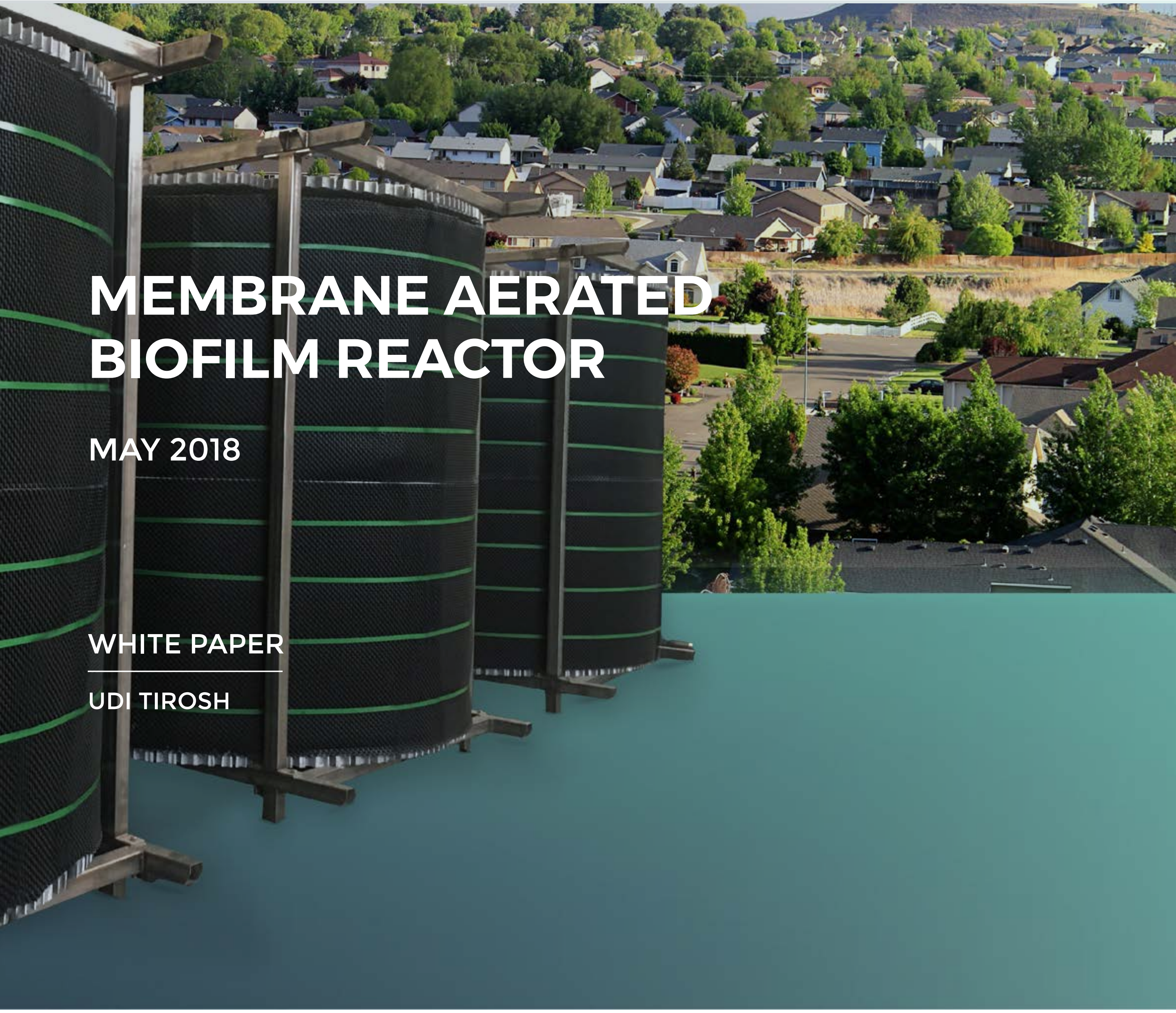

MEMBRANE AERATED BIOFILM REACTOR

MAY 2018

WHITE PAPER

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MEMBRANE AERATED BIOFILM REACTOR: TECHNOLOGY OVERVIEW

Introduction

The Fluence Membrane Aerated Biofilm Reactors (MABR) were introduced in 2015 to the general wastewater treatment market after decades of R&D at several different universities and in the industry. This extensive research has generated a basis for modeling the process [1], provided different applications for MABR, such as hydrogen - based biofilm denitrification [2], and introduced different process configurations, such as a hybrid or Integrated Fixed-film Activated Sludge (IFAS) process [3].

The following paper provides an overview of MABR technology and details the modular MABR system that utilizes spirally wound membranes, currently being produced by Fluence Corporation.

An MABR is a biological wastewater treatment process that utilizes seemingly passive aeration through oxygen-permeable membranes. Oxygen transfer through the MABR membranes is diffusion based, driven by concentration differences such that oxygen passes from air at atmospheric pressure into water at a higher hydrostatic pressure. This oxygen transfer mechanism, where air is supplied to the process at very low pressure, is the reason MABRs have significantly lower energy consumption compared to other wastewater treatment processes, such as conventional activated sludge (CAS), that utilize diffusers. This energy savings is one of the key reasons MABRs are gaining traction in the municipal wastewater industry.

