A Review on Development of Aerobic Granular Sludge Membrane Bioreactor for the Industrial Effluent Treatment

Rakshanda M Ingale*, Sanjaykumar R Thorat

School of Environmental and Earth Sciences, Kavayitri Bahinabai Chaudhari North Maharashtra University, Jalgaon, Maharashtra, INDIA.

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ABSTRACT

The technology of aerobic granular sludge and Membrane Bioreactor (MBR) were combined to develop an Aerobic Granular Sludge Membrane Bioreactor (AGMBR). Biomass content is high, higher the retention time of biomass, and the capacity of phosphorus and nitrogen removal has been shown by aerobic granular sludge; now a day it is a promising option for wastewater treatment. Reclaiming wastewater one of the favourite choices is Membrane technology in removing organic and inorganic impurities they have recognised as moderately operative with biological entities removal from wastewater. Consequently, the wastewater treatment membrane bioreactor and aerobic granular sludge technology are dynamic and new trending cost-efficient technologies. This article aims to review all the potential applications and principles in AGMBR technology.

Keywords: Aerobic granular sludge, Membrane bioreactor, AGMBR, Membrane fouling, industrial wastewater, Cost-efficient.

Correspondence:
Ms. Rakshanda M Ingale,
School of Environmental and Earth Sciences, Kavayitri Bahinabai Chaudhari North Maharashtra University, Jalgaon-425001, Maharashtra, INDIA.

Email: rmingale01@gmail.com

INTRODUCTION

Availability of water in the present world and exploration scenario investigate all accessible options in reducing the freshwater resources. Globally one of the regularly generated water resources is wastewater. The developing human era increased population, and industrial activities hence to accommodate the ample needs of man. The production processes of textiles or their treatments and finishing processes of textile materials are enormous consumers of water with high quality. In the mechanical procedures of spinning and weaving, water spent is very small as compared to textile processing operations, where water is used widely. Water pools are used for the application of all dyes and for finishing chemicals process to textile surfaces. As aqueous systems are mostly used in fabric preparation stages, such as scouring, bleaching, desizing and mercerizing. A facility producing 20,000 lf fabric per day is utilising 36000 litres of water, according to the USEPA. Various researches have been made over the centuries to publish wastewater treatment technologies such as filtration, coagulation-flocculation, and biological treatment systems among others. Upgrades to existing technology are also made to meet current discharge standards. Membrane technology is one of the improved wastewater treatment methods witnessed during this time. due to its excellent efforts to treat wastewater, The fully- grown and the substantial technology has in the last couple of decades. Membrane technology according to Quist-Jensen *et al.*,[1] offers a various options in wastewater treatment with a significant reduction in equipment size and low cost. According to Singh. *et al.* the effectiveness of membrane technology as affordable gap and sustainability gap can be coupled by the capabilities of membrane technology, at the same time low chemical utilization, eco-friendliness, and full access to many.[2-3]

Membrane technology in advanced time for wastewater treatment technology has been developed as a beneficial option for wastewater treatment. At, present in terms of

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energy, quality of percolation ability, space demand, and technical efficiency requirements membrane technology isn't the alternate innovation, the varying nature and complication of wastewater make opportunity for enhancements, the strength to reduce the membrane fouling, which may be a major piece of work for membrane processes in addition to continuous mutation of membrane elements and membrane modules.

WASTEWATER TREATMENT THROUGH MEMBRANE TECHNOLOGY

In general, as mentioned in Figure 1 of membrane technology for wastewater treatment schematic flow diagram, A membrane is a barricade which is having separated two stages from each other by limiting the movement of components through it in a selective way[4] Since then, to make membranes better suitable a lot of upgrades have been taken place for different applications.[5] Particularly, membranes have been differentiated as isotropic and anisotropic. As with consistent composition and physical structure are isotropic membranes. Anisotropic membranes, on the other hand, are formed with multiple layers and have varied structures and compositions that are non-uniform over the region of the membrane. Membranes are also classified on the basis of organic and inorganic in terms of their composition of the material. Organic membranes are prepared with synthetic organic polymers. Inorganic membranes are formed from materials such as metals, ceramics, silica or zeolites.

