Efficiently Nitrify Lagoon Effluent Using Moving Bed Biofilm Reactor (MBBR) Treatment Processes

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ABSTRACT

The City of Lone Oak, Texas' (City) wastewater treatment plant (WWTP) was a three lagoon plant. The first two lagoons treated the organic load entering the plant and the third lagoon served as a polishing lagoon. While this lagoon treatment system was able to adequately treat the organic load entering the WWTP, the process was not able to provide satisfactory nitrification treatment. The City, recognizing corrective action was required to address this issue, authorized their engineer to investigate treatment options for the WWTP. Two options identified as best suited for the City's situation were:

- Replace the existing three lagoon treatment system with a new conventional activated sludge treatment process, or
- Continue to utilize the existing lagoon treatment system, which was acceptably achieving organic matter reduction, and install supplemental treatment of the lagoon effluent to achieve the required nitrification

Supplemental treatment of the lagoon effluent was determined to be the most cost effective course of action for the City.

Of available supplemental treatment systems, the City's engineer determined a fixed film process was ideally suited to meet the City's requirements. Fixed film technologies are well known for effective biological treatment of ammonia. In fixed film processes, the treatment microorganisms grow in a biofilm on a media maintained within the reactor vessel (basin). Growing on the media provides the microorganisms an environment protected from both temperature variations and possible wash out high flow events.

The Moving Bed Biofilm Reactor (MBBR) treatment technology was the fixed film process selected for the Lone Oak WWTP. In a MBBR process, the biofilm (or biomass) grows on small carrier elements suspended throughout the liquid in the reactor. Biofilm carrier elements (referred to as biocarriers) are made of polyethylene, which has a density slightly less than water. Shaped like a small cylinder each biocarrier is approximately 10 mm in diameter and 7 mm height. Internal cross members installed in each biocarrier increase the available interior surface area for biofilm attachment. Longitudinal fins incorporated on the external surface of the biocarrier increase the external surface area available for biofilm growth. Aeration in the reactor keeps the biofilm carriers in suspension.

Sieve assemblies with approximately 5 mm openings, placed on the effluent ports of the reactor/basin, keep the biocarrier inside the reactor. Part of the design of each MBBR reactor is an aeration system. In addition to providing the required oxygen, the aeration system ensures the biocarriers are evenly distributed throughout the reactor. As the biocarriers move thoughout the

MBBR reactor they contact the surface of the sieve assemblies in a scouring action. That scoring action effectively scrubs the sieve assemblies preventing clogging.

By employing the MBBR treatment technology the City of Lone Oak was able to meet their nitrification requirements in the colder winter temperatures. This was achieved without replacing the existing lagoon based treatment process, which greatly reduced the expected cost of achieving TCEQ discharge permit compliance.

KEYWORDS

Moving Bed Biofilm Reactor, Fixed Film, Integrated Fixed Film Activated Sludge (IFAS), Cold Weather Nitrification

INTRODUCTION

The City of Lone Oak, Texas (City) Wastewater Treatment Plant (WWTP) was a lagoon based wastewater treatment process. The WWTP was comprised of an influent screening structure followed by two treatment lagoons arranged in series for the organic treatment. Effluent from the second treatment lagoon passed through a third polishing lagoon before final discharge. While the organic loading on the WWTP was within design parameters during the winter months, with the accompanying colder ambient operating temperatures, the lagoon treatment process was not able to meet the WWTP's discharge permit nitrification requirements.

The WWTP's inability to achieve nitrification was not an isolated event. As the ambient temperatures decreased each winter, the WWTP's nitrification problems became continuous. The failure to achieve acceptable levels of nitrification was not caused by any action or inaction in operating the WWTP. Nor, were the nitrification problems a short coming of the original design. When the WWTP was designed and constructed, nitrification was not required.

Recognizing their duty to fully comply with the Texas Commission on Environmental Quality (TCEQ) discharge permit requirements to achieve nitrification, the City directed their engineer to investigate potential corrective actions at the WWTP. The goal of that investigation was to identify available treatment options that could cost effectively achieve acceptable nitrification levels. The City's engineer identified two options as best suited for the City's situation. Those options were:

- Replace the existing three lagoon treatment system with a new conventional activated sludge treatment process, or
- Continue to utilize the existing lagoon treatment system, which was acceptably achieving organic matter reduction, and install supplemental treatment of the lagoon effluent to achieve the required nitrification

Supplemental treatment of the lagoon effluent was determined to be the most cost effective course of action for the City from both construction and operational cost considerations.

