FULL SCALE MABR EXPERIENCE: INTENSIFICATION OF NUTRIENT REMOVAL AND ENERGY REDUCTION

J. Peeters, SUEZ North America, 3239 Dundas Street West, Oakville L6M 4B2, Canada; G. Kicsi, SUEZ Singapore, 10 Science Park Road, Alpha Building, #04-16, Science Park 2, 117684 Singapore; N. Oschmann, SUEZ Australia & New Zealand, Level 4 – 3 Rider Blvd, Rhodes, NSW 2138, Australia; D. Tyszler, SUEZ Australia & New Zealand, Level 6 – 63 Albert Street, 1010 Auckland, New Zealand

ABSTRACT

The membrane aerated biofilm reactor (MABR) process is an innovative technology that has gained much interest in the past five years for the potential benefits it offers for a wide range of applications. The MABR process employs a gas permeable media to deliver oxygen to a biofilm that is attached to the surface of the media. Oxygen is delivered to the biofilm by molecular diffusion, without the use of bubbles. Benefits of the technology include the ability to perform aerobic treatment in an otherwise unaerated reactor, providing a resilient solution to augment nitrifying organisms, significantly reducing the energy required for oxygen transfer, and modularity that allows utilities to minimise capital expenditure. SUEZ's ZeeLung MABR technology has been demonstrated at more than 20 municipal utilities at pilot or demonstration scale. The world's two largest commercial MABR installations – the Yorkville-Bristol Sanitary District in USA and Schilde in Belgium – were commissioned in 2018. The successful startup of these two full-scale plants paves the way for implementation of other full scale MABR systems.

Membrane Aerated Biofilm Reactor, MABR, ZeeLung, nutrient removal, intensification, energy, innovation

PRESENTER PROFILE

Jeff Peeters is a Professional Engineer with expertise in combining biological remediation and membrane technology for water and wastewater treatment challenges. Jeff has 20 years of experience with the development and commercialization of innovative technologies, including ultrafiltration, membrane bioreactor, and membrane aerated biofilm reactor.

1 INTRODUCTION

The membrane aerated biofilm reactor (MABR) process is an innovative technology that has gained much interest in the past five years for the potential benefits it offers for a wide range of applications. The MABR process employs a gas permeable media to deliver oxygen to a biofilm that is attached to the surface of the media. Oxygen is delivered to the biofilm by molecular diffusion, without the use of bubbles, resulting in energy efficient treatment independent of tank depth. This bubble-less oxygen transfer produces a unique environment within the biofilm where oxygen enters from one side and substrate (ammonia, organics) enter from the other side. This creates a range of process opportunities, including performing nitrification in reactors that are not otherwise aerated and developing different strata of microbes through the depth of the biofilm.

MABR products have been designed as modular solutions that enable cost-effective implementation.

SUEZ's ZeeLung MABR technology has been demonstrated at more than 20 municipal utilities at pilot or demonstration scale. The world's two largest commercial MABR installations were commissioned in 2018. This paper describes the implementation of the technology at full scale.

2 MABR TECHNOLOGY

The MABR process employs a gas permeable media to deliver oxygen to a biofilm that is attached to the surface of the media. Oxygen is delivered through the media by molecular diffusion, without the use of bubbles.

MABR technology can be used in a range of applications. The most common application has been the upgrade of conventional activated sludge (CAS) plants for nutrient removal and capacity expansion in existing tank volumes (Kunetz et al., 2016). In this application, MABR intensifies treatment capacity and improves performance by increasing the biomass inventory while also significantly reducing the energy required for aeration. For this hybrid configuration, MABR media is installed into an activated sludge reactor. A biofilm grows on the media surface and increases the total inventory in the system at the same suspended growth mixed liquor concentration.

