Application of Granular Sludge Membrane Bioreactor in the Treatment of Wastewater

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Abstract

The technology of aerobic granular sludge has the advantages of high biomass content, high biomass retention, strong ability to withstand shock-loadings, and capacity of simultaneous nitrogen and phosphorus removal; it is a promising option for efficient wastewater treatment. Membrane bioreactor (MBR) is a novel biotechnology for wastewater treatment, and has the potential advantages of low excess sludge production, small land requirement, and high loading rate capability. Thus, the combination of aerobic granular sludge technology and membrane bioreactor was proposed and became the research hotspot and frontier in the field of wastewater treatment. The background, operation characteristics and problems of the combination of the two technologies are discussed and summarized in this study. The latest research achievements and prospects are also presented.

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Keywords: Aerobic granule; Membrane bioreactor (MBR); membrane fouling; organic loading rate; wastewater

1. Emergence of Granular Membrane Bio-Reactor (GMBR)

Membrane Bio-Reactor (MBR) has attracted increased interests in recent years, due to its high effluent quality, small land requirement, high metabolic activity, low excess sludge production, strong ability to withstand shock-loadings and unfavorable environmental conditions, and particularly adaptable to automation. Extensive research has been done to investigate the basic theoretical issues. However, serious membrane fouling usually occurs after long operation time, and significantly reduces membrane performances and membrane life. Thus, the problem of membrane fouling has become the primary

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bottleneck hindering further development of the MBR process; membrane fouling control is the main research direction in the application of MBR technology [1, 2].

The major causes for membrane fouling include properties of membrane materials, operational conditions of reactor, characteristics of activated sludge, etc. While, characteristics of activated sludge has the remarkable effect on membrane fouling progress [3]. In the activated sludge system, microorganism populations and its metabolites, solid and colloidal particles, and soluble macromolecule (such as extracellular polymeric substances (EPS) and soluble microbial products (SMP)) become the substances absorbing to or settling on the surface and inner holes of membrane under physicochemical interaction or mechanical force, which compresses or even blocks the pore for permeation, finally causes irreversible deterioration of permeating flux and separation performances of membrane [4, 5]. Therefore, adjustment and improvement of sludge characteristics has been considered as the significant effective approach for membrane fouling control. Powdered activated carbon and flocculants have been applied to decrease the compressibility of sludge flocs, enlarge the porosity of sludge layer on the membrane surface, and further improve the membrane permeate flux [5-7]. Some novel packing has also been used for attached growth of microbial, so as to decrease the concentration of suspended sludge, and alleviate membrane fouling in MBR system [8]. In summary, certain spatial scale and strength of activated sludge in the MBR should be guaranteed to encourage the excellent separation of slurry, mitigate membrane fouling and improve the MBR performance.

2. Characteristics of GMBR

Above analysis indicates that GMBR has great advantages over those of conventional biological treatment processes. However, up to now, information on application of GMBR in the wastewater treatment is very limited. The latest research achievements and prospects were presented in this paper.

