# 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. As such literature on actual operational experiences with full scale MBR plants 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) were drained down for routine inspection and maintenance.

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 along with observable operational warning signs of the onset of sludge build-up between the membrane panels.

How the membrane inspection and cleaning process was planned and executed is discussed along with lessons learned both operationally and from a treatment plant design perspective as to how this process can be done most efficiently to minimise both cost and treatment plant down-time.

## KEYWORDS

**Membrane Bioreactor, MBR, Membrane Fouling, Membrane Caking, Membrane Inspection, Membrane Cleaning, Membrane Maintenance.**

# 1 INTRODUCTION

The membrane bio-reactor (MBR) process is a relatively recent and emerging technology. However, since the construction of the first MBR plants in the early 1990s the technology has experienced, and continues to experience, significant growth. Globally the number of MBR plants has increased considerably over recent years, but more significantly for this paper is the recent increase in the New Zealand market. Since the installation of the first community MBR plant in 2006 (Tirau WWTP) the number of new and proposed installations across the country has been considerable.

The MBR process was historically seen as a high cost, high risk option. The membrane equipment was expensive and the operating life expectancy of the membranes relatively uncertain. As the technology has matured and the number of suppliers on the world market has increased the capital cost of the membrane equipment has decreased. In conjunction with this the increasing drivers for higher quality effluent and smaller footprint treatment plants has resulted in the technology becoming competitive with conventional activated sludge plants, especially where the building site is limited and a small plant footprint is essential.

Despite a continued trend in the increasing use of the MBR process for waste water treatment there is a lack of published operational advice and experiences available. The MBR process requires the plant operators to have a high level of skill to ensure optimal operation and early detection of degradation in membrane performance. As such literature providing information from other plants operational experiences will provide valuable assistance to operations staff.

The MBR plants at Turangi, Te Aroha and Tirau were the first community scale municipal MBR installations in New Zealand. The oldest of which, the Tirau Wastewater Treatment Plant (WWTP), has been in operation for four years. Each of these plants has undergone some form of membrane inspection recently, allowing observations on plant performance to be made. 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.

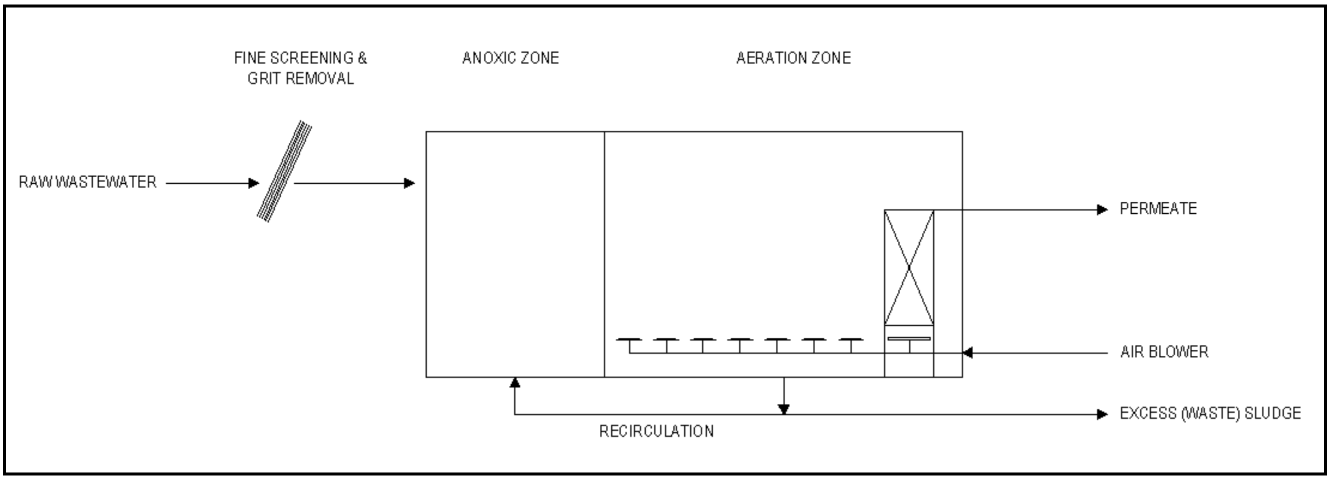
This paper presents the findings from the recent plant inspections and discusses the cause and effect of the various observations. In addition the cleaning and inspection procedure is discussed, along with the actual cost of this activity. Finally improvements are suggested to both reduce the risk of sludge caking and improve the efficiency with which the cleaning and inspection processes are undertaken.