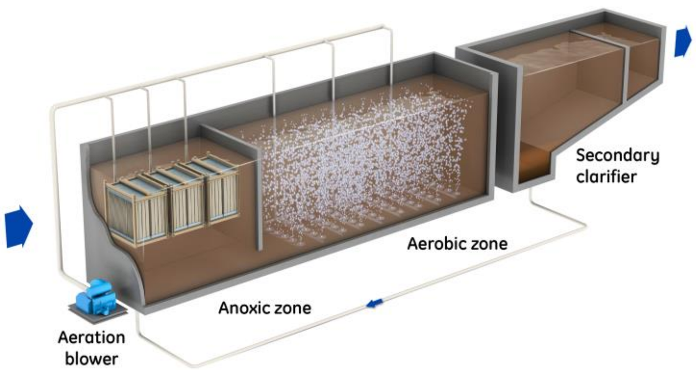

Figure 1: MABR for the upgrade of a conventional activated sludge system

Installing MABR media in an anoxic zone results in the additional benefit of simultaneous nitrification and denitrification (SND) where nitrification occurs in the aerobic biofilm and denitrification in the unaerated suspended biomass. Experience has shown that nitrifiers preferentially grow at the surface of the media due to the high diffusivity of ammonia into a biofilm, as compared to other organic substrates, and due the counter-diffusion of oxygen from the media surface. Preferential growth of nitrifiers versus heterotrophs in a counter-diffusional biofilm is a key differentiator of MABR as compared to conventional co-diffusional biofilm technologies, in which BOD removal is considered a necessary step prior to nitrification.

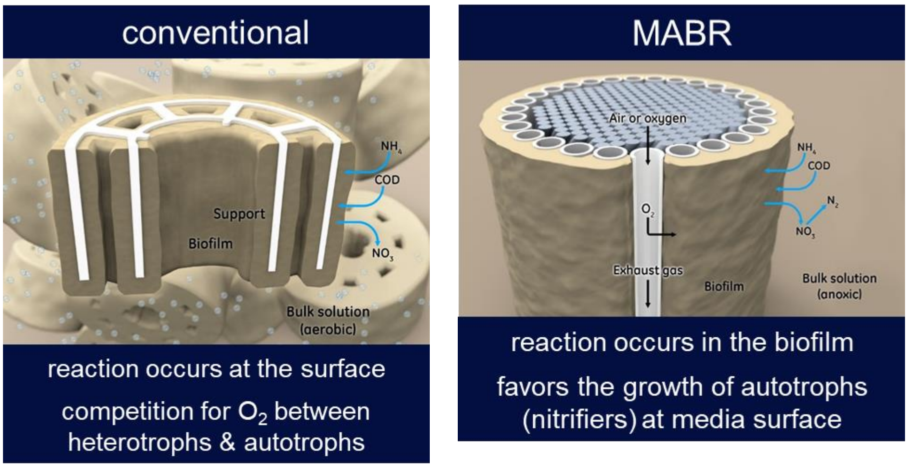

Figure 2: Unique conditions in an MABR biofilm compared to conventional biofilm

ZeeLung is the MABR product offered by SUEZ. ZeeLung is a supported hollow fibre configuration with multiple gas transfer membrane filaments oriented around a structural support that forms a robust cord construction. Multiple cords are potted into a top and bottom header to create a module and a series of modules are installed in a stainless-steel cassette, which forms the modular building block for an MABR system. Low-pressure air is delivered to the cassette using typical process aeration blowers. The air is distributed down the length of the ZeeLung filament lumens where oxygen is transferred through the media to satisfy the oxygen demand in the biofilm. The remaining "exhaust" air is collected and used to mix the cassette via a coarse bubble aeration grid that is integral to the cassette. This mixing provides sufficient energy to renew substrate at the biofilm surface and slough-off excess biomass to control the biofilm thickness in a range of 200 to 500 µm.

