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Hespeler WWTP MABR Installation Project

Lessons Learned Report

1. Introduction

1.1 Overview of MABR Technology

The membrane aerated biofilm reactor (MABR) is a bubbleless aeration technology where oxygen is transferred through an oxygen permeable membrane (Lakshminarasimman et al., 2023). This membrane transfers oxygen to a biofilm that sustains the bacteria population that breaks down the organic wastewater components, meanwhile ammonia diffuses into the biofilm from the mixed liquor suspended solution (MLSS). As this technology does not rely on bubbled aeration, it results in improved aeration efficiency and a decrease in electricity consumption when compared to standard conventional activated sludge (CAS) and extended aeration (EA) systems. MABR technology is also able to facilitate both nitrification and denitrification at the same time when it is used in a hybrid mode, where nitrification occurs in the aerobic areas of the biofilm, while denitrification occurs in the anoxic areas of the biofilm and in the mixed liquor (Lakshminarasimman et al., 2023). The installation of the MABR at the Hespeler wastewater treatment plant was followed by monitoring of the full-scale installation to determine its performance, ability for nitrogen and ammonia removal, and greenhouse gas (GHG) emissions.

1.2. Hespeler Wastewater Treatment Plant (WWTP)

The Hespeler WWTP is located at 900 Beaverdale Road, Cambridge, and is owned by the Region of Waterloo (Region), and operated by the Ontario Clean Water Agency (OCWA), servicing a portion of the City of Cambridge. This plant currently has a rated capacity of 9,320 m^3/d, with average daily flows of 6,828 m3/day, and an average SRT of 4-5 days year round (Lakshminarasimman et al., 2023). The Hespeler plant's treatment process before the MABR upgrade included aerated grit removal, aeration, the addition of alum for phosphorus removal, secondary clarification, sodium hypochlorite disinfection, and dechlorination, followed by the effluent being discharged to the Speed River (Region of Waterloo, 2018). Waste activated sludge (WAS) was sent to aerated sludge holding tanks, where it was thickened and then transported to either the Kitchener or Galt WWTPs for further treatment and disposal. MABR technology was installed at this plant to increase the capacity of the plant, improve its capability for year-round nitrification, and test its capabilities compared to standard CAS and EA configurations. A comparison of the Hespeler plant before and after the implementation of MABR can be seen in Figure 1, where the implementation of a third clarifier can also be seen.

The MABR has been implemented after screening and grit removal, and directly before the aeration tank stage of wastewater treatment. Four hybrid MABR tanks have been installed, each tank being 21.4 m long, 2.4 m wide, and 3.1 m deep, and individually containing 9 Veolia ZeeLung™ cassettes each, for a total of 36 cassettes overall (Lakshminarasimman et al., 2023). Every cassette has a membrane surface area of 1920 m^3 for biofilm growth. The ZeeLung™ MABR technology consists of yarn-like membrane cords that support gas permeable membrane filaments which allow for the transfer of oxygen, which are then mounted on the steel frame of the cassettes (Lakshminarasimman et al., 2023). Figure 3 shows what one ZeeLung™ cassette looks like. Figure 4 is an up close image of what a ZeeLung™ cassette looks like after it has been in use.

The performance of the MABR is variable, depending on multiple factors. To test the impact of temperature on the MABR performance, the MABR technology was monitored over a course of 12 months. It was found that the nitrification rate in the MABR was impacted by seasonal temperature shifts, where the nitrification rate was higher in warmer weather, and lower in cold weather. The MABR's performance also relied on the conditions for mixing within the tank. It was found that a higher airflow than initially expected was required to provide mixing in the tank for sufficient nitrification and ammonia removal.

Figure 1: Hespeler WWTP before and after MABR upgrades (Lakshminarasimman & Parker, 2023b)

