Development of Aerobic Granular Sludge Membrane Bioreactor (AGMBR) for Wastewater Treatment and Reclamation

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INTRODUCTION

The membrane bioreactor (MBR) technology is a compact and efficient technology for wastewater treatment and reclamation. An MBR combines conventional activated sludge and membrane filtration for liquid-solids separation. The technology offers the unique advantages of high-quality effluent, higher organic loading rates (OLR), long solids retention time, low sludge production, small footprint, and potential for nitrogen removal [1,2]. MBRs have been successfully used for the treatment and reclamation of both municipal and industrial wastewaters [3,4].

However, MBRs are limited by membrane fouling [5] which reduces membrane performance and lifespan, resulting in a significant increase in operating and maintenance (O&M) cost [6]. Bacteria and their by-products, extracellular polymeric substances (EPS), are major contributors to membrane fouling [5,7].

To mitigate membrane fouling, current research is focused on coupling a novel biotechnology - aerobic granular sludge - with MBR to enhance system performance. Research in this direction is gradually developing the aerobic granular sludge membrane bioreactor (AGMBR) technology. AGMBR offers the distinct advantage of utilising EPS for granule formation; and once formed, the granules provide a surface for bacteria to attach to rather than the membrane surface. This presentation provides an overview of the development of AGMBR and the status of current research.

AEROBIC GRANULAR SLUDGE

Aerobic granulation is the process of microbe-to-microbe self immobilisation without any biocarriers [8, 9]. The resulting granules are dense microbial consortia containing millions of organisms per gram of biomass and with several microbial species that can collectively degrade pollutants in wastewater [10, 11].

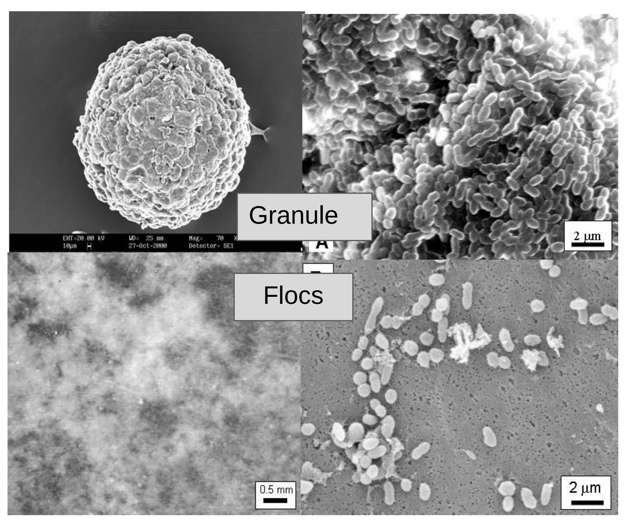

Figure 1 – Granules vs Flocs

Advantages of granular sludge [9 - 11]

- Improved settleability
- High biomass retention
- Diverse microbial community
- Small footprint requirement
- Resistance to toxic compounds
- High removal efficiency
- Short hydraulic retention time (HRT)
- High organic loading rate
- Low sludge growth yield

MATERIALS AND METHODS

A semi-pilot scale cylindrical reactor with high height-to-diameter (H/D) ratio was used for granule formation. The reactor had a working volume of 20 L and a diameter of 15 cm. The system was operated in SBR mode with 50% volumetric exchange ratio and 4 hours cycle time, giving HRT of 8 hours. Fine air bubbles were supplied at the bottom of the reactor at a superficial upflow air velocity of 3 cm/s.

The system was seeded with activated sludge. Synthetic wastewater containing sodium acetate as the carbon source was used. The initial OLR was 9.0 kg COD/m^3·day. The OLR was reduced to 5.5 kg COD/m^3.day after about one month of operation.

COD was determined using Hach kits. Total organic carbon (TOC) and total nitrogen (TN) were analyzed using Shimadzu TOC Analyzer (TOC-L) and Shimadzu TN Measuring Unit (TNM-L), respectively. PO_4-P was analyzed using Metrohm Compact IC Flex.