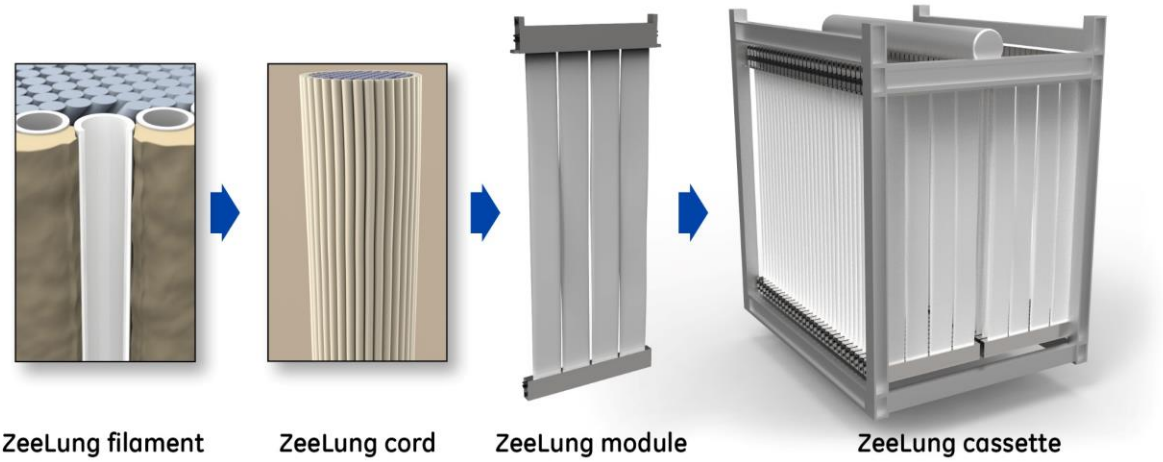

Figure 3: ZeeLung MABR product

Key performance indicators for the MABR process include Oxygen Transfer Efficiency (OTE), Oxygen Transfer Rate (OTR), and Nitrification Rate (NR). OTE is the percent of the oxygen in the air supply that is transferred to the biofilm, measured in %. OTE is measured by monitoring the oxygen concentration of the exhaust gas, i.e.; after the air has passed through the media lumen. OTR is the specific rate at which oxygen is transferred to the biofilm, reported as g-O_2/m^2/d. OTR can be calculated from the OTE if the airflow rates are at a known temperature and pressure. NR is the specific rate at which ammonia is oxidized by the biofilm, reported as g-N/m^2/d. Typically, NR is approximately 1/5th of the OTR, which is consistent with the stoichiometry for nitrification.

3 FULL SCALE EXPERIENCE

3.1 YORKVILLE-BRISTOL SANITARY DISTRICT

The Yorkville-Bristol Sanitary District (YBSD) wastewater treatment plant in Yorkville, Illinois USA serves a population of 18,500 and discharges to the Fox River. The plant is rated for a design average flow of 13.7 MLD. Prior to 2017 the facility was a single-stage nitrifying activated sludge system. Population growth and the arrival of new industrial contributions were anticipated to result in the facility exceeding its rated organic capacity. At the same time, YBSD had to comply with a new total phosphorous limit of 1 mg/L. This situation required the plant to be upgraded to increase organic treatment capacity and implement phosphorous removal. The existing site is footprint constrained; a conventional upgrade would require construction of a separate treatment plant on adjacent property. YBSD sought a retrofit solution that would minimise capital expenditure and avoid significant civil modifications to the facility, while accelerating the implementation schedule by avoiding the time required to permit and construct a new plant.

YBSD chose to upgrade the plant with MABR technology in combination with enhanced biological phosphorous removal (EBPR) for the following reasons: (1) MABR enables a 45% increase in organic treatment capacity in the existing bioreactor volume; (2) 75% capital cost savings compared to building a new conventional plant; (3) the solution could be implemented in a compressed schedule; (4) the synergy between MABR and EBPR - simultaneous nitrification and denitrification reduces the nitrate load to the EBPR anaerobic reactor; and (5) despite the increased capacity and tighter effluent limit, no net increase in energy consumption.

Prior to the ZeeLung and EBPR upgrade, the YBSD activated sludge system was configured with two parallel treatment lanes each with five aerobic reactors in series. The upgrade involved modifying the first tank to an anaerobic zone (to promote the growth of phosphorous accumulating organisms) and the second tank to an anoxic zone populated with ZeeLung cassettes. The ZeeLung cassettes support a nitrifying biofilm that enables simultaneous nitrification and denitrification to occur in the anoxic zone.

Phase one of the ZeeLung upgrade, which involved retrofitting one of the two treatment lanes, was commissioned in 2018 (Photograph 1).

Photograph 1: ZeeLung cassette installation in existing tanks at Yorkville-Bristol Sanitary District

The MABR upgrade will increase the design organic treatment capacity of the plant by 45% at the full implementation (Figure 4). Figure 5 demonstrates the MABR intensification of nitrogen removal by comparing the profile of total inorganic nitrogen through the plant using composite data and comparing this to modelling of a conventional EBPR upgrade without MABR.