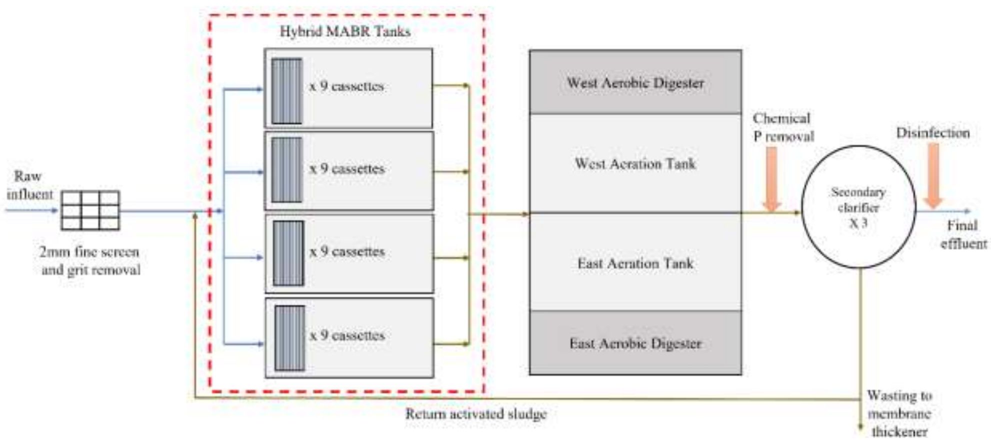

Figure 2: Overview of the MABR process, starting at screening and grit removal, and ending at final effluent (Lakshminarasimman et al., 2023)

Figure 3: ZeeLung™ MABR Cassette (Region of Waterloo, 2023b)

Figure 4: ZeeLung™ MABR Cassette After it has Been in Use (Tank 2 Cassette 6 Back, in cassette lifting on Nov 16, 2023 folder)

2. Advantages of MABR Technology

2.1 Increased Nitrification and Ammonia Removal

The monitoring of the MABR technology found that it significantly increased nitrification rates while reducing solids residence times. Before the installation of the MABR, the Hespeler WWTP was only capable of seasonal nitrification under warm weather conditions. The installation of the MABR allowed for year round nitrification, resulting in a significant decrease in the concentration of effluent nitrate. This increase in nitrification is due to the simultaneous nitrification and denitrification (SND) aspect of the MABR technology. The overall nitrification rate after the installation of the MABR ranged between 0.7-2.2 $gNm^{-2}d^{-1}$, with an overall total nitrogen (TN) removal between 75-85% compared to a TN removal of 40-50% with the previous CAS configuration (Lakshminarasimman et al., 2023).

In addition to increased nitrification, the installation of the MABR also allowed for increased ammonia removal, due to diffusion from the mixed liquor into the biofilm. Prior to the MABR configuration, the Hespeler WWTP had effluent ammonia concentrations between 10-25 mg-N/L under cold weather conditions, and effluent ammonia concentrations below 5 mg-N/L under warm weather conditions. After the successful installation of the MABR, the final effluent ammonia concentration under cold weather conditions fell below 10 mg-N/L. Under warm weather conditions, the final effluent ammonia concentration fell even further to 0.36 ± 0.3 mg-N/L. Lowering the final effluent ammonia concentration for the plant overall is a significant first step while upgrades are still ongoing to achieve these concentrations in the MABR effluent.

2.2 Simultaneous Nitrification and Denitrification (SND)

The installation of the MABR technology allowed for SND at the Hespeler WWTP. As mentioned in section 2.1, an increase of SND in the MABR tanks resulted in a significant reduction in the effluent concentration of nitrogen, in turn improving the overall total nitrogen (TN) removal at the Hespeler plant. Altogether, the MABR had a denitrification efficiency of 87 ± 16%, with an average denitrification rate of 100-200 gN m^{-3} d^{-1}. Throughout the monitoring phase of the MABR, it was found that the denitrification rate was dependant on the nitrification rate. As the nitrification rate increased, the denitrification rate increased as well, and as the nitrification rate decreased, the denitrification also decreased, emphasizing the importance of maintaining high nitrification rates within the MABR so that the TN removal at the Hespeler WWTP can be maintained at a consistently high level (Lakshminarasimman et al., 2023).

The increase in SND at the Hespeler WWTP not only helped increase the TN removal at the plant, it also helped to lower the overall energy consumption at the plant. The high levels of nitrification and denitrification worked to reduce the loading to the downstream aeration tanks, meaning less air was needed to sustain the bacteria levels and remove the organic components from the substrate.