The oxygen-permeable membranes used in MABRs are submerged in a wastewater treatment tank and while providing oxygen, they also support the development of an aerobic biofilm on their surfaces. Under suitable operating conditions, this biofilm performs simultaneous nitrification and denitrification (SND). This enables the biological process to produce a low effluent total nitrogen (TN) concentration with less (or no) supplemental carbon and with no internal circulation. The inherent ability to provide SND with minimal chemical addition or operator intervention is another key reason for the rising popularity of MABR, especially for decentralized wastewater systems. A deep dive into nutrient removal mechanisms in MABR is available in a separate document on this topic.

With these benefits in mind, Emefcy, later merged into Fluence, created a modular MABR system that has and is being deployed in multipal locations in US, China, Ethiopia and Israel.

The Fluence MABR Product Overview

The Fluence MABR is structured as modules of spirally wound membranes. These membrane modules are submerged in reactor tanks of various sizes and depths, as shown in the single module and general plant views in Figure 1. The membranes are shaped as sleeves with an internal air flow spacer. They are spirally wound to allow process air to flow through their length at a pressure that is less than 10% of that required for a typical wastewater aeration diffuser. A water spacer separates the wraps of the spiral to allow mixed liquor to mix freely in the water volume without clogging.

The reactor is equipped with a set of coarse bubble diffusers beneath the modules for intermittent mixing. The frequency and duration of the mixing with air is a controlled parameter, with a typical duty cycle of 2.5%-5% of the time. The combination of energy used for process air, flowing through the membrane, and mixing air, applied intermittently underneath the modules, is compared to typical activated sludge parameters later in the Energy Savings and Comparisons section of this document.