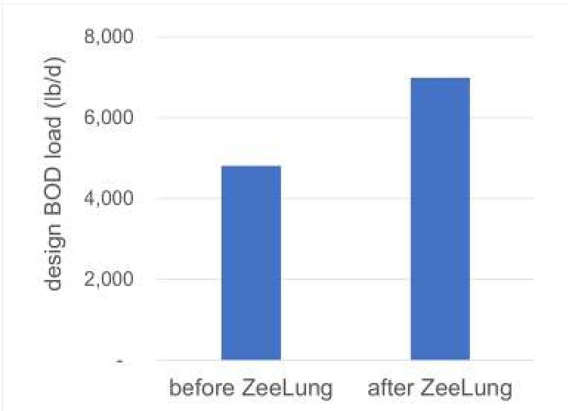

Figure 4: Design BOD load before and after ZeeLung upgrade

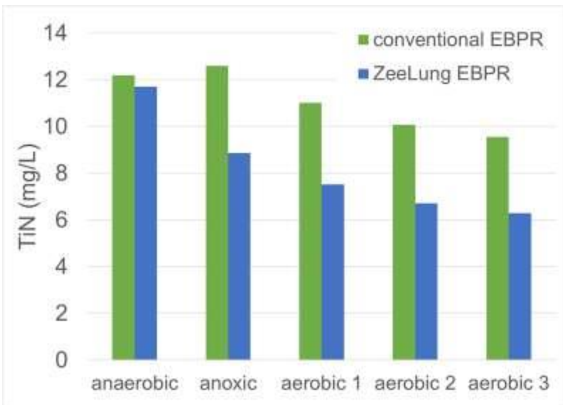

Figure 5: Nitrogen profile of ZeeLung EBPR compared to conventional EBPR

The improved removal of nitrogen by MABR has a positive impact on phosphorous removal by reducing the nitrate load to the anaerobic zone. Biological phosphorous removal performance at YBSD is summarized in Figure 6.

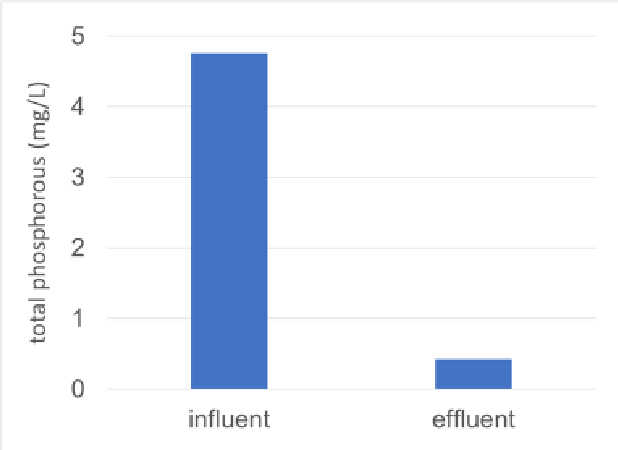

Figure 6: Phosphorous removal after ZeeLung EBPR upgrade

3.2 SCHILDE

The Schilde wastewater treatment plant in Belgium is a 16 MLD facility that consists of two parallel treatment trains – MBR and conventional activated sludge (Photograph 2).

Photograph 2: Schilde conventional activated sludge lane prior to MABR upgrade

The plant faced a more stringent total nitrogen removal requirement and sought a solution to improve total nitrogen removal in the activated sludge line. The activated sludge line was fully aerobic and therefore was not able to remove total nitrogen. In 2018 the plant implemented an MABR upgrade where a portion of the tank was isolated to create an anoxic zone and ZeeLung cassettes were installed in the anoxic zone to augment the aerobic inventory that was cannibalized for the anoxic zone. The ZeeLung cassettes were installed in the activated sludge reactors without having to dewater the tanks (Photograph 3).

Photograph 3: ZeeLung cassette installation in existing tanks at Schilde

4 CONCLUSIONS

MABR technology has the potential to solve contemporary challenges that many utilities face, including increasing treatment capacity, delivering improved nutrient removal, and reducing energy costs. The technology has gained much interest in the past five years. In 2018 the world's two largest MABR installations were commissioned. In both instances, the technology was chosen because it was the lowest cost solution to augment capacity with the secondary benefit of energy savings. The successful startup of these two full-scale plants paves the way for implementation of other full scale MABR systems.

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