Figure 3 – Aerobic granular reactor: working volume 20 L

FOULING MITIGATION IN AGMBR

- In AGMBR, EPS are utilised in granule formation
- The granules provide a surface for bacteria to attach to rather than the membrane surface
- The large size and rigid granule structure reduces:
  - cake-layer formation
  - pore blocking
  - membrane surface deposition

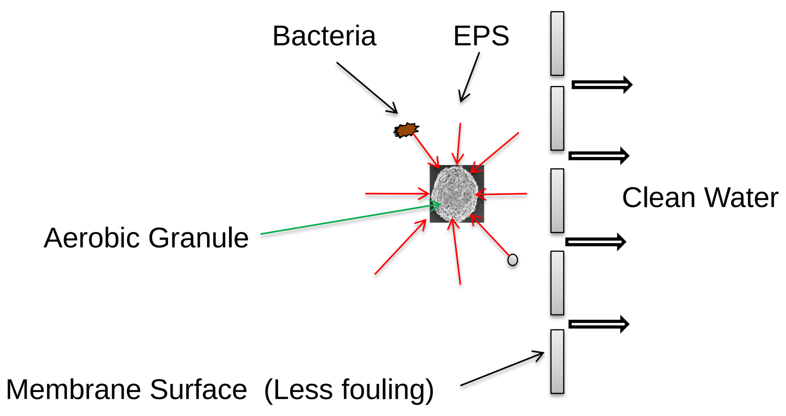

Figure 2 – Mechanism for fouling abatement in AGMBR

Table 1 below presents AGMBR research findings on membrane fouling mitigation as reported in the literature.

Table 1 – Reported performances of AGMBR

†COD Conc. (mg/L)	Membrane fouling mitigation	COD removal efficiency (%)	Ref
*300 ±150	membrane permeability was > 50% higher than MBR	80 – 95	[12]
*2000	AGMBR exhibited much better filtration with membrane permeability loss being twice as low as that of the conventional MBR	99	[13]
*2000	Reduced membrane fouling in MBR when aerobic granules were introduced into the MBR system. This is attributable to the bounding of secreted EPS to the granules, hence low soluble EPS in the supernatant.	> 85	[14]
*500	Improved membrane performance in AGMBR (indicated by fouling rate being continuously below 0.1 kPa/day at MLSS > 18,000 mg/L)	93.8 - 98.4	[15]
300 ± 25	Membrane fouling rate (TMP rise) was about 8 times lower in AGMBR than MBR with flocculent sludge	-	[16]

*†COD = Chemical Oxygen Demand; *synthetic wastewater*

- Other reported findings on AGMBR include:
  - stable operation at 20 L/m^2.h for 61 days with significantly improved filtration [17];
  - extension of filtration period by 78 days without physical cleaning [18]; and
  - remarkable fouling control with 99% organics removal [19].

However, disintegration of the granule structure in long-term operation is a key problem [9]. This disintegration increases the concentration of soluble EPS (soluble microbial products - SMPs), hence increase in membrane fouling [19, 20].

RESULTS AND DISCUSSION

Granules started to form from day 3 of operation. The reactor became predominantly granular by day 10 (i.e. mean size of granules >200 μm). At steady state, the compact granules had an average diameter of ~ 576 μm.