MBRs are to be extensively grown and implemented for the treatment and wastewater reclamation of industries. due to the prolonged acclimatization of microorganisms which results in high-quality effluent disinfection, the ability to uphold longer solid retention time (SRT), shorter hydraulic retention times (HRTs), tolerate high organic loading rates (OLRs), resulting in sludge generation, and high potential to biodegrade recalcitrant substratum. Moreover, it has excluded the need for secondary clarifiers.

On the other hand, Membrane fouling remains a vital problem that prevents the MBR from being used more widely.[6] biofouling commonly referred to as bacteria are grown and attached to the membrane surface, and the adsorption of the by-product of bacteria, and soluble microbial products (SMP) on the membrane surface that is pore blocking caused by the deposition on the surface and inside membrane pores and forming porecake.

Recently, from aerobic granular sludge (AGS) technology the establishment of granules to mitigate membrane-

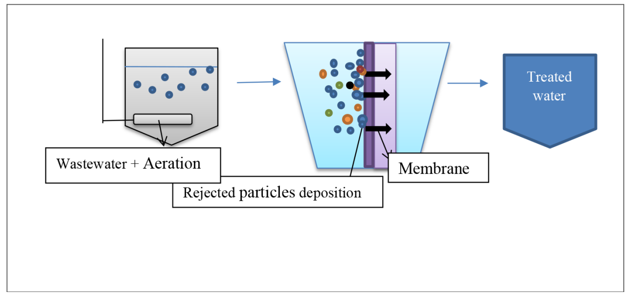

Figure 1: Membrane Technology for Wastewater flow diagram Treatment.

fouling in MBRs technology has been expressed the great attention[7-8] through different approaches that can significantly reduce the operational and maintenance costs for fouling in MBR.[9]

AEROBIC GRANULAR SLUDGE

The pillar of aerobic granular membrane technology is granule development. The organic matter, nitrogen, and phosphorus in wastewater have been removed by application of aerobic granules recently been studied. Aerobic granules present various advantages related to the conventional activated sludge process such as admirable settling properties, compacted microbial structure, virtuous biomass retention, and ability to resist shock and toxic loadings;[10-11] The mechanisms of aerobic granule formation can be described to occur in four different stages were[12] as mentioned in Figure 2 a schematic diagram of aerobic granulation. the bacteria cells attach to each other,[13] aggregates are formed due to attractive forces between the bacterial cells,[10] the aggregates are matured due to microbial forces and[14] the aggregate is designed to a three-dimensional assembly.

Liu and Thay[15] AGS systems are the results of Sequencing Batch Reactor (SBR) processes that operate in full aerobic circumstances and encourage the key chemicals that promote granular microbial aggregation of secret extracellular polymeric substances (EPSs).[16] Liu *et al*., reviewed in 2003 Up-flow anaerobic sludge blanket (UASR) reactor and gave some creditable mechanisms of anaerobic granule formation.[17] Various comparable theories have been suggested for aerobic granulation additionally. During waste-water treatment in sequenced batch reactors (SBRs), Aerobic granules are usually produced, as the population of microbe and their condition during the process differ in aerobic and anaerobic environments, more research comparing the aerobic and anaerobic granule formation pathways

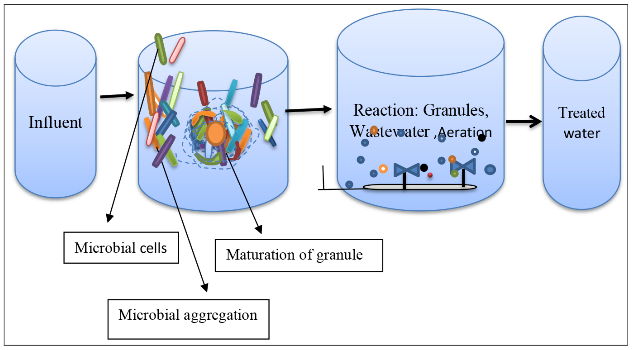

Figure 2: Aerobic granular sludge flow diagram in SBR.