PROJECT DESIGN

Introduction to the Moving Bed Biofilm Reactor

The Moving Bed Biofilm Reactor (MBBR) is a biofilm variation of the activated sludge wastewater treatment process. In the MBBR process, the biofilm grows on biocarriers freely suspended in the mixed liquor of the reactor (basin). Biocarrier movement within the reactor is produced by an engineered aeration system. Effluent screens (referred to as sieves) keep the biocarriers in the reactor.

As the biofilm grows a natural “sloughing” of the biofilm off the biocarriers occurs. That sloughing maintains the biofilm at a thickness supported by the incoming organic load. Biomass that sloughs off passes through the effluent sieve. Clarification/sedimentation is then employed to remove the sloughed off biomass from the treated wastewater. The biofilm carrier elements are made of high density polyethylene and have a specific gravity of 0.96.

The MBBR treatment process can offer numerous advantages over a suspended growth activated sludge treatment process. Those advantages include:

- Resilient Treatment Population: The biocarriers provide the biofilms a protected environment. That protected environment often translates to providing a more resilient treatment population.
- Denser treatment population per unit volume: The treatment population per unit volume is denser compared to conventional suspended growth activated sludge systems. That often translates into smaller treatment volumes (i.e. smaller foot print) and greater capacity to successfully treat incoming organic loads.
- Focus on Specific Treatment Populations: Within the biofilm layers develop favoring specific types of treatment organisms. That enables the biofilms to develop specifically focused for the organic load.
- Energy efficient
- Small foot print: MBBR footprint is smaller than comparable aerated wastewater treatment systems for either industrial or municipal wastewaters.
- Easy to operate: MBBR system for the Lone Oak WWTP does have a Return Activated Sludge component or sludge wasting.
- High Loading Conditions: The ability of the biofilm to grow as organic loading increases enables a MBBR process to successfully handle extremely high loading conditions with very little operator intervention.

Biofilms and Biocarriers

As noted above, the core principal of the MBBR treatment process is the treatment of the incoming wastewater by microorganisms growing in a biofilm on biocarriers suspended in the liquor in the MBBR reactor. The biocarriers “carry” the microorganisms throughout the reactors. Figure 1 shows an AnoxKaldnes K1 biocarrier with biofilm growth.

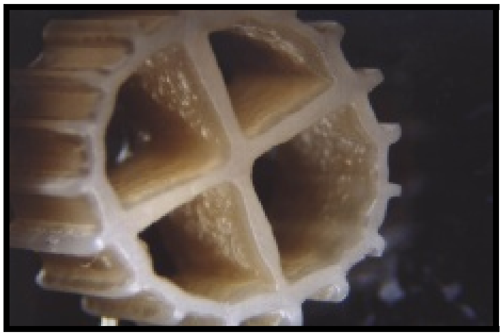


Figure 1
Biocarrier with Biofilm

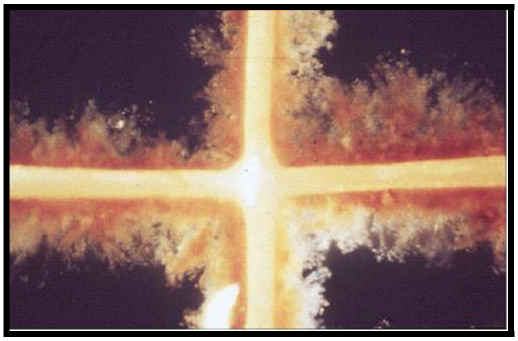


Figure 2
Biofilm on a Biocarrier

Biofilms are communities of microorganisms growing on surfaces. The microorganisms in the biofilms are essentially the same as those in suspended activated sludge wastewater treatment systems. Most of the microorganisms in the biofilm are heterotrophic (they use organic carbon to create new biomass), with facultative bacteria predominating. Facultative bacteria can use the dissolved oxygen in the mixed liquor or, if dissolved oxygen is not available, they will utilize the available nitrate/nitrite as electron acceptors.