Wang [5] used glycogen accumulating organism (GAO) granules, cultivated by flocculent activated sludge in an anaerobic-aerobic sequencing batch reactor (SBR), as inoculation to investigate the organics, nitrogen, phosphate removal performances and simultaneous nitrification, denitrification and phosphate removal characteristics, mechanism and effect factors in continuous granular sludge membrane bioreactor (CGMBR) and sequencing batch granular sludge membrane bioreactor (SBGMBR). The seed granular sludge appeared gray black, with the size of 0.8-1.5 mm, and the morphology of granules was nearly spherical or elliptical, with dense structure and clear outline under the optic microscope and environmental scanning electron microscope [9]. Its SVI was 30-40 mL/g. CGMBR was stably operated for 71d; TOC, ammonium and total nitrogen removal efficiencies in the system were 85%-92%, 85.4%-99.7% and 41.7%-78.4%, respectively. The percentage of granules with diameter larger than 0.18mm was 52%-60% throughout the experiment. Cake layer in the CGMBR contributed to 77.8% of the total membrane fouling resistance. With compared to the cake layer sludge, mixed liquor sludge had better properties, with respect to the size distribution, surface charge, specific resistance to filtration (SRF) and EPS. X-ray electron spectrometer (XPS) results of membrane surface fouling in the CGMBR indicated that the carbon combination bonds of membrane surface fouling were mostly consisted with $R\overline{\text{C}}\overline{\text{H}}$ and $R\overline{\text{C}}\text{═O}$ [5]. In comparison, SBGMBR was stably operated for 120d, with excellent simultaneous organics, nitrogen and phosphate removal performances driven by intracellular storage polymer. During steady state operation, TOC, ammonium, total nitrogen, and phosphate removal efficiencies were 65.7%-98.6%, 85.4%-98.9%, 66.1%-95.1% and 60%~80%, respectively. Remarkable SND performance was achieved. The percentage of granules with diameter larger than 0.18mm was 60%-65% in the SBGMBR. In comparison with CGMBR, cake layer fouling and cake layer sludge properties of SBGMBR were both better than CGMBR [5].
Li et al. used aerobic granular sludge, cultivated from anaerobic granular sludge, as inoculation to develop a membrane bioreactor with aerobic granular sludge (MGSBR), which was used to treat municipal wastewater [10-13]. The feasibility of the MGSBR for wastewater treatment and membrane fouling was examined in detail. Results indicated that COD removal efficiency was 80-95% under the conditions of HRT of 6h, DO of 4-6mg/L, organic loading rate of 7.2kg/(m³·d). When the NH₃-N loading rate was 0.17kg/ (m³·d), SND was achieved with the NH₃-N removal efficiency around 60%. MLSS in the MGSBR remained at 14-16g/L under stable operational stages, with the granule size around 2.0mm. There was an overgrowth of filamentous bacteria due to the combined effects of continuous aeration mode, reduced DO concentration, long SRT and high EPS concentration, SVI increased to 70±10mL/gSS, which caused the poorer settling ability of aerobic granules. VSS/SS ratio and OUR declined slightly caused by the effect from accumulation of microbial metabolites. When aerobic floc sludge was used as inoculums in a conventional MBR (MFSBR) system to treat artificial wastewater, aerobic biogranule with average diameter of 0.5 mm emerged on day 21 of operation, and grew to 1.2 mm on day 31. The appropriate polysaccharides/proteins ratio was 0.6:1.0 for aerobic granulation in MBR system. The sludge/supernatant EPS ratio of 44-45 and 110-130 mg/gMLSS of the total EPS amount were favourable for biogranulation [13]. In addition, comparison between MGSBR and MFSBR showed that the membrane permeability of MGSBR was more 50% higher than that of MFSBR. The cleaning recovery of hydraulic cleaning in membrane flux from the MGSBR was 87.7%, which was near 10% lower than that of MFSBR system. However, the chemical cleaning could remove most of blocking substances on the membrane surface and within the pores with the recovery of near 100% [10].

Zhang and Zhou [14] utilized conventional floc sludge as inoculums to investigate the formation, characteristics and organic and nitrogen removal performances of aerobic granules in membrane bioreactor (MBR) at different organic loadings of 0.47, 1.68 and 3.36 kg/(m³·d). Experiment results showed that no granules formed in the MBR at organic loading of 3.36 kg/(m³·d). In comparison, yellow globular aerobic granules formed in the MBR at organic loadings of 0.47 and 1.68 kg/(m³·d), under the operational conditions: DO of 0.3-0.5mg/L, SRT of 45d, reaction temperature of 25℃, pH of 7.0-8.0. The diameter of the largest granules was 4mm; relative density of the granules was 1.05; settling velocity of the granules was 20-71m/h; MLVSS/MLSS was 0.97, higher than 0.8 of seed sludge. TN removal efficiencies in the MBR at organic loadings of 0.47 and 1.68 kg/(m³·d) were 27%-90% and 39%-47.7% respectively, higher than 6.8%-23.6% in the MBR at organic loading of 3.36 kg/(m³·d), with no granule existing.

Short-term membrane fouling between aerobic granular sludge system and activated sludge system were investigated in the literature [15, 16]. The results showed that resistance of the cake layer accounted for 72.68% of the total membrane fouling resistance in the activated sludge MBR system. In comparison, fouling resistance accounted for 44.2% of the total membrane fouling resistance in the aerobic granular sludge MBR system, higher than the percentage of cake resistance. Thus, it is reasonable to consider that the large size of granules could alleviate the formation of cake layer, and mitigate the severe membrane pore-blocking.

Tay et al. operated a novel aerobic granular sludge membrane bioreactor (AGMBR) for four months. The average diameter of the aerobic granules was about 0.7mm. When the transmembrane pressure (TMP) increased by 8-fold from 5KPa, the membrane permeability loss was 34.5% with AGMBR mixed liquor, or 1.68-fold lower than that of a traditional submerged membrane bioreactor (SMBR). When the membrane flux increased by 3-fold from 20L/ (m²·h), the membrane permeability loss was 2.4% with AGMBR mixed liquor, or 21-fold lower than that of SMBR [17].
3. Application prospect of GMBR

Above case studies of GMBR showed that formation or cultivation of aerobic granules in a MBR can effectively mitigate membrane fouling, improve the permeate flux, ensure the longer membrane life, and further cut down the operating costs and energy consumption. Meanwhile, simultaneous nitrogen of phosphorus removal can be realized in the multiple microenvironments of aerobic granules. Thus, GMBR has great applied potentialities, deserves great attention and deep investigation in the future.

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