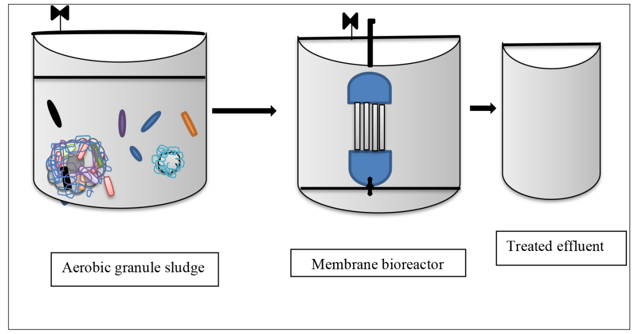

Figure 3: Separate aerobic granular membrane bioreactor.

would be beneficial to our understanding of granule initiation and improvement.

In the development of aerobic and anaerobic granules elements should be determined. When opposed to flocculated sludge, AGS has a higher density and specific gravity, which allows for faster solid-liquid separation.[16] However, the fundamental disadvantage is the stability of Aerobic granular sludge technology is a reduction over time, meaning granule breaking and associated solids loss in the sewage.[13] Hence, in this research paper, in the membrane bioreactor, aerobic granular sludge was inoculated to set up the aerobic granular sludge membrane bioreactor (AGMBR).

BASIC CONCEPTS OF AEROBIC GRANULAR MEMBRANE BIOREACTOR

Research in AGMBR, at lab and pilot scale, there is a need for alignment and performance before scaling up this technique. The path to merge the pros and the challenges linked with both the processes as Aerobic granular sludge with MBR technology, granular sludge effluent with its the high-level concentrations of suspended solids to mitigate membrane fouling caused in Membrane bioreactor. It has been classified as a hybrid system where the biomass consists are granules and filtration is acquired with MBR's is the Aerobic granular sludge membrane bioreactors (AGMBRs). In a full-scale Effluent Treatment Plant, AGMBR would be highly attractive as compared to conventional biological treatment to achieve high-quality effluent by using a lesser space than conventional biological treatment.[12-14] Along with granular sludge, simultaneously removal of nutrients, organic carbon and consequently single reactor could be substituted on the different biological tanks.

In membrane filtration as the partition of the treated water, sludge provides superior quality of effluent, which depends on the membrane pore size. As compared to floccular sludge the membrane fouling would moreover be diminished by the physical characteristics of granular sludge, for instance, its compact structure, larger size particle and higher concentration. Micro-membrane, ultrafiltration membranes are commonly used to treat wastewater in MBRs.[18-19] To date, in AGMBRs mainly hollow- microfiltration membranes have been employed, as the most used membrane material is polyethylene or polyvinylidene fluoride.

AGMBR process is used in SBR reactor for the generation of stable granules, and in the separate reactors for the rest of the procedure. SBR–MBR it acts as a tertiary wastewater treatment system that separates the wastewater suspended solids from SBR reactor is feeds into MBR with effluent from the submerged reactor.[20] For the cultivation of aerobic granules, the SBR reactor is followed by a reactor containing aerobic granules with mixed liquor in submerged MBR. As shown in Figure 3. Another common plant configuration is providing. Most of the two technologies can only use in separated reactors, which is the application configuration for the AGMBR process. A single reactor in Continuous-flow mode in AGS is a viable option. aerobic granules are in direct contact with the membrane fibre.[21]

FINDINGS OF PREVIOUS STUDIES

- Zhang 2021, reported that using an Aerobic granular sludge with submerged MBR (PVDF—pore size 0.22 μm) in continuous flow operation mode with synthetic water resulted in more than 90% organic removal, about 30% phosphorous removal and 45% nitrogen removal, and fouling resistances to filtration decrease as AGS ratio increased, enhancing the permeable.[22]
- Zhang *et al*,.[23] Separated Sequencing Batch Reactor (SBR) used synthetic wastewater; separate sequential batch reactor and Submerged MBR (PVDF and PTFE pore size 0.1 μm) operation were carried out, resulting in more than 98% of organic matter

removal. The author demonstrated that the PTEF membrane had better anti-fouling performance, compared to PVDF membrane.