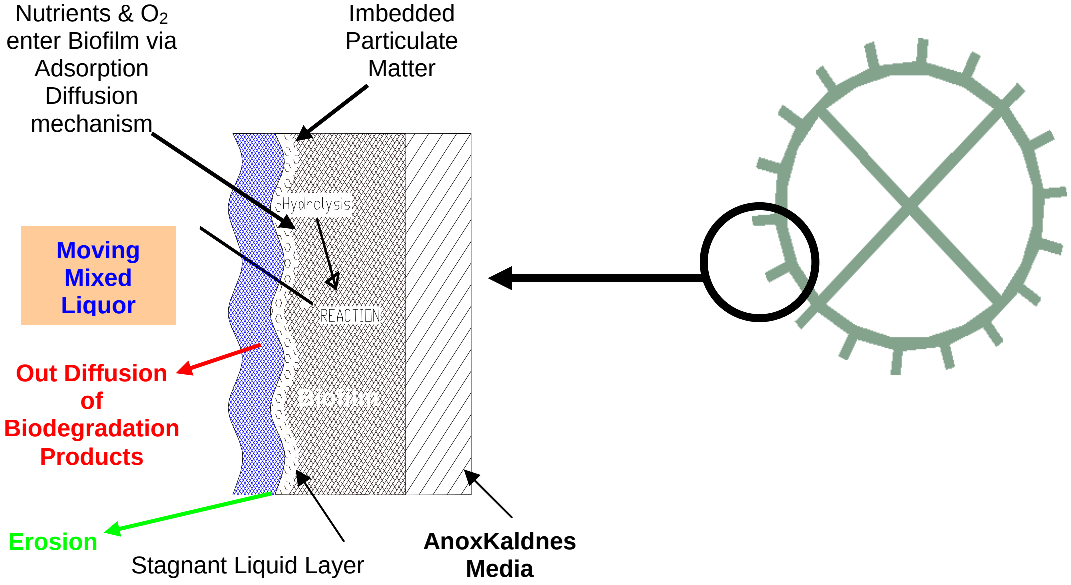


Figure 3
Nutrient Path through a Biofilm

At the surface of the biofilm is a stagnant liquid layer that separates the biofilm from the moving mixed liquor in the reactor. Nutrients and oxygen diffuse across the stagnant liquid layer from the moving mixed liquor to the biofilm. While nutrients (substrates) and oxygen diffuse through the stagnant layer to the biofilm, biodegradation products diffuse outward from the biofilm to the moving mixed liquor. These "back and forth" diffusion processes are continuous. Figure 3 above shows these diffusion processes.

As the microorganisms grow and multiply, the biomass on the biocarriers grows, or thickens. Biomass thickening affects the ability of dissolved oxygen and substrate in the reactor to "reach" all of the biofilm microorganisms. Microorganisms in the outer layers of the biofilm have "first access" to the dissolved oxygen and substrate diffusing through the biofilm. As the dissolved oxygen and substrate diffuses through each subsequent layer in the biofilm, more and more is consumed by the microorganisms in the preceding biofilm layers. The decrease of available dissolved oxygen through the biofilm produces aerobic, anoxic and anaerobic layers in the biofilm.

Different biological action occurs in each of those layers as specific microorganisms grow in the different environments within the biofilm. An examination of the microorganisms in each layer of the biofilm will show a population best suited for the oxygen/substrate environment in that layer. In the upper layers of the biofilm, where dissolved oxygen and substrate concentrations are high, the microorganism population will be aerobic higher level organisms. Deeper into the biofilm, where the oxygen and substrate concentrations decrease, facultative bacteria are the predominant microorganism present. In those layers nitrification occurs as nitrates become "electron acceptors of choice" for the facultative bacteria.

Eventually, microorganisms at the biofilm/bio-carrier interface will be adversely affected by the decrease in substrate and oxygen reaching their layer in the biofilm. As the microorganisms in the biofilm's attachment layer weaken, the shearing action of the moving mixed liquor washes the biofilm away from the biocarrier. The washing away process, referred to as sloughing, is a function of both hydraulic and loading rates in the reactor.