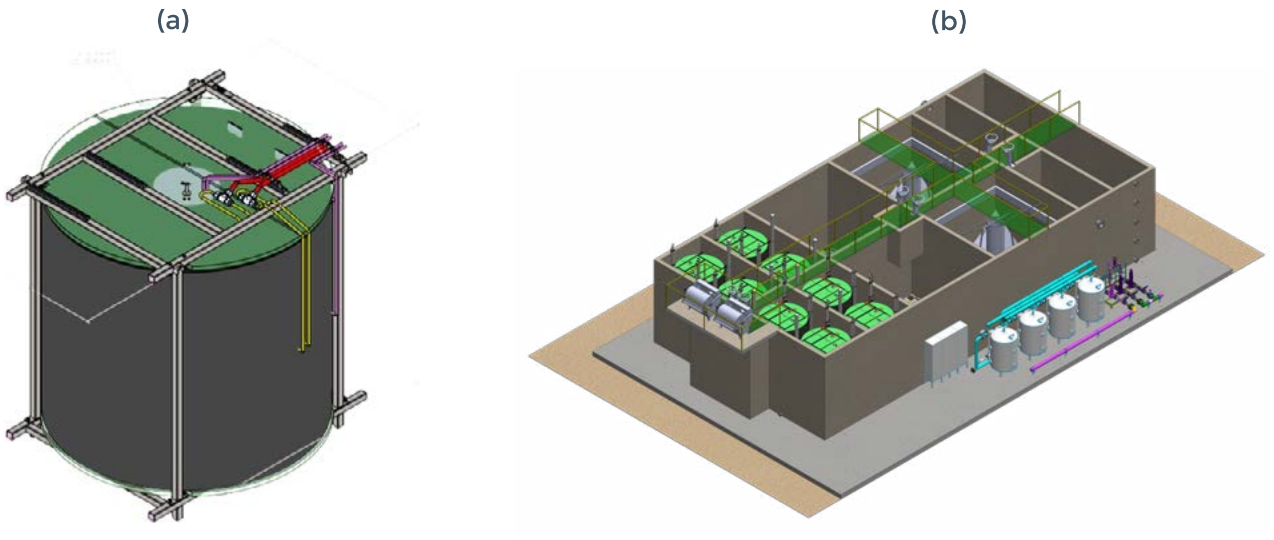

Figure 1: MABR Module (a) standalone and (b) inside concrete reactor structure

MABRs are most efficient when operated with a suspended biomass as an Integrated Fixed-film Activated Sludge (IFAS) system, wherein the fixed film is a nitrifying aerobic biofilm on the membrane in the presence of suspended solids that are circulated through the process, as in the activated sludge process. Periodic mixing, through air diffusers at the bottom of the reactor, are sufficient to keep the mixed liquor solids in suspension.

This IFAS process creates an environment where the biofilm is mainly comprised of autotrophic nitrifying bacteria in an oxygen rich environment created at the membrane wall, while heterotrophic bacteria oxidize the BOD, primarily by denitrification. As oxygen is mostly taken up by the biofilm, anoxic conditions prevail in the mixed liquor, thus promoting denitrification and BOD removal. Due to immediate uptake of any nitrate produced along the process for BOD oxidation, less supplemental carbon is required, compared to processes that alternate between anoxic and aerobic conditions. This mechanism is illustrated in Figure 2 below. Additional detail on suspended solids management in the process is provided in the following section.

