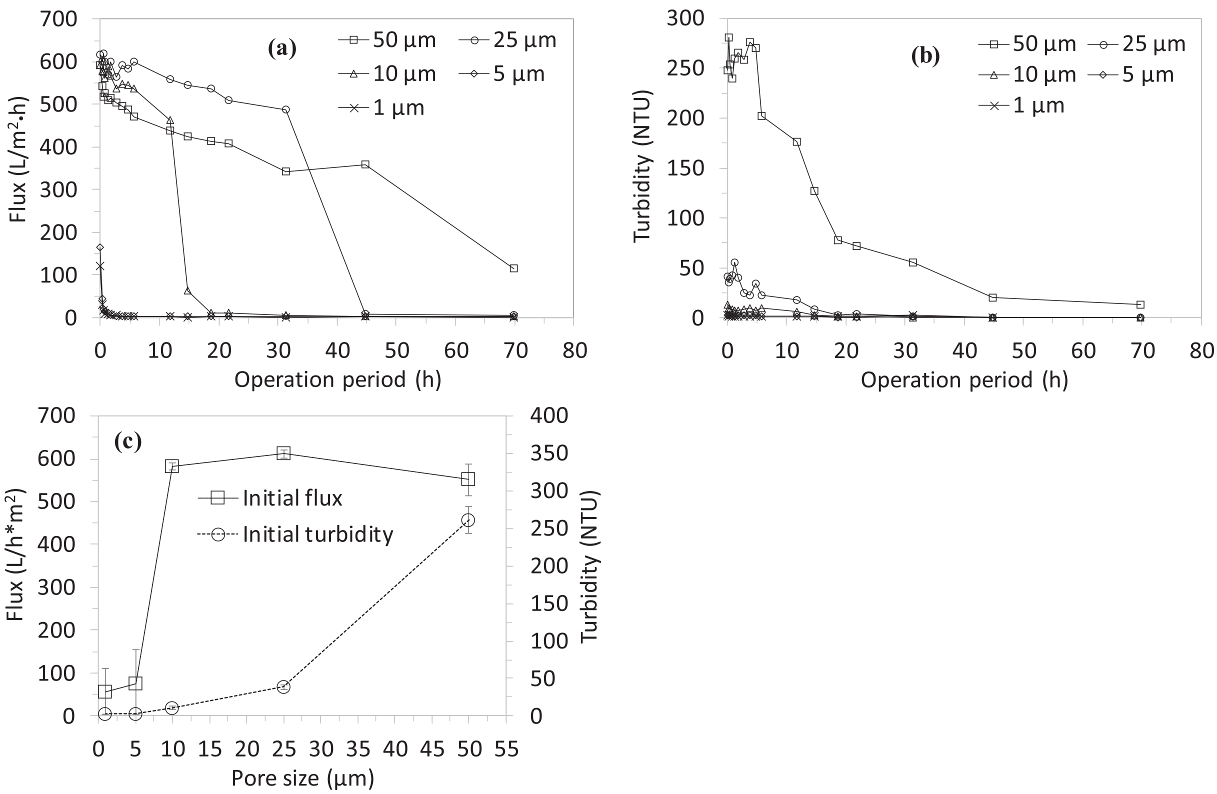

Fig. 2. Changes in the (a) flux and (b) filtrate turbidity for the mesh filters with different pore sizes during the screening test; (c) correlation between initial flux or initial turbidity and mesh filter pore size. Transmembrane pressure = 0.049 kPa, air-scouring strength = 400 mL/min.

3.2. Long-term test results

The screening test indicated that the initial turbidity for 50-µm filter was too high, while the flux for 1-µm filter was too low. Therefore, the 5-, 10-, and 25-µm mesh filters were selected for the long-term test. The long-term test lasted for nearly 80 days and the MLSS was 3000–5500 mg/L. As shown in Fig. 3(a), the TMP was maintained below 0.6 kPa during the first 61 days. Starting from the 62nd day, however, the water level in the reactor increased and gradually reached the maximum water head loss on 78th day (TMP = 8.2 kPa). The 25-µm filter was in operation at a very low TMP of 0.02 kPa (0.2 cm water head loss), while the 10-µm and 5-µm mesh filters start to run at a TMP of 0.04 kPa and 0.11 kPa, respectively (Fig. 3(b)). This suggested that the clean filter with a greater pore size had lower filtration resistance.