- Thanh[24] claimed that using industrial citrus wastewater "Sequencing Batch Airlift Reactor (SBAR) and Submerged MBR (PVDF pore size 0.04 μm)" in separate reactor "Batch (SBAR) Continuous (MBR)" removal of 95% of organic matter.
- Sajjad[25] used a "submerged aerobic granular sludge MBR with PVDF membrane (pore size 0.22 μm)" in the AGS SBR—continuous flow MBR operation mode with synthetic wastewater, which removed 80% of organic matter removal and nitrogen.
- Thanh,[24-26] used a "submerged aerobic granular sludge MBR—PVDF membrane (pore size 0.04 μm)" in sequence batch airlift-continuous operation mode with synthetic wastewater and achieved a 95% organic matter, the drawback was irremovable fouling which shortens the membrane life.
- Juang,[27] performed with "Continuous flow membrane bioreactor (CFMBR) seeded with aerobic granular sludge (AGS)" in continuous flow mode with real wastewater, CFMBR technology has shown the filterability of aerobic granular sludge with more than three flocculant sludge. The mitigation of membrane-fouling through granule formation in CFMBR minimized the sludge floc concentration. The frequency of membrane cleaning has been significantly delayed due to the periodic renewal of granules.
- Iorhemen *et al*.,[28] performed with "Batch Granulation Membrane Aerated Bioreactor (BG-MABR)—Separated Sequencing Batch Airlift Reactor (SBAR) and Membrane Airlift Bioreactor MABR" bioreactor the main source for the formation of soluble in the system include "MABR Polyethylene (pore size 0.1 μm)" in batch mode with synthetic wastewater which resulted in 99% of organic matter removal with deflocculation and lysis processes. The membrane indicating PN and PS deposits on the surface of the membrane and inside the pore retained 30% and 50% of the soluble PN and PS, respectively, the granulation reactor showed advantages in coupling with MABR which showed good settling in the granular sludge and the MABR sludge. But this has caused the membrane irreversible fouling.
- Wang *et al*.,[21] used "submerged aerobic granular sludge MBR—PVDF membrane (pore size 0.4 μm)" in SBR reactor with synthetic wastewater and found that there was resistance to pore-blocking the most important factor in aerobic granular sludge. When compared to more than the 50 days of filtration without the need for cleaning allowed in AGMBR, a higher value if compared with less than 50 days has shown for flocculent and bulking and size of granular sludge become smaller, respectively, during operation granules were stable.
- Thanh *et al*.,[20] have performed with Batch Granulation Membrane Bioreactor (BG-MBR)—Separated Sequencing Batch Airlift Reactor (SBAR) and Submerged MBR Polyethylene (pore size 0.1 μm) with Batch (SBAR)— Continuous (MBR) used synthetic wastewater which has shown about 97.3% of organic matter removal and without any need for physical cleaning has extended filtration period for 78 days. the granules during the study period were stable.
- Liu *et al*.,[11,29] have performed "submerged aerobic granular sludge MBR—microfiltration" in continuous flow with synthetic water, which resulted in 83% of organic matter removal and as per author granular sludge and dynamic membrane by combining these two technologies membrane-fouling could be significantly relieved.
- Xuan, *et al*.,[30] performed with "Submerged aerobic granular sludge MBR (GMBR)— PVDF membrane (pore size 0.22 μm)" operated in continuous flow mode, with synthetic wastewater author showed the feature as reducing membrane pollutant aerobic granules play a vital role.

Removal Efficiencies of AGMBR

The notable removal of nutrients by Di Trapani *et al.* achieved an extraordinary organic matter has been removed and about 95% as COD, when treating industrial wastewater efficiency equivalent to conventional Membrane Bioreactor has achieved.[2] The COD removal by the system attained more than 97% PO4-P removal, 95–99% TN removal. In AGS-MBR, the separate reactor has removal efficiency, Thanh *et al*.,[24,31] after completing a removal rate of more than 96% of organic matter after a few years, the same authors found a "97.3% dissolved organic matter (DOC) and in another experiment removal efficiency of total nitrogen up to 59%"[20]with a similar reactor setup.