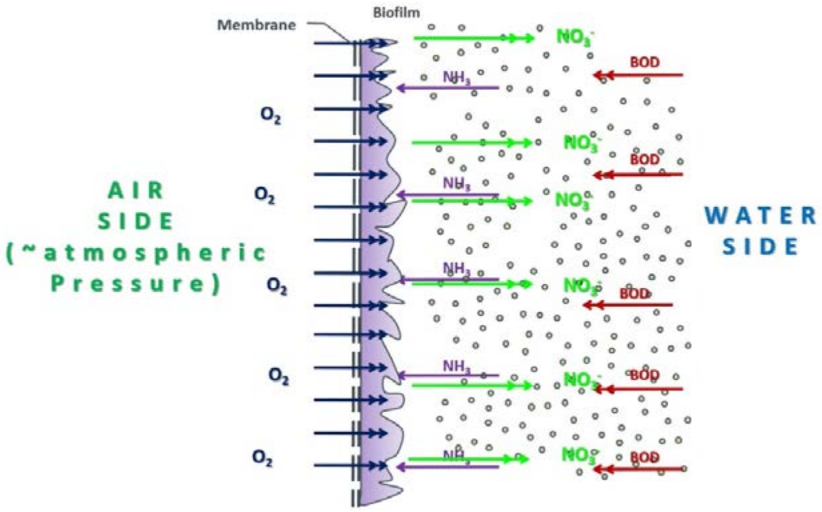

Figure 2: Biological operating principle of a Membrane Aerated Biofilm Reactor

The MABR Process Description

An MABR is a biological process unit that utilizes conventional treatment processes for pre- and post-treatment. The pre-treatment process is similar to that in conventional activated sludge plants and preferably includes an oil and grit separator, fine screens and an equalization tank, as shown in Figure 3. Oil separation is generally recommended in cold weather and at specific sites where excess FOG is anticipated. Equalization is commonly provided to ensure high performance of the secondary clarifier, especially at smaller treatment plants where flow variation is higher. However, the fine screening requirement is specific to the MABR, and is similar to membrane bioreactor (MBR) pretreatment requirements.

As shown in Figure 3, the process uses a secondary clarifier, like other IFAS processes, to clarify the effluent and circulate activated sludge through the biological treatment. Return Activated Sludge (RAS) is combined with the wastewater and distributed to the modules through their inlets.

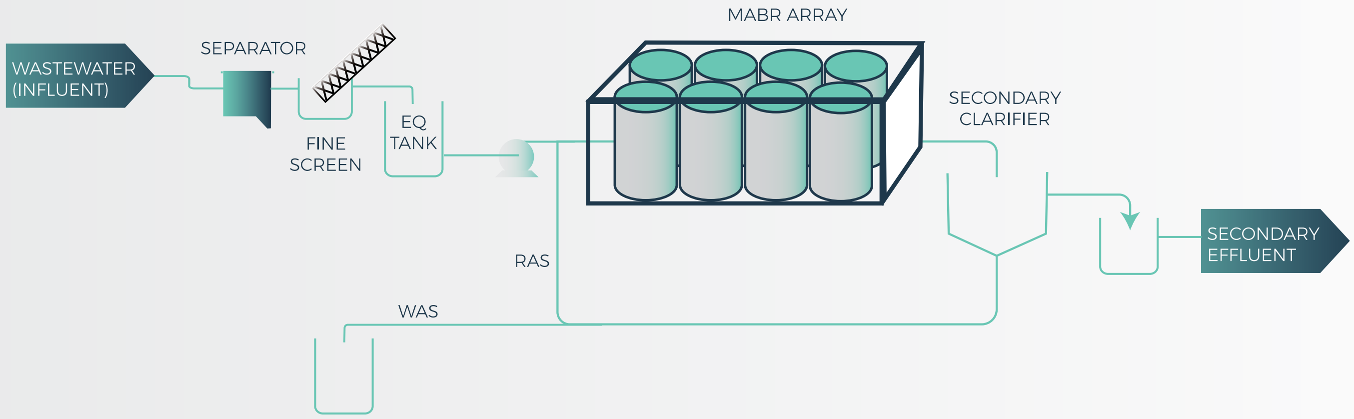

Figure 3: Schematic MABR-based Process Flow Diagram

To maintain the solids in suspension and provide sufficient mixing for mass transfer, periodic mixing is provided through air diffusers in each module (15-30 seconds, several times per hour). This can be increased to enhance nitrogen removal: increasing the mixing frequency improves mass transfer, and in the case of MABR, it enhances nitrification and the releases of nitrate for BOD oxidation.

Groups of modules, or arrays, can typically be connected in series to create a multi-stage process to further optimize process design in terms of performance per unit. Figure 4 shows how, for 2 different effluent quality requirements there is an advantage in using multiple stages. As can be seen, the difference is much more significant for low effluent TN requirements, where 3-5 process stages require about a quarter of the volume of ta single stage design.