## 1.1 MBR PROCESS OVERVIEW

To appreciate the operational observations and commentary included in this paper it is important to initially introduce the treatment process itself. The MBR process is a suspended growth activated sludge system which employs micro-porous membranes to filter solids, above the membrane pore size, from the mixed liquor suspended solids (MLSS). The liquid which passes through the membrane is known as permeate.

The biological process can be configured in a number of ways, however, a typical configuration is shown in Figure 1. In this example the plant consists of a basic 2 stage activated sludge plant configuration consisting of an anoxic zone and an aerobic zone, in which the membrane modules are installed.

*Figure 1: Typical Process Schematic for a Membrane Bioreactor System*




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.

## 1.2 SPECIFIC TREATMENT PLANT INTRODUCTION

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

### 1.2.1 TURANGI WWTP

The Turangi WWTP is located at the southern end of Lake Taupo and receives wastewater from the Turangi township catchment. The plant was commissioned in 2006.

Influent undergoes preliminary screening (3mm perforated plate spiral sieve screen) and grit removal prior to flowing via gravity to an anoxic zone and finally entering an aerobic tank in which the membrane modules are installed. The plant uses Kubota flat sheet membrane modules (model EK400). The original plant was fitted with eight modules, but an upgrade in 2009 increased the number of modules to twelve. The process is separated into two identical process trains, each with six EK400 modules.

The plant utilises one of the pre-existing oxidation ponds to provide flow balancing during high flow periods and wet weather events.

The key influent flow and load data and effluent quality criteria are summarised in Table 1 below.

*Table 1: Turangi WWTP Summary Data*

| Parameter | Units | Median or Average* | Peak or 95 %ile* |
|---|---|---|---|
| Current Average Dry Weather Flow (ADWF) | $m^3/d$ | 1250 | |
| Current Peak Wet Weather Flow (PWWF) | $m^3/d$ | | 1600 (peak) |
| Maximum Flow to Treatment | $m^3/d$ | | 2074 (max) |
| $cBOD_5$ – Influent | mg/l | 148 | 177 |
| TKN – Influent | mg/l | 48 | 63 |
| TSS – Influent | mg/l | 260 | 710 |
| $cBOD_5$ – Effluent | mg/l | 15 (median) | 30 (90%ile) |
| TN – Effluent | mg/l | 8 (median) | 15 (90%ile) |
| TSS – Effluent | mg/l | 20 (median) | 30 (90%ile) |
| Faecal Coliforms - Effluent | cfu/100ml | 100 (median) | 400 (80%ile) |

*Quoted as Average or 95%ile unless stated otherwise.

### 1.2.2 TE AROHA WWTP

The Te Aroha WWTP is located on the outskirts of the Waikato township of Te Aroha at the base of the Kaimai ranges. The plant receives wastewater from the Te Aroha township catchment. The plant was commissioned in late 2006.

Influent undergoes preliminary screening (2mm perforated plate spiral sieve screen) and grit removal prior to flowing via gravity to a combined ‘swing’ anoxic or aerobic zone (mode of operation dependant on overall DO demand) before entering the membrane tank in which the membrane modules are installed. The plant uses 12 Kubota flat sheet membrane modules (model EK400). The process is separated into two identical process trains, each with six EK400 modules.