Figure 4 – Granules formed in the lab

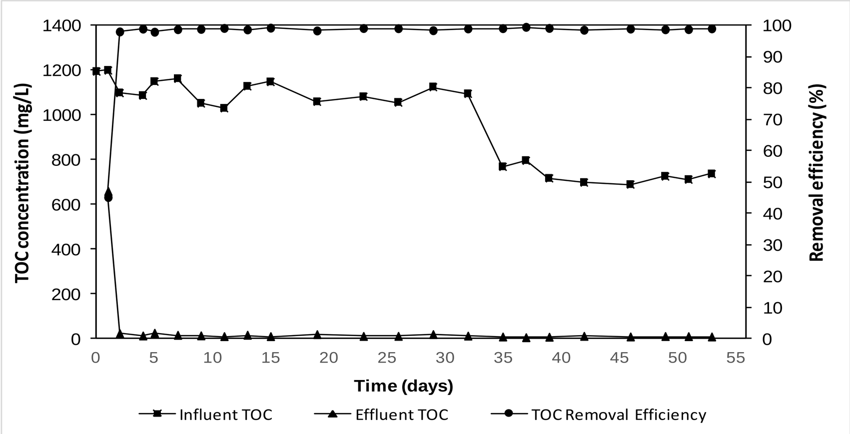

Figure 5 – TOC removal profile

- The system exhibited >97% organics removal (indicated by TOC).
- TN removal was consistently in excess of 98%. With increased influent TN, the removal efficiency dropped for a few days but recovered back to >98%.
- Remarkable PO_4-P removal (~99%) was achieved. This is attributable to the layered granular structure.

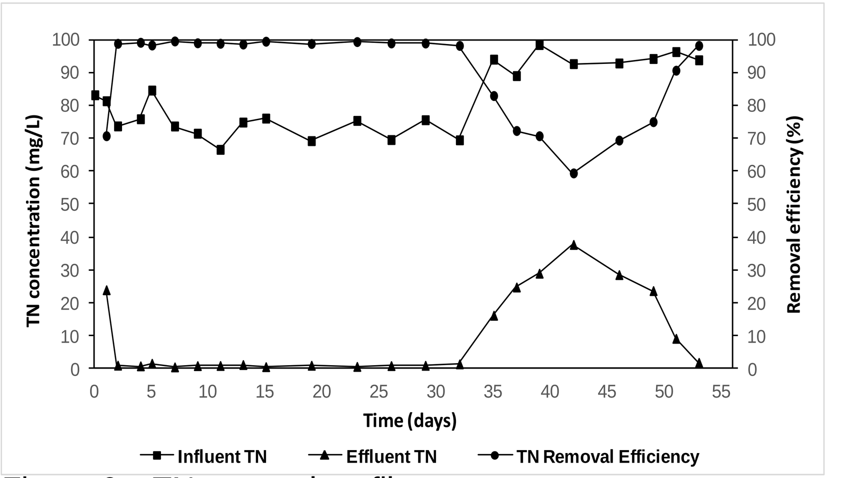

Figure 6 – TN removal profile

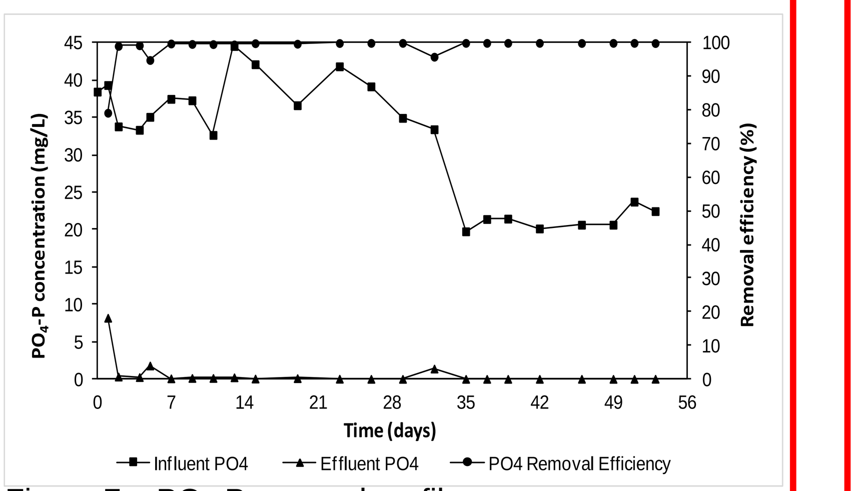

Figure 7 – PO_4-P removal profile

CONCLUSIONS AND FUTURE WORK

The integration of aerobic granular sludge and membrane filtration offers a compact wastewater treatment and reclamation technology, AGMBR. Granule formation in AGMBR mitigates membrane fouling, thus, lowering O&M costs. AGMBR offers:

- membrane fouling mitigation (reduced O&M costs)
- complete wastewater reclamation;
- simultaneous organics and nutrients (N & P) removal in entirely aerobic conditions; and
- a compact technology with small footprint.