The reactor water level was mainly governed by the 25-µm filter during the long-term test since its flux was significantly higher than the other two filters (Fig. 3(b)). Though a low TMP of less than 0.6 kPa was maintained before the 61st day, interestingly, unlike other studies (Fuchs et al., 2005; Wang et al., 2012), the flux for the 25-µm filter did not decrease consistently during the whole test. For instance, the flux for the 25-µm filter decreased to 42 $L{\cdot}m^{-2}{\cdot}h^{-1}$ (TMP = 0.54 kPa) on the 19th day and increased back to 90 $L{\cdot}m^{-2}{\cdot}h^{-1}$ on the 45th day (TMP = 0.01 kPa). Correspondingly, its resistance increased from 6.6E + 08 to 3.3E + 10 in the first 19 days and then decreased to 2.8E + 08 on the 45th day (data not shown). This indicated that from the 19th to 45th day, the membrane fouling was mitigated significantly. In addition to regular aeration, no backwash and any other membrane fouling control measures were taken during long-term test. The DM was mainly composited of sludge cake layer and gel layer (Huang et al., 2015). The self-mitigation of membrane fouling from the 19th to 45th day was possibly caused by the detachment of sludge cake layer (including the biofilm) and/or the decay of gel layer.

As shown in Fig. 3(c), the effluent turbidity for 25-, 10-, and 5-µm filters were consistently low and their averaged values were 0.77 ± 0.33, 0.72 ± 0.37, and 0.72 ± 0.21, respectively. The low and similar effluent turbidity strongly indicated that, the filters had achieved effective solids separation and the DM formed on the 5-, 10-, and 25-µm support materials could have similar pore size for water filtration. The averaged effluent COD for the 25-, 10-, and 5-µm filters were 17.5 ± 2.9, 14.5 ± 2.0, and 16.2 ± 4.0 mg/L (Fig. 3(d) and (e)), respectively, suggesting that the pore size did not impact the effluent COD concentrations during the stabilized period. The low effluent COD and ammonia concentrations also confirmed that the DM had retained both heterotrophic biomass and nitrifiers effectively.

3.3. Implications

During the start-up stage before the DM was formed, the pore size of support material had a great impact on the initial effluent SS. At 50-µm, the initial turbidity could be more than 250 NTU (Fig. 2(c)). With a pore size from 70 to 500 µm, the initial SS concentration could be greater than 1000 mg/L (Kiso et al., 2000; Fan and Huang, 2002; Chu et al., 2008). In that case, the initial effluent had to be returned to prevent the excessive loss of biomass and accelerate the formation of DM (Chu et al., 2008; Fan and Huang, 2002; Fuchs et al., 2005). With a pore size of 25 µm or less, however, the initial turbidity would be less than 40 NTU. The initial effluent SS and the DM formation time were also affected by the air scouring strength, operational flux, and TMP (Chu et al., 2010; Kiso et al., 2000; Salerno et al., 2017). With a lower flux of 92.8 $L{\cdot}m^{-2}{\cdot}h^{-1}$ and moderate air scouring, the initial effluent turbidity could be less than 10 NTU for the 25-µm filter (Fig. 3(c)). For the fine-pore filters (≤ 10 µm), the formation of DM is not necessary to achieve excellent solids separation.

Fig. 3(e) indicated that the three filters (5-, 10-, 25-µm) had similar effluent turbidity during the stabilized stage when the DM was formed. With a pore size of 30–100 µm, the averaged effluent SS or turbidity during the stabilized stage were less than 5 mg/L or 10 NTU (Kiso et al., 2000; Fan and Huang, 2002; Fuchs et al., 2005; Chu and Li, 2006; Chu