Sloughing does not compromise treatment. It allows the MBBR biofilm technology carriers to be self-regulating and maintenance free. Figure 4 depicts the decrease in the oxygen and substrate concentration through the biofilm.

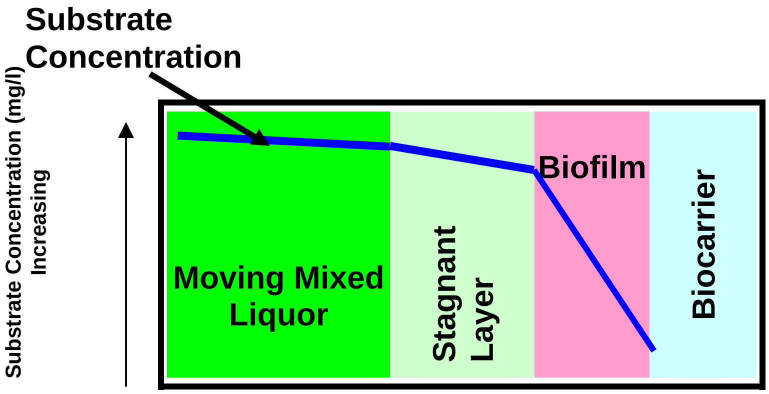
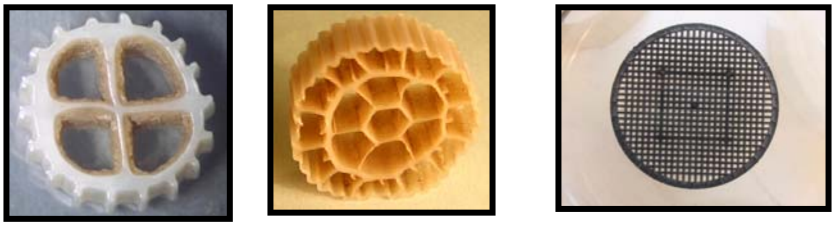


Figure 4
Substrate concentration as a Function of Biofilm Depth

Selecting the MBBR Biocarriers

As described earlier, in the MBBR biofilm technology the biofilm grows in a "protected environment" within engineered plastic carriers. The main goal of biocarrier design is to provide a high internal surface area that will promote biofilm growth in a protected environment. Proper design of the biocarriers is critical to successfully ensure efficient mass transfer of both substrate (food) and oxygen to the biofilm microorganisms.



K1 **K3** **Biochip P**

Figure 5 - Examples of Biocarriers Produced by AnoxKaldnes

Table 1 presents the available internal surface areas for the biocarriers presented in Figure 5.

Table 1
AnoxKaldnes Biocarriers and Available Internal Surface Area

Model	Length (mm)	Diameter (mm)	Protected Surface Area[1,3] (ft^2/ft^3)	Total Surface Area[2,3] (ft^2/ft^3)
K1	7	9	152	243
K3	12	25	152	182
Biofilm-Chip P	3,0	45	273	300

Notes:

1. Protected surface area is the biocarrier internal area.
2. Total surface is the internal "protected" area plus the external surface area of the biocarrier.
3. Area is the available area provided by the specific biocarrier filling a known volume, in this case a cubic meter volume.

Selection of which biocarrier is employed in the MBBR is an engineering design decision. Typical design factors considered in selecting the type of biocarrier include:

- Influent concentrations
    - BOD/COD
    - TSS
    - Nitrogen
    - Phosphorous
    - Alkalinity
- Operating temperature
- MBBR Treatment process selected
- Existing basin configuration (when applicable)

For the Lone Oak WWTP, the treatment focus was nitrification. As there were no existing basins for conversion, the design of the MBBR focused on the most cost effective reactor configuration for the existing two lagoon treatment system. The biocarrier selected for the WWTP MBBR was the K1.

Aeration and Mixing Systems

Aerated reactors in the AnoxKaldnes MBBR biofilm technology process can employ either diffused air or jet aeration. The goal of either system is to provide oxygen to the biofilm, along with the mixing energy required to keep the biocarriers suspended and completely mixed within the reactor.