2.3 Reduced Energy Consumption

The increased aeration efficiency due to the MABR has greatly reduced the total energy consumption of the Hespeler WWTP. Currently in CAS configurations, aeration makes up approximately 23% of the total electricity consumed throughout the entire wastewater treatment process (IESO, 2018). The oxygen permeable membrane of the MABR improved the oxygen transfer efficiency, and the biofilm helped to reduce the downstream BOD and ammonia loading. In addition, the increased SND of the MABR also helped to reduce the downstream loading to the aeration tanks. The reduced loading to the aeration tanks resulted in a decrease in airflow required for aeration, and a decrease in energy consumption. Overall, the MABR upgrades lead to a decrease in airflow and electricity consumption of up to 50%.

The reduction in energy consumption also results in an overall decrease in the greenhouse gasses emitted by the wastewater treatment process. The MABR uses less air, and also reduces the amount of air needed in the aeration tanks, reducing the amount of oxygen wasted by the aeration process, resulting in a decrease in the amount of GHG emitted by the wastewater treatment process. Through monitoring it was found that the electricity consumption of the MABR was proportional to the airflow, so as less air was used, the amount of electricity used also decreased, resulting in both fewer GHG emissions and less energy consumed (Region of Waterloo, 2023a).

2.4 Reduced N_2O Emissions

Wastewater treatment plants are responsible for the emission of GHGs primarily through aeration, including carbon dioxide and nitrous oxide N_2O, a gas with a higher global warming potential than CO_2. Before the upgrade, the average mass emission of N_2O was between 560-1920 g N_2O-N, and after the upgrade the average mass emission of N_2O was between 101-252 g N2O-N. Overall, the MABR upgrade reduced the Hespeler WWTP's N_2O emissions by 84-90% (Lakshminarasimman & Parker, 2023a). This significant reduction in N_2O emissions is largely due to the decreased airflow required for the MABR and downstream aeration tanks to function, as well as the reduced ammonia loading from the MABR to the downstream aeration tanks (Lakshminarasimman & Parker, 2023a). In addition, the denitrification capability of the MABR means it can act as a sink for N_2O, further contributing to the reduction in N_2O emissions. The N_2O produced from nitrification in the MABR tanks gets diffused into the suspended solution (MLSS), where it undergoes heterotrophic denitrification, reducing the N_2O emissions from the MABR (Lakshminarasimman & Parker, 2023a). Further, MABRs also have the potential to engage in N_2O gas scrubbing, leading to another source of reduction in N_2O emissions (Lakshminarasimman & Parker, 2023a). Overall, MABR technology provides multiple avenues through which to decrease N_2O emissions.

2.5 Reduced Expansion Area

At the Hespeler WWTP, the ZeeLung™ cassettes were installed in ZeeLung™ tanks built just upstream of the aeration tanks. In comparison to the space needed for aeration tanks in CAS configurations, ZeeLung™ tanks were considerably smaller, reducing the space needed for construction. In this situation, building the new ZeeLung™ tanks also meant that the already existing aeration tanks did not have to be modified, and that the Hespeler WWTP could remain in operation throughout the entirety of the MABR installation, further reducing the overall cost of the MABR upgrade (Stantec Consulting Ltd., 2017). In some cases, the ZeeLung™ cassettes can even be installed within already existing bioreactors at WWTPs, minimizing the expansion area needed for the installation of MABR technology while also making use of already present technology. This reduced expansion area when compared to CAS configurations, also allows for the preservation of environmentally significant areas (ESAs) which are often located next to, or in close proximity to WWTPs, helping to ensure that WWTPs engage in more environmentally friendly practices. The preservation of ESAs also helps to maintain positive relationships with local community members who place a high value on the continued existences of these areas.

3. Challenges Faced and their Resolutions

3.1 Lack of Mixing in MABR Tank

Having a sufficient level of airflow in the MABR tank was necessary to provide oxygen to the membrane and create enough mixing within the MLSS. Throughout the monitoring phase of the MABR, it was found that the blowers that were initially installed provided an inadequate level of airflow for the mixing requirement. Without sufficient mixing, the solids were settling to the bottom of the tank and decomposing further, releasing more components into the substrate.

This issue will be solved with the implementation of small blowers and diffusers to the bottom of the MABR tank that will be able to increase the mixing so that the overall airflow could prevent solids from settling at the bottom of the tank. The proposed equipment will eliminate the problem of insufficient mixing within the MABR tank.