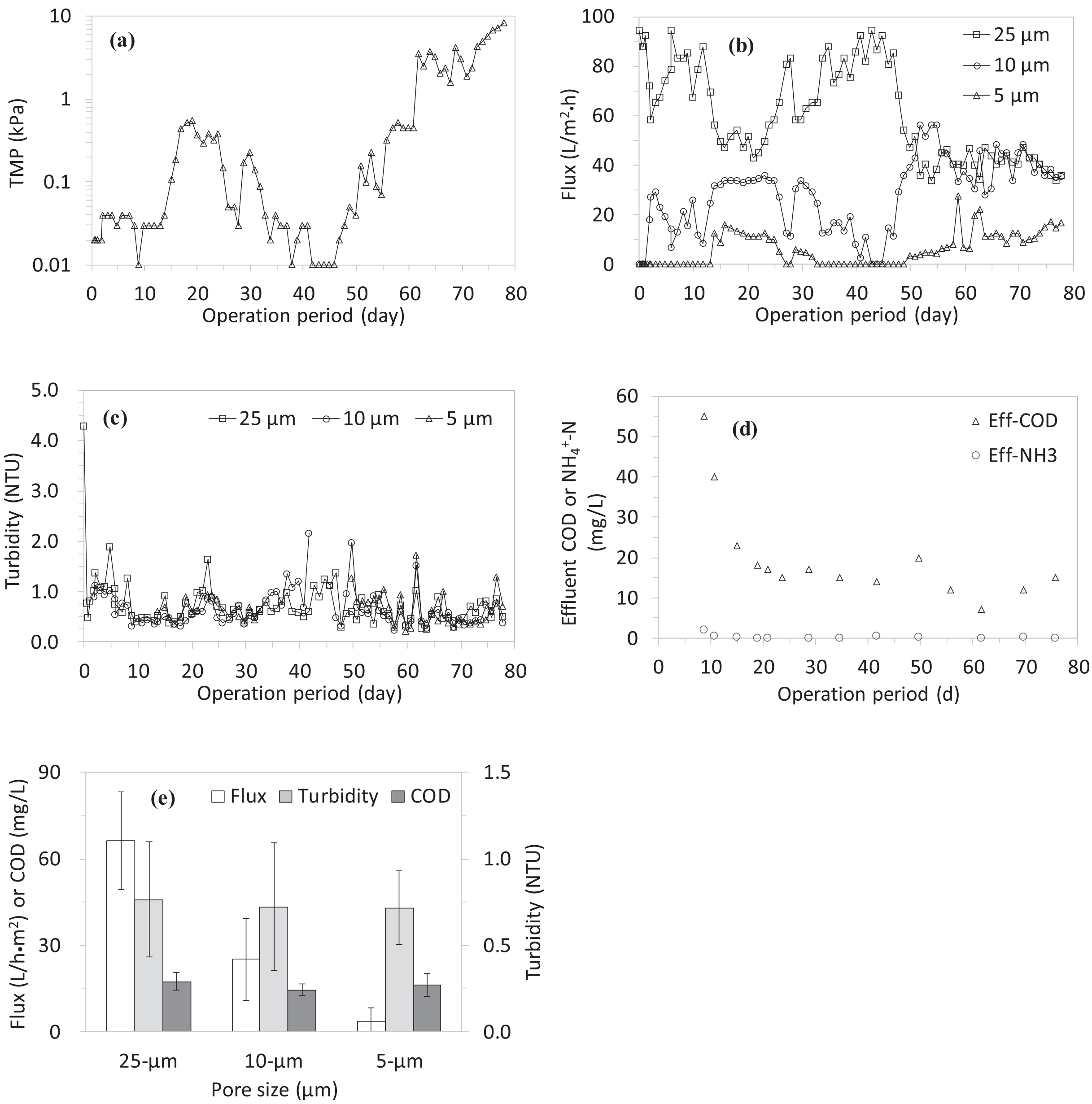

Fig. 3. Changes in the (a) transmembrane pressure (TMP), (b) flux, (c) effluent turbidity, and (d) effluent COD and ammonia concentrations during the long-term test; (e) average flux, turbidity, and COD for the mesh filters with different pore size during the stabilized stage from 2nd to 61st day (TMP = 0.14 ± 0.16 kPa).

et al., 2008; Wang et al., 2012; Li et al., 2012). For most cases, the averaged effluent SS or turbidity under the stabilized stage were less than 2 mg/L or 2 NTU (Kiso et al., 2000; Fan and Huang, 2002; Chu et al., 2008; Wang et al., 2012). Therefore, during the stabilized stage when the DM was formed, the pore size of support material (5–100 µm) did not have a great impact on the effluent SS or turbidity. The slight difference in the effluent turbidity from different experiments could be caused by the varying experimental conditions, e.g., wastewater characteristic, MLSS concentration, and air scouring strength.

When using pore sizes of 70–100 µm, the reported flux under the stabilized stage was in the range of 8.8–130 $L{\cdot}m^{-2}{\cdot}h^{-1}$ at a low TMP < 0.5 kPa (Kiso et al., 2000; Fan and Huang, 2002; Chu et al., 2008; Wang et al., 2012; Li et al., 2012). In our study, the averaged flux for the 25-µm filter was 66 $L{\cdot}m^{-2}{\cdot}h^{-1}$ during the stabilized condition and it lasted for about 60 days. Compared to 70–100 µm, the operation flux at 25 µm under the stabilized conditions was not reduced significantly. At pore sizes of 10 and 5 µm, however, their flux under the stabilized conditions was much lower than that of the 25-µm filter when tested in the same reactor (Fig. 3(e)). Please note that the advertised open area percentage for the 25-, 10-, and 5-um mesh were approximately 19%, 4%, and 1% respectively. The low flux for the 10- and 5-um filters was more likely caused by the mesh open area. Due to fabrication limitation of mesh materials, the open area for mesh size less than 10 µm could not be enlarged significantly, which was too small to be suitable for DMBR. Therefore, to avoid unallowable high effluent turbidity during start-up or after membrane cleaning and to achieve high flux with low pressure filtration, a mesh size of approximately 25 µm is more suitable for DMBR.

4. Conclusions

The initial turbidity at a mesh size ≥50 µm was too high, which could lead to significant biomass loss during start-up or after cleaning. Though a size ≤10 µm could achieve excellent solids rejection without assistance of DM, their flux was significantly lower than that of the 25-µm filter. The 25-µm filter had maintained an averaged flux of

66.4 $L \cdot m^{-2} \cdot h^{-1}$ at TMP < 0.6 kPa for two months without backwash or cleaning. Its effluent turbidity and COD were below 2 NTU and 20 mg/L, respectively. Therefore, a mesh size of approximately 25 μm is more suitable for DMBR.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.biortech.2018.02.007.

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