According to Di Bella *et al*., 99% high COD removal by both AGS–MBR and traditional MBR was achieved.[32] Zhou *et al*., performed the separation with AGS and submerged MBR the removal efficiencies of COD were 94%, and TN 91% removed in the sequencing of AGS–MBR.[33-34] With reference, Li *et al*., COD removal in the single-reactor AGS–MBR obtained about 80-95% and 85-91%, correspondingly.[35-36] Zhang *et al*., also observed higher COD removal for both AGS-MBRs equipped with different membrane materials.[23] Wang *et al*., stated a total nitrogen removal 78.4% and a 91.9% TOC for a continuous-feed AGS–MBR. For both configurations, TN removal of almost 66% and Nitrification of close to 99% were registered.[37-38]

Viewpoints of AGMBR Technology

Development of granules

The main tasks of the AGMBR are the formation of granules in a Membrane bioreactor. The hitches of larger initial capital costs and enlarged footprint can be eliminated by accepting two stages AGMBR could be the easier way. Though, if operated in only one stage AGMBR would be a striking option for the development of granules. Thus, Aerobic granules are also developed under continuous operation it has been seen Xin X, Morales.[39-40] One more strategy was established by Sajjad *et al*., in a pilot-scale system. In a sequential batch reactor, aerobic granules were developed which were inoculated into the Aerobic granular membrane bioreactor[25,22] and after every 10 days, the sludge between the SBR and AGMBR is replaced for the maintenance of granules. This intended that the AGMBR has been operated in continuous mode with a combination of granular and floccular sludge.

Granular Constancy

AGMBR stability can be guaranteed by the proper putting of keeping the effect of granules towards membrane fibres, the durability of the membrane and the fouling are controlled.[24] By differentiating the traditional activated sludge method of MBR from the AGMBR, it is conceivable to proclaim the main advantage of AGMBR allied without observing the fouling rate of the membrane and its permeability. Through specific operational conditions, the management of an AGMBR the upkeep of the stability of AGS structure and membrane fouling is mitigated. For the long-term AGMBR is more critical than traditional MBR pore-blocking is avoided for irreversible fouling.

Fouling in AGMBRs

Particularly, in AGMBRs the predominant foulant of the membrane is described as EPS, pore blockage is less important with sludge particles or colloidal foulant in both one or two-stage systems[41] according to studies, the chemical composition of EPS changes granulation of floccular sludge into granules. The fundamental structural component of aerobic granules is gel-forming polysaccharides, and it has been proposed that alginate-like polysaccharide[36] are proposed by two distinct polymers and granules.[42,3] Furthermore, as EPS is generated in the process, granule breaking has been linked to an increase the fouling[43] As a result; more research into the chemical composition of EPS in aerobic granules and how they interact with the membrane is required and are not yet known to us. Thus, it is also significantly known biofouling in AGMBR.

FUTURE SCOPE

Although combining aerobic granular sludge and membrane filtration is challenging, the advantage gained from AGMBR development could be quite appealing. In wastewater treatment, reactors with high treatment efficiency and smaller footprint are in high demand. Likewise, water reutilization is required in many sites, and the need for water reclamation is growing as a result of global warming. AGMBRs might feasibly accomplish these desires in a timely manner.

CONCLUSION

This research is focused on the issues of environmental protection against wastewaters generated by the textile industry. Primary (screening, sedimentation, neutralization, mechanical flocculation, chemical coagulation), Secondary (aerobic and anaerobic treatment, aerated lagoons, activated sludge process, trickling filtration, oxidation pond) and Tertiary (membrane technologies, adsorption, oxidation technique, electrolytic precipitation and electrochemical processes, ion exchange method, photocatalytic degradation, thermal evaporation) are the methods of purification. The purification procedure is determined by the composition of wastewaters.

The combination of AGS and MBR technologies, resulting in AGS–MBR has expressed a piqued interest during the last decade as a way to ease fouling from the membrane. AGS is a new type of biofilm technology that has various advantages, including, the ability to break down nutrients, and organic carbon at the same time, increased resistance to hazardous chemicals of industrial wastewater, and higher biomass concentration with a strong microbial form. The performance of AGMBR is evaluated in terms of Membrane-fouling. However, membrane fouling is the high expense associated with physical/chemical membrane cleaning, which prevents MBR from being widely used. Though, granular sludge structural stability is he major issue that affects AGS technology and granule breakage is a problem that implies an increase of irreversible membrane-fouling.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