3.2 Managing Biofilm Thickness

Maintaining a higher airflow than initially implemented was necessary to provide enough mixing in the MABR tank, and it was found that it was also necessary to control the thickness of the biofilm. As the MABR upgrade was put into operation and monitored, the biofilm continued to develop and grow thicker, with an initial thickness in the range of 250-500 µm, developing to thicknesses between approximately 800-1000 µm (Region of Waterloo, 2023b). As the biofilm grew thicker, it prevented ammonia from diffusing into the inner layers of the MABR, causing the overall nitrification rate to decline as well. The initial air flow to the MABR tank did not provide sufficient scouring to the biofilm, allowing it to develop this additional thickness. To overcome this issue, the airflow within the MABR tank was increased. The amount of sparging air was increased, scouring the biofilm and reducing its thickness to a manageable level where the ammonia loading and nitrification rate could be maintained at a consistently high level.

3.3 Inaccurate Monitoring Equipment

To accurately evaluate the functioning of the MABR within the Hespeler WWTP, various pieces of monitoring equipment were installed in the MABR. One piece of monitoring equipment installed included ammonia probes, which were used to measure the levels of ammonia and determine the total nitrogen present in the MABR tank. After the installation of the ammonia probes, they were exposed to the bacteria present within the MABR tank, fouling the probes and causing them to give inaccurate readings of the ammonia and total nitrogen levels in the MABR.

Another piece of monitoring equipment installed within the MABR were air exhaust probes, used to measure the amount of oxygen present in the exhaust and examine the performance level of the MABR. The air exhaust probes reported inaccurate readings as the MABR tank had highly humid conditions that had not been accounted for before installation, and resulted in condensation on the probes that limited their functionality. To address this issue, a condensate removal system was installed to clean the air analyzed by the air exhaust probes, ensuring that the readings from these probes provided accurate information about the oxygen levels and performance of the MABR.

4. Future Considerations

4.1 Implementation of Sufficient Mixing Alongside MABR from the Onset of Construction

One future consideration for the installation of MABR technology at other WWTPs is the implementation of technology that provides sufficient mixing within the MABR from the onset of the MABR upgrade. In the case of the Hespeler WWTP, additional blowers and diffusers have to be added after the initial installation of the MABR in order to supply an adequate airflow throughout the tank, resulting in an increase in incurred costs, and an initially lower than optimal performance of the MABR. To prevent this issue in future installations of the MABR, an additional source of airflow or other means of providing mixing should be implemented into the design of the MABR, so that there will be an adequate level of mixing in the MABR. Potential technologies that could be implemented to promote mixing within the MABR include aeration blowers, which are able to pump air directly into the biofilm to reduce the comparative wastage associated with aeration tanks, where the blowers, mechanical mixers or jets provide air directly into the MLSS, allowing oxygen to be wasted through evaporation.

4.2 Selection and Maintenance of Probes

Another future consideration for the installation of MABR technology at other WWTPs is the selection of probes that fit the environmental and climatic conditions of the WWTP, and the proper maintenance of these probes to ensure that they are able to effectively and efficiently meet their purpose. At the Hespeler WWTP, the cold climatic conditions, and the resulting humidity within the MABR were not considered when implementing the air exhaust probes, resulting in inaccurate readings due to condensation gathered on the probes. To prevent this issue from occurring in the future, either a different kind of probe that will not be negatively effected by these cold climatic conditions needs to be considered, or proper equipment needs to be installed alongside these probes to prevent these issues from occurring. At the Hespeler WWTP, heat tracing was implemented in the pipes to regulate the temperature and prevent condensation from forming; if air exhaust probes are to be added to future MABR installations in similar environmental conditions, similar measures should also be implemented at these installations as well.

In another situation at the Hespeler WWTP, the ammonia probes installed within the MABR quickly became fouled by the bacteria present within the MLSS, resulting in inaccurate readings. To solve this issue, auto-cleaning should be be implemented in order to maintain the cleanliness of the ammonia probes. Going forwards, auto-cleaning options should be considered and installed at the same time as ammonia probes, to prevent this issue from occurring in the future. When implementing future MABR upgrades at other WWTPs, the environmental conditions of the plant and surrounding area must be considered in order to determine the actions that will be needed in order to properly maintain the probes. In cold climates, condensate removal should be implemented alongside air exhaust probes, and ammonia probes should be installed with auto-cleaning options, in order to ensure their continued accuracy.

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