FLAT SHEET MEMBRANE BIOREACTOR OPERATIONAL EXPERIENCES – A NEW ZEALAND PERSPECTIVE

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ABSTRACT

Membrane bio-reactor (MBR) technology is a relatively recent and maturing wastewater treatment technology in Australia and New Zealand. As such literature on actual operational experiences with full scale MBR plants in Australasia and how these experiences may be translated into design and operational improvements is somewhat limited.

This paper discusses the operational experiences and the lessons learnt regarding operating full-scale flat sheet MBR municipal wastewater treatment plants. In particular the discoveries made when the first three of these types of treatment plants installed in New Zealand (at Tirau, Turangi and Te Aroha) have been drained down for routine membrane cleaning, membrane inspection, and damaged membrane replacement over the first 8 years of operation.

All three of the subject MBR plants experienced varying degrees of sludge caking between the individual membrane panels and lint build-up around the membrane module housings and associated appurtenances. The contributing factors and mechanisms for membrane caking, associated membrane performance parameters and operational issues are discussed. Membrane failure rates after 8 years of operation at the Tirau and Te Aroha MBR plant are also discussed.

KEYWORDS

Membrane Bioreactor, MBR, Membrane Fouling, Membrane Caking, Membrane Inspection, Membrane Cleaning, Membrane Maintenance, Membrane Failure Rate

1.0 INTRODUCTION

The membrane bio-reactor technology is gaining popularity globally as a result of increased effluent quality requirements and continued drivers to minimise treatment plant footprints. The technology is proving to be successful in meeting these objectives, however, there is a lack of practical operational information available to assist plant operators and designers to optimise the technology.

A number of variations of membrane are available, the most common of which for municipal wastewater are: flat sheet, hollow fibre, tubular, capillary tube, pleated filter cartridge and spiral wound. This paper focuses on experiences with the flat sheet style of membrane.

The flat sheet MBR plants at Turangi, Te Aroha and Tirau were the first community scale municipal MBR installations in New Zealand and have been in operation since 2006. During membrane inspections at all three sites some degree of sludge caking was noted between the membrane sheets, as was a build-up of lint around the membranes, permeate tubes, coarse bubble diffusers, membrane module housings and associated appurtenances.

This paper discusses the cause and effect of the various observations during the membrane inspections. Improvements are suggested to reduce the occurrence of sludge caking and lint build-up.

1.1 Description of Kubota Flat Sheet Membrane Modules

The Kubota submerged membrane unit comprises the membrane and diffuser cases. Two of the three plants considered in this paper employ the Kubota EK400 membrane module which consists of two membrane cases, one stacked upon the other, with a single diffuser case at the bottom. The EK400 module holds 400 membrane sheets (200 in each membrane case). One of the three plants considered in this paper (Tirau WWTP) employs the Kubota ES200 membrane module which consists of one membrane case stacked upon a diffuser case below. The ES200 module holds 200 membrane sheets in a single case.

The sheets sit at 7 mm spacing from one another. The membrane sheets have a nominal pore size of 0.4 micron. Sheets of chlorinated polyethylene are ultrasonically welded to both the front and back of an ABS panel. The filtered water (permeate) is collected through a series of recessed channels formed in the panel surface that lead to a nozzle located at the top of the panel. Permeate is forced by the water head through each membrane panel up through the nozzle to a collection tube above the membranes. The permeate is then conveyed from the tubes into a common permeate header. The header pipe then connects into the plant's permeate pipework system. The three MBR plants that are the subjects of this paper operate under gravity permeate discharge.

The diffuser case supports the modules off the base of the tank whilst also housing the coarse bubble aeration diffusers. These diffusers are critical to the performance of the system and perform two key roles: to provide oxygen for the biological process and to scour the membrane surface to prevent fouling.

1.2 Key Indicators for Membrane Performance

The key performance indicator for the flat sheet membranes is the relationship between trans-membrane pressure (TMP) and membrane flux rate. TMP is effectively the pressure loss across the membrane module, and as such this provides a measure of the degree of membrane fouling. Over time the TMP for a given flux rate will slowly trend upwards, even after the plants specific air scour (commonly known as membrane relaxation) phase. Eventually a chemical clean in place (CIP) is required to reverse the fouling and restore the performance of the membrane.