Future work involves the determination of optimal operational conditions for membrane fouling mitigation, simultaneous organics and nutrients removal, and enhancement of granule stability in long-term operations. Experiments will be conducted in both side-stream and submerged AGMBR configurations.

References:

[1] Metcalf & Eddy Inc., *et al.* (2014). *Wastewater Engineering: Treatment & Resource Recovery.* New York, MGraw-Hill.
[2] WEF. (2011). *Membrane Bioreactors: Water Environment Federation (WEF) MOP No. 36.* New York, McGraw-Hill.
[3] Le-Clech, P., Chen, V., Fane, T. A. G. (2006). *J. Membr. Sci.*, 284(1–2): 17-53.
[4] Mutamim, N. S. A., Noor, Z. Z., Hassan, M. A. A., Yuniarto, A., Olsson, G. (2013). *Chem. Eng. J.*, 225: 109-119.
[5] Meng, F., Chae, S.-R., Drews, A., Kraume, M., Shin, H.-S., Yang, F. (2009). *Water Res.*, 43(6): 1489-1512.
[6] Chang, I., Le Clech, P., Jefferson, B., Judd, S. (2002). *J. Environ. Eng.*, 128(11): 1018-1029.
[7] Lin, H., Zhang, M., Wang, F., Meng, F., Liao, B.-Q., Hong, H., Chen, J. (2014). *J. Membr. Sci.*, 460: 110-125.
[8] Tay, J.-H., Liu, Q.-S., Liu, Y. (2001). *J. Appl. Microbiol.*, 91: 168 – 175.
[9] Adav, S. S., Lee, D.-J., Show, K.-Y., Tay, J.-H. (2008). *Biotechnol. Adv.*, 26(5): 411-423.
[10] Tay, J.-H., Liu, Y., Tay, S.-L., Hung, Y.-T. (2009). Aerobic Granulation Technology. In *Advanced Biological Treatment Processes*. L. Wang, N. Shammas and Y.-T. Hung, Humana Press. 9: 109-128.
[11] Liu, Y.; Tay, J.-H. (2004). *Biotechnol. Adv.*, 222(7): p. 533-563.
[12] Li, X., Gao, F., Hua, Z., Du, G., Chen, J. (2005). *Sep. Purif. Technol*, 46(1–2): 19-25.
[13] Tay, J. H., Yang, P., Zhuang, W. Q., Tay, S. T. L., Pan, Z. H. (2007). *J. Membr. Sci.*, 304(1–2): 24-32.
[14] Yu, G.-H., Juang, Y.-C., Lee, D.-J., He, P.-J., Shao, L.-M. (2009). *J. Taiwan Inst. Chem. Eng.,* 40(4): 479 - 483.
[15] Tu, X., Zhang, S., Xu, L., Zhang, M., Zhu, J. (2010). *Desalination*, 261(1–2): 191-196.
[16] Sajjad, M., Kim, I. S., Kim, K. S. (2016). *J. Membr. Sci.,* 497: 90 - 98.
[17] Wang, Y., Zhong, C., Huang, D., Wang, Y., Zhu, J. (2013). *Bioresour. Technol.*, 136: 488-495.
[18] Thanh, B. X., Visvanathan, C., Ben Aim, R. (2013). *Int. Biodeterior. Biodegrad.*, 85(0): 491-498.
[19] Vijayalayan, P., Thanh, B. X., Visvanathan, C. (2014). *Int. Biodeterior. Biodegrad.*, 95: 139 – 143.
[20] Thanh, B. X., Visvanathan, C., Spérandio, M., Aim, R. B. (2008). *J. Membr. Sci.,* 318(1–2): 334-339.

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