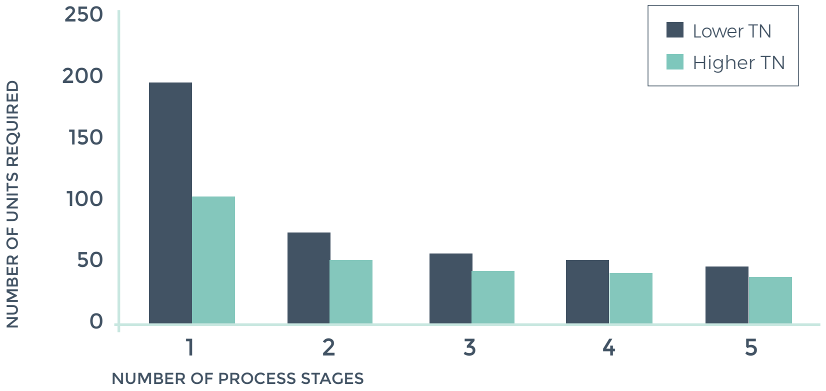

Figure 4: Number of MABR units required for treatment as a function of number of Process Stages

Energy Savings and Comparisons

The industry baseline for most energycomparisons is the conventional activated sludge (CAS) process, which it is still the most common biological wastewater treatment process and has is a lot of data and information readily available. In Table 1, a value of 0.685 kWh/m^3 is used to represent a typical small, nitrifying CAS secondary treatment plant [4]. The table illustrates that the aeration energy requirements in the MABR are just 13% of a CAS. This is mainly because the aeration is achieved using less than 10% of the pressure of conventional blowers and the additional mixing air operates less than 10% of the time.

Table 1 - MABR aeration energy consumption expressed as a percentage of CAS

	Pressure	Flow	Duty	Power
Mixing	80%	500%	1.7%	6.7%
Process	7.7%	80%	100%	6.2%
Total				12.8%

The typical values for energy consumption factors in MABR are further illustrated in Figure 5.

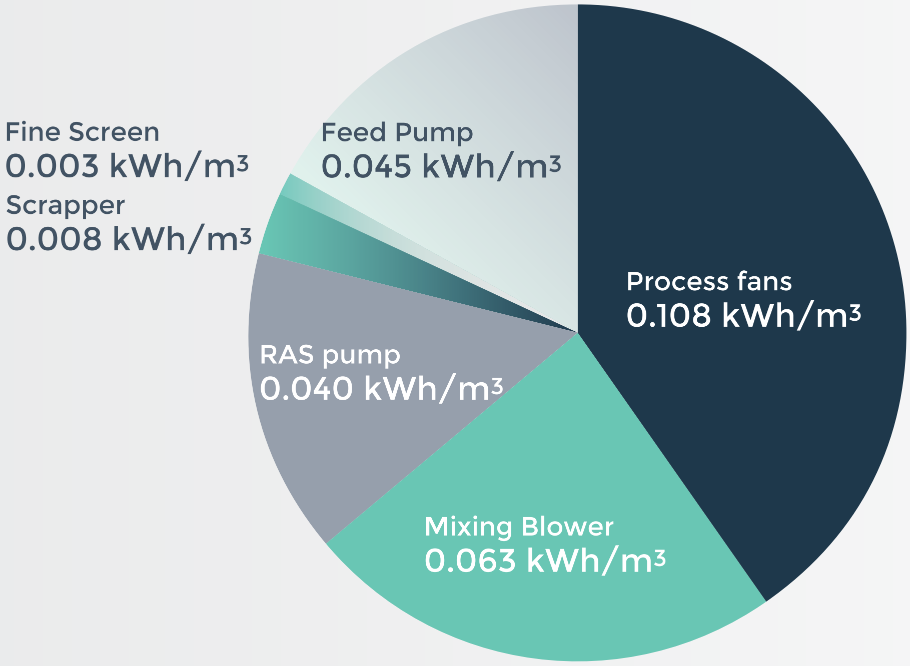

Figure 5: Breakdown of MABR 0.267kWh/m^3 energy consumption

MABR treatment plants have been installed and perform according to specifications in multiple locations around the globe, including US Virgin Islands, California, China and Israel.

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