1.3 Specific Treatment Plant Information

The configuration and key information relating to the three MBR plants discussed in this paper are presented in the following table.

Table 1: ***WWTP summary data***

Parameter	Units	Turangi	Tirau	Te Aroha
Year Commissioned	AD	2006	2006	2006
Average Dry Weather Flow (ADWF)	m^3/d	1250	300	1775
Peak Wet Weather Flow (PWWF)	m^3/d	1600	900	9805*
Maximum Flow to Treatment (MFT)	m^3/d	2074	440	2407
Inlet Screen		3mm perforated plate spiral sieve	3mm perforated plate spiral sieve	2mm perforated plate spiral sieve
Membrane Module Model		Kubota EK400	Kubota ES200	Kubota EK400
Number of Modules		12	4	12

** Flows in excess of MFT capacity are treated through pre-existing oxidation ponds*

1.4 Membrane Sheet Sludge Caking

At each of the three plants varying degrees of sludge caking was observed between the membrane sheets at the time of the first membrane inspection. The severity of the sludge caking differed from plant to plant and from module to module. The sludge caking at the Turangi WWTP during the first inspection there was the most prolific and severe.

The sludge caking at its worst was extremely thick and well compacted, forming an almost dry dense and brittle cake, which completely filled the void between the sheets. In slightly less severe cases the space between the sheets was filled but the level of compaction was less, leaving the caking with more typical sludge characteristics.

Figure 1: ***Sludge caking between membrane sheets (Te Aroha 24/05/2010) causing displacement of neighbouring sheets***

2.0 CONTRIBUTING FACTORS TO SLUDGE CAKING

The key contributing factors for the presence of sludge caking between the membrane sheets are discussed below.

2.1 Inlet Screening and Lint Build Up

Satisfactory influent screening is vital for the protection of the downstream membranes. The membranes are relatively fragile and can easily be damaged by sharp objects in the waste stream. To protect the membranes most suppliers specify a screening aperture size of between 1 and 3 mm in all directions.

During the initial inspection of the Turangi WWTP a very high membrane sheet failure rate was observed, in the order of 30% over a three year period. It was discovered that the screen installed was not in accordance with the original design specification. The design called for a 3 mm perforated plate screen, however, a 5 mm perforated plate was installed. It is suspected that this was the main cause of the high failure rate, however pieces of a plastic warning sign that had fallen into the tanks and been smashed up by a mixer were also discovered during the inspection.

The plant at Te Aroha which had the correct screen had a sheet failure rate of less than 2% on its first inspection within a similar timeframe from the commissioning of the plant. The reported annual failure rate of membranes at the Tirau plant is 5% with no noticeable increase in failure rate over time. In the 4 year period between 2010 and 2014 inspections, the Te Aroha plant recorded a membrane failure rate of around 30% (7.5% per annum).

From observation it appears the inlet screening is required to do more than simply protect the membrane sheets from physical damage. The inlet screening stage must also have a high efficiency in removing lint and hair to minimise the amount of this material entering the reactors as the presence of this fibrous material was observed to interfere with the uniformity of the coarse bubble aeration. This is caused by a build-up (agglomeration) of lint and hair at the base of the membrane banks and around the permeate tubes of the lower bank restricting the free passage of airflow between the sheets above the lint agglomerations. Figure 2 illustrates an example of severe lint/hair agglomeration at the base of a membrane module. Significant sludge caking was observed between the membrane sheets above.

Figure 2: ***Example of lint/hair agglomeration under membrane module (Turangi WWTP)***

It is recommended that MBR plants are fitted with inlet screens with an aperture size of 1-2mm in all directions with a type of screen that has a 90° change of direction in the water flow as the water passes through the aperture to prevent hair and fibres from "streamlining" through the screen holes. Also screens that have a cleaning mechanism that tends to push material through the screen apertures in the direction of flow should be avoided in MBR installations.

2.2 Coarse Bubble Aeration Settings

Correct performance of the coarse bubble aeration system is the single most important parameter for protecting against developing sludge caking. It is critically important that the blower system design and operation is set up correctly to provide the necessary scour air flow rates as prescribed by the membrane manufacturer.