ABBREVIATIONS

MBR: Membrane Bioreactor; **AGMBR:** Aerobic Granular Sludge Membrane Bioreactor; **USEPA:** united states environmental protection agency; **SRT:** solid retention time; **HRT:** hydraulic retention times; **OLR:** organic loading rates; **SMP:** soluble microbial products; **AGS:** aerobic granular sludge; **SBR:** Sequencing Batch Reactor; **EPS:** extracellular polymeric substances; **UASR:** Up flow anaerobic sludge blanket; **PVDF:** polyvinylidene fluoride; **PTFE:** polytetrafluoroethylene polymer; **SBAR:** Sequencing Batch Airlift Reactor; **CFMBR:** Continuous flow membrane bioreactor; **BG-MABR:** Batch Granulation Membrane Aerated Bioreactor; **COD:** chemical oxygen demand; **DOC:** dissolved organic matter; **TN:** Total Nitrogen;

REFERENCES

1. Quist-Jensen CA, Macedonio F, Drioli E. Membrane technology for water production in agriculture: desalination and wastewater reuse. Desalination. 2015;364:17-32. doi: 10.1016/j.desal.2015.03.001.
2. Di Trapani D, Corsino SF, Torregrossa M, Viviani G. Treatment of high strength industrial wastewater with membrane bioreactors for water reuse: effect of pre-treatment with aerobic granular sludge on system performance and fouling tendency. J Water Process Eng. 2019;31. doi: 10.1016/j.jwpe.2019.100859, PMID 100859.
3. Seviour T, Lambert LK, Pijuan M, Yuan Z. Structural determination of a key exopolysaccharide in mixed culture aerobic sludge granules using NMR spectroscopy. Environ Sci Technol. 2010;44(23):8964-70. doi: 10.1021/es102658s, PMID 21033741.
4. Takht Ravanchi M, Kaghazchi T, Kargari A. Application of membrane separation processes in petrochemical industry: a review. Desalination. 2009;235(1-3):199-244. doi: 10.1016/j.desal.2007.10.042.
5. Fane AT, Wang R, Jia Y. Membrane technology: past, present and future. In: Membrane and desalination technologies. Berlin, Germany: Springer; 2011. p. 1-45.
6. Meng F, Chae SR, Drews A, Kraume M, Shin HS, Yang F. Recent advances in membrane bioreactors (MBRs): membrane fouling and membrane material. Water Res. 2009;43(6):1489-512. doi: 10.1016/j.watres.2008.12.044, PMID 19178926.
7. Iorhemen OT, Hamza RA, Tay JH. Membrane fouling control in membrane bioreactors (MBRs) using granular materials. Bioresour Technol. 2017;240:9-24. doi: 10.1016/j.biortech.2017.03.005, PMID 28314664.
8. Iorhemen OT, Hamza RA, Zaghloul MS, Tay JH. Aerobic granular sludge membrane bioreactor (AGMBR): extracellular polymeric substances (EPS) analysis. Water Res. 2019;156:305-14. doi: 10.1016/j.watres.2019.03.020, PMID 30927626.
9. Iorhemen OT, Hamza RA, Sheng Z, Tay JH. Submerged aerobic granular sludge membrane bioreactor (AGMBR): organics and nutrients (nitrogen and phosphorus) removal. Bioresour Technol Rep. 2019;6:260-7. doi: 10.1016/j.biteb.2019.03.015.
10. Beun JJ, Hendriks A, Van Loosdrecht MCM, Morgenroth E, Wilderer PA, Heijnen JJ. Aerobic granulation in a sequencing batch reactor. Water Res. 1999;33(10):2283-90. doi: 10.1016/S0043-1354(98)00463-1.
11. Liu Y, Tay JH. State of the art of biogranulation technology for wastewater treatment. Biotechnol Adv. 2004;22(7):533-63. doi: 10.1016/j.biotechadv.2004.05.001, PMID 15262316.
12. Adav SS, Lee DJ, Show KY, Tay JH. Aerobic granular sludge: recent advances. Biotechnol Adv. 2008;26(5):411-23. doi: 10.1016/j.biotechadv.2008.05.002, PMID 18573633.