AnoxKaldnes classifies the diffused air system employed in the MBBR process as a medium bubble system. With the biocarriers, the transfer efficiency is quite effective. The improved efficiency is the result of the biocarriers physical interaction with the medium bubbles.

The MBBR aeration system is all stainless steel construction. Aeration grids are floor mounted, with individual diffuser laterals branching from larger header pipes. Air flows from the laterals into the liquor in the MBBR reactor through four millimeter openings drilled into the underside of each lateral. The spacing of both the diffuser holes and the laterals on the header pipes are functions of the air volume and flowrate requirements of the specific MBBR design. Figure 6 shows a MBBR diffused aeration system installation in a rectangular basin.

Figure 6
MBBR Diffused Aeration System

The Lone Oak WWTP design employs a single grid aeration system in each MBBR reactor.

Jet aeration is an alternative to diffused aeration. In jet aeration a two phase gas/liquid contactor is used to provide mixing action and to inject the required dissolved oxygen into the reactor. Pumping a high velocity liquid stream through the injector, while injecting air into that stream, creates hydrodynamic conditions that produce very efficient oxygen transfer and mixing performance. Figure 7 shows a slot injector installation.

Figure 7
Slot Injector Aeration System

An analysis of the aeration requirements at the Lone Oak WWTP identified diffused aeration as the most cost effective aeration method for this project.

MBBR Influent and Effluent Screens (Sieves)

In a MBBR system treated wastewater flows from the MBBR reactor through a grid or sieve. The sieve retains the MBBR biocarriers in the reactor, while allowing the mixed liquor to flow from the reactor. Sieve design in the MBBR each reactor is based on a maximum headloss of 2-inches at the plant peak flow rate. MBBR processes can employ two different sieve types, a circular wedge wire type, and a flat screen type. Type of sieve used is dependent upon the MBBR process. Figure 8 shows a circular wedge wire sieve arrangement in a MBBR biofilm reactor. Figure 9 is a close up photograph of that type of sieve. A flat screen type sieve, such as shown in Figure 10, was required for the Lone Oak WWTP design.

Figure 8
Circular Wedge Wire Sieve Installation

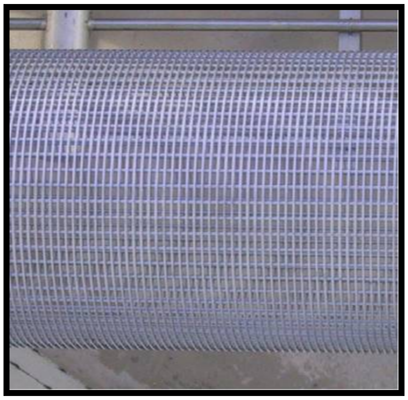


Figure 9
Close View of Wedge Wire Sieve

Figure 9
Typical Flat Screen Sieve Installations

Design of Ammonia Removal in a Lagoon Treatment System

In a municipal lagoon application, the Total Kjeldahl Nitrogen (TKN) equals the ammonia concentration. TKN is the measure of the total organic and ammonia nitrogen concentrations. For a lagoon treatment system, such as the Lone Oak WWTP, (a post-nitrification system), the design engineer will assume the entire organic nitrogen (N) hydrolyzes into ammonia. In such instances then, the TKN equals the ammonia concentration.

For the MBBR design, the influent ammonia concentration can be estimated given the lagoon effluent BOD concentration. Wastewater treatment bacteria generally consume 4 to 5 mg/l of ammonia for every 100 mg/l BOD. Following that guide, the ammonia concentration in the MBBR reactor can be calculated using the following equation.

Influent Ammonia (or TKN) Concentration (mg/l) to Lagoons
– [(4 mg/l NH_3/100 mg/l BOD) *X* Influent BOD Concentration (mg/l) to Lagoons

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Influent Ammonia Concentration (mg/l) into MBBR post-nitrification system

To demonstrate this concept, assume the lagoon influent BOD concentration is 200 mg/l and the influent ammonia concentration is 40 mg/l. Then, the expected MBBR reactor influent ammonia concentration will be:

40 mg/l (Influent Ammonia to Lagoon)
– [(4 mg/l NH_3/100 mg/l BOD) *X* 200 mg/l (Influent BOD to Lagoon)]

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32 mg/l (Influent Ammonia concentration into MBBR reactor)

Knowing the MBBR influent ammonia concentration, and the desired MBBR effluent ammonia concentration, the design engineer can calculate the overall amount of ammonia that must be nitrified in the MBBR reactor. The following equation presents calculation.