Early in 2009, after nearly three years of operation at the Turangi WWTP it was discovered that the coarse bubble aeration system was not delivering sufficient air flow in comparison to the membrane suppliers specified air flow rate. The shortcoming in aeration delivery appeared to have arisen from an error in the configuration of the blower variable speed drive set points during commissioning. Upon increasing the aeration to the specified flow rate the plant performance was noted to increase significantly.

If permeation occurs without coarse bubble aeration the membranes will foul very rapidly. It is very important that all flat sheet MBR plants include suitable interlocks to prevent this scenario from occurring i.e. permeate valves cannot be in an open state without the coarse bubble aeration system in operation.

2.3 Coarse Bubble Diffuser Blockage

Deterioration of the coarse bubble aeration pattern was witnessed at all three plants over time. Upon draining and cleaning of the reactor tanks at the Te Aroha WWTP, the membrane tanks were partially refilled with clean water and the coarse bubble aeration system operated. The purpose of this was to check the uniformity of the coarse bubble aeration pattern prior to reinstalling the cleaned and refurbished membrane modules. As can be seen in Figure 3 below (left) considerable variation in aeration intensity was evident across each module and from module to module.

<u>Figure 3</u>: ***Coarse Bubble Aeration Pattern Pre Diffuser Cleaning (left) and Post Diffuser Cleaning (right) [Te Aroha WWTP]***

The locations of poor coarse bubble air flow noted during the initial uniformity check correlated very well with the areas of heavy sludge caking observed during the sheet inspection. The membrane tanks were drained and the diffusers were cleaned. Figure 3 (right) shows the aeration pattern after the diffuser cleaning operation.

Inspection of the coarse bubble aeration diffusers at both the Turangi WWTP and the Te Aroha WWTP showed significant blockages in both the lateral diffuser pipes and the diffuser nozzles. A significant amount of sludge was extracted from the majority of the diffusers, however, the areas of poorest air flow were not obviously more significantly blocked than the other areas. Figure 4 illustrates the diffuser cleaning process.

<u>Figure 4:</u> ***Coarse bubble aeration diffuser cleaning [Te Aroha WWTP]***

The postulated contributing causes of the coarse bubble aeration diffuser blockage are a combination of:

- Ineffective inlet screening – poor fibrous solids capture efficiency allowing large amounts of hair and lint into the treatment plant and;

- The current method of diffuser flushing – in the diffuser flush sequences a venturi effect is induced in the diffuser pipework drawing MLSS into the diffuser pipework. The shear force induced by the fluid flow is intended to clear the diffuser nozzles of fouling and sludge build up. However, it is hypothesised that fibrous material present in the MLSS (lint and hair) drawn into the diffusers during the flushing sequence leads to blockages in the diffusers, which once blocked is followed by the accumulation of sludge. This hypothesis is supported by the observation of hair and lint within the sludge removed from the diffusers during the diffuser cleaning procedure.

3.0 CONCLUSIONS & RECOMMENDATIONS

Based on the observations made over the first eight years of flat sheet MBR plant operation in New Zealand and the findings from plant inspections undertaken at Turangi WWTP, Te Aroha WWTP and Tirau WWTP a number of potential improvements are suggested below that could improve plant performance and operability. It was noted at all three sites that the inlet screen (despite meeting the membrane supplier's specifications) was failing to provide the process with suitable protection from lint and hair. The other key area which was noted to underperform was the coarse bubble aeration system which was observed to be unable to provide uniform scouring air in the process conditions and as a result sludge caking was observed at all three plants. The sludge caking ultimately reduced the achievable permeate flux from the membranes.

Some of these suggested improvements have the potential to be retrospectively incorporated into operational plants, but all should be considered at the design stage of any future flat sheet MBR plants.

Suggested Improvements

1. Improved Influent Screening (1-2mm with 90° direction change)
2. Continuous MLSS Screening (e.g. RAS screening)
3. Alternative Diffuser Flushing Methods (e.g. high volume flushing with permeate)
4. Fail Safe Systems to prevent permeation without aeration
5. Continuous Monitoring of Coarse Bubble Aeration Flow Rates
6. Design of Facilities for Easy Tank Draining and Membrane Cleaning

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