13. Bassin JP, Tavares DC, Borges RC, Dezotti M. Development of aerobic granular sludge under tropical climate conditions: the key role of inoculum adaptation under reduced sludge washout for stable granulation. J Environ Manage. 2019;230:168-82. doi: 10.1016/j.jenvman.2018.09.072, PMID 30292012.
14. Campo R, Lubello C, Lotti T, Di Bella G. Aerobic granular sludge–membrane BioReactor (AGS–MBR) as a novel configuration for wastewater treatment and fouling mitigation: A mini-review. Membranes. 2021;11(4). doi: 10.3390/membranes11040261, PMID 33916529.
15. Liu Y, Tay JH. The essential role of hydrodynamic shear force in the formation of biofilm and granular sludge. Water Res. 2002;36(7):1653-65. doi: 10.1016/S0043-1354(01)00379-7, PMID 12044065.
16. Nancharaiah YV, Kiran Kumar Reddy G. Aerobic granular sludge technology: mechanisms of granulation and biotechnological applications. Bioresour Technol. 2018;247:1128-43. doi: 10.1016/j.biortech.2017.09.131. PMID 28985995.
17. Liu Y, Xu HL, Yang SF, Tay JH. Mechanisms and models for anaerobic granulation in upflow anaerobic sludge blanket reactor. Water Res. 2003;37(3):661-73. doi: 10.1016/s0043-1354(02)00351-2, PMID 12688701. : 10.3390/membranes11040261, PMID 33916529.
18. Radjenovi_c J, Mato_si_c M, Mijatovi_c I, *et al*. Membrane bioreactor (MBR) as an advanced wastewater treatment technology. In: Barcel_o D, Petrovic M, editors. Emerging contaminants from industrial and municipal waste. Berlin, Heidelberg: Springer; 2008. p. 37–101.
19. Liébana R, Modin O, Persson F, Wilén BM. Integration of aerobic granular sludge and membrane bioreactors for wastewater treatment. Crit Rev Biotechnol. 2018;38(6):801-16. doi: 10.1080/07388551.2017.1414140, PMID 29400086.
20. Thanh BX, Visvanathan C, Ben Aim R. Fouling characterization and nitrogen removal in a batch granulation membrane bioreactor. Int Biodeterior Biodegrad. 2013;85:491-8. doi: 10.1016/j.ibiod.2013.02.005.
21. Wang Y, Zhong C, Huang D, Wang Y, Zhu J. The membrane fouling characteristics of MBRs with different aerobic granular sludges at high flux. Bioresour Technol. 2013;136:488-95. doi: 10.1016/j.biortech.2013.03.066, PMID 23567721.
22. Zhang W, Liang W, Zhang Z, Hao T. Aerobic granular sludge (AGS) scouring to mitigate membrane fouling: performance, hydrodynamic mechanism and contribution quantification model. Water Res. 2021;188:116518. doi: 10.1016/j.watres.2020.116518, PMID 33137525.
23. Zhang B, Huang D, Shen Y, Yin W, Gao X, Zhang B *et al*. Treatment of municipal wastewater with aerobic granular sludge membrane bioreactor (AGMBR): performance and membrane fouling. J Clean Prod. 2020;273. doi: 10.1016/j.jclepro.2020.123124, PMID 123124.
24. Thanh BX, Visvanathan C, Spérandio M, Aim RB. Fouling characterization in aerobic granulation coupled baffled membrane separation unit. J Membr Sci. 2008;318(1-2):334-9. doi: 10.1016/j.memsci.2008.02.058.
25. Sajjad M, Kim IS, Kim KS. Development of a novel process to mitigate membrane fouling in a continuous sludge system by seeding aerobic granules at pilot plant. J Membr Sci. 2016;497:90-8. doi: 10.1016/j.memsci.2015.09.021.
26. Tu X, Zhang S, Xu L, Zhang M, Zhu J. Performance and fouling characteristics in a membrane sequence batch reactor (MSBR)system coupled with aerobic granular sludge. Desalination. 2010;261(1-2):191-6. doi: 10.1016/j.desal.2010.03.034.
27. Juang YC, Lee DJ, Lai JY. Fouling layer on hollow-fibre membrane in aerobic granule membrane bioreactor. J Chin Inst Chem Eng. 2008;39(6):657-61. doi: 10.1016/j.jtice.2008.08.003.