Influent Ammonia (or TKN) Concentration (mg/l) to Lagoons
– [(4 mg/l NH_3/100 mg/l BOD) *X* Influent BOD Concentration (mg/l) to Lagoons
– Desired MBBR Reactor Effluent Ammonia Concentration (mg/l)

Ammonia Concentration (mg/l) to be nitrified in the MBBR reactor

FINAL DESIGN

Table 2 presents the final design elements and parameters for the Lone Oak WWTP MBBR system.

Table 2
Lone Oak WWTP
Final Design

Parameter	Value
Average Daily Design Flow (ADF)	40,000 gal/day
Maximum Flow (for treatment design)	120,000 gal/day
Peak Flow (For Sieve Design)	500,000 gal/day
Influent BOD$_5$ (Total) to MBBR	35 mg/l (12 lb/day)
Influent TSS to MBBR	45 mg/l (15 lb/day)
Influent NH$_3$-N to MBBR	15 mg/l (5 lb/day)
Effluent Soluble BOD$_5$ from MBBR	<30 mg/l
Effluent NH$_3$-N - 30-day Avg. Conc.	< 3 mg/l
Effluent NH$_3$-N - 7-day Avg. Conc.	< 6 mg/l
Effluent NH$_3$-N - Daily Max	<10 mg/l
Effluent NH$_3$-N – Single Grab	<15 mg/l
Wastewater Temperature – Minimum	8^{o} C
Wastewater Temperature – Maximum	31^{o} C
pH	6.0 – 9.0
Number of Process Trains	1
Number of Reactors per Process Train	2
MBBR Dimensions	7 ft x 7 ft x 10 ft SWD
Effective Water Volume	7,330 gal
Freeboard	2 ft
Total MBBR Structure Wall Height	12 ft
MBBR Aeration Type	Medium bubble
Design Residual Dissolved Oxygen	4.0 mg/L summer; 6.0 mg/L winter
Total Actual Oxygen Requirement (AOR)	1.5 lb/hr
Total Standard Oxygen Requirement (SOR)	3.9 lb/hr
Required Air Flow	55 SCFM
Aeration System Supply Header Diameter	2-inch
Blower Pressure Required	3.89 psig (static water pressure)
	0.75 psig (for line losses)
	4.65 psig total at inlet flange to MBBR aeration system
Percent Biocarrier Fill in MBBR	50%
Biocarrier Volume	494 ft^3
Surface Area Loading Rates (BOD)	3.5 g Total BOD/m^2-day
Surface Area Loading Rates (NH$_3$-N)	0.7 g NH$_3$-N/m^2-day
Sieve Assemblies – Number per MBBR Reactor	1
Sieve Assembly Type	Flat Screen
Sieve Assembly Dimensions	4 ft wide x 5 ft long

INSTALLED EQUIPMENT

The following photographs present various post construction views of the MBBR installation at the Lone Oak WWTP.

Figure 10
MBBR Reactors with Positive Displacement Type Aeration Blower

Figure 11
MBBR Structure Showing Reactor #1 Effluent Sieve
White material in reactor is biocarriers (prior reactor going online)

Figure 12
MBBR Reactor #2
Overhead view showing Aeration System Down Header, Effluent Sieve on Wall at Left Biocarriers (white, snow like material in reactor). The brown material is leaves that have fallen into the reactor. Prior to the reactor being placed online view.

Figure 12
Final Effluent Sieve in MBBR Reactor #2

Figure 13
MBBR Structure in Background – Lagoon #2 Effluent Structures in Foreground

CONCLUSION

Employing MBBR technology enabled the City of Lone Oak to improve the treatment capability of the existing WWTP. By adding MBBR technology after the second treatment lagoon, the City introduced post-nitrification capability to the WWTP in a cost effective manner. That enabled the City to comply with the WWTP discharge permit requirements and avoid TCEQ administrative action and associated fines.