28. Iorhemen OT, Hamza RA, Zaghloul MS, Tay JH. Simultaneous organics and nutrients removal in side-stream aerobic granular sludge membrane bioreactor (AGMBR). J Water Process Eng. 2018;21:127-32. doi: 10.1016/j.jwpe.2017.12.009.
29. Song W, Xu D, Bi X, Ng HY, Shi X. Intertidal wetland sediment as a novel inoculation source for developing aerobic granular sludge in membrane bioreactor treating high-salinity antibiotic manufacturing wastewater. Bioresour Technol. 2020;314:123715. doi: 10.1016/j.biortech.2020.123715, PMID 32645570.
30. Xuan W, Bin Z, Zhiqiang S, Zhigang Q, Zhaoli C, Min J *et al*. The EPS characteristics of sludge in an aerobic granule membrane bioreactor. Bioresour Technol. 2010;101(21):8046-50. doi: 10.1016/j.biortech.2010.05.074, PMID 20566286.
31. Wang Z, Ma J, Tang CY, Kimura K, Wang Q, Han X. Membrane cleaning in membrane bioreactors: a review. J Membr Sci. 2014;468:276-307. doi: 10.1016/j.memsci.2014.05.060.
32. Bella GD, Trapani DD. A brief review on the resistance-in-series model in membrane bioreactors (MBRs). Membranes. 2019;9(2):24. doi: 10.3390/membranes9020024, PMID 30717246.
33. Zhou J, Yang FL, Meng FG, An P, Wang D. Comparison of membrane fouling during short-term filtration of aerobic granular sludge and activated sludge. J Environ Sci (China). 2007;19(11):1281-6. doi: 10.1016/s1001-0742(07)60209-5, PMID 18232219.
34. Wei Y, Li G, Wang B. Application of granular sludge membrane bioreactor in the treatment of wastewater. Procedia Environ Sci. 2011;10:108-11. doi: 10.1016/j.proenv.2011.09.019.
35. Li X, Gao F, Hua Z, Du G, Chen J. Treatment of synthetic wastewater by a novel MBR with granular sludge developed forcontrolling membrane fouling. Sep Purif Technol. 2005;46(1-2):19-25. doi: 10.1016/j.seppur.2005.04.003.
36. Lin Y, de Kreuk M, van Loosdrecht MC, Adin A. Characterization of alginate-like exopolysaccharides isolated from aerobic granular sludge in pilot-plant. Water Res. 2010;44(11):3355-64. doi: 10.1016/j.watres.2010.03.019, PMID 20417539.
37. Wang J, Wang X, Zhao Z, Li J. Organics and nitrogen removal and sludge stability in aerobic granular sludge membrane bioreactor. Appl Microbiol Biotechnol. 2008;79(4):679-85. doi: 10.1007/s00253-008-1466-6, PMID 18465123.
38. More GB, Jadhav SK, Thorat S. Development of a novel submerged membrane bioreactor (SMBR) for treatment of textile wastewater publisher: -International. J Res Advent Technol. 2019;7:4. doi: 10.5281/zenodo.1048830.
39. Xin X, Lu H, Yao L, Leng L, Guan L. Rapid formation of aerobic granular sludge and its mechanism in a continuous- flow bioreactor. Appl Biochem Biotechnol. 2017;181(1):424-33. doi: 10.1007/s12010-016-2221-6, PMID 27600810.
40. Morales N, Figueroa M, Mosquera-Corral A, Campos JL, Méndez R. Aerobic granular-type biomass development in a continuous stirred tank reactor *et al*. continuous stirred tank reactor. Sep Purif Technol. 2012;89:199-205. doi: 10.1016/j.seppur.2012.01.024.
41. Sonawane AC, Thorat SR. Biculture characteristics of dye decolorizing bacteria isolated from textile industry treatment of wastewater. J Pure Appl Microbiol. 2008;2:497-500.
42. Seviour T, Lambert LK, Pijuan M, Yuan Z. Structural determination of a key exopolysaccharide in mixed culture aerobic sludge granules using NMR spectroscopy. Environ Sci Technol. 2010;44(23):8964-70. doi: 10.1021/es102658s, PMID 21033741.
43. Vijayalayan P, Thanh BX, Visvanathan C. Simultaneous nitrification denitrification in a Batch Granulation Membrane Airlift Bioreactor. Int Biodeterior Biodegrad. 2014;95:139-43. doi: 10.1016/j.ibiod.2014.05.020.

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