The plant utilises the existing oxidation ponds to provide flow balancing during high flow periods and wet weather events.

The key flow and influent and effluent quality data are summarised in Table 2 below.

*Table 2: Te Aroha WWTP Summary Data*

| Parameter | Units | Median or Average* | Peak or 95 %ile* |
|---|---|---|---|
| Current Average Dry Weather Flow (ADWF) | $m^3/d$ | 1,775 (median) | |
| Current Peak Wet Weather Flow (PWWF) | $m^3/d$ | | 9,805 (Peak) |
| Maximum Flow to Treatment | $m^3/d$ | | 2,407 (max) |
| $BOD_5$ – Influent | mg/l | 90 | 170 |
| TKN – Influent | mg/l | 43 | 98 |
| TSS – Influent | mg/l | 214 | 478 |
| $cBOD_5$ – Effluent | mg/l | <1 (median) | 4 |
| TN – Effluent | mg/l | 22 (median) | 34 |
| TSS – Effluent | mg/l | <3 (median) | <3 |
| Faecal Coliforms - Effluent | cfu/100ml | <2 (median) | <2 |

*Quoted as Average or 95%ile unless stated otherwise.

### 1.2.3 TIRAU WWTP

The Tirau WWTP is located in the Waikato township of Tirau. The plant receives wastewater from the Tirau township catchment. The plant was commissioned in 2006 and was the first community scale municipal MBR plant commissioned in New Zealand.

Influent undergoes preliminary screening (3 mm perforated plate spiral sieve screen) and grit removal prior to flowing via gravity to a aerobic treatment tank in which the membrane modules are installed. The plant uses 4 Kubota flat sheet membrane modules (model ES200). The process is separated into two identical process trains, each with two ES200 modules.

The plant utilises an influent balance tank to provide flow balancing during high flow periods and wet weather events.

The key flow and influent and effluent quality data are summarised in Table 3 below:

*Table 3: Tirau WWTP Summary Data*

| Parameter | Units | Median or Average* | Peak or 95 %ile* |
|---|---|---|---|
| Current Average Dry Weather Flow (ADWF) | $m^3/d$ | 300 | |
| Current Peak Wet Weather Flow (PWWF) | $m^3/d$ | | 900 (peak) |
| Maximum Flow to Treatment | $m^3/d$ | | 440 (max) |
| $BOD_5$ – Influent | mg/l | 250 | N/A |
| Ammonia – Influent | mg/l | <40 | N/A |
| TSS – Influent | mg/l | 250 | N/A |
| $BOD_5$ – Effluent | mg/l | 3 | 4 |
| Ammonia – Effluent | mg/l | 3.2 | 4.4 |
| TSS – Effluent | mg/l | 4 | 5 |
| Faecal Coliforms - Effluent | cfu/100ml | <50 | <100 |

*Quoted as Average or 95%ile unless stated otherwise.

## 1.3 DESCRIPTION OF KUBOTA FLAT SHEET MEMBRANE MODULES

The Kubota submerged membrane unit is comprised of the membrane case and the diffuser case. The number of membrane sheets and the size and configuration of the membranes are dependent on the particular model. 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 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 (referred to by the supplier as the membrane cartridges) have a nominal pore size of 0.4 micrometer. The sheets themselves are manufactured by ultrasonically welding sheets of chlorinated polyethylene to both the front and back of an ABS resin panel. The filtered water (permeate) is distributed through a series of recessed channels formed on the panel surface that lead to a nozzle located at the top of the sheet.

The permeate is forced through the sheets and up the collection hose by the water head above the membranes. The collected permeate is then conveyed from all the sheets into a common permeate header. This header pipe then connects into the plant's permeate pipework system. The three MBR plants that are the subject of this paper operate under gravity permeate discharge. An alternative configuration is to use a pump to draw the fluid through the sheets under suction. Under the gravity scenario the permeate pipework includes a control valve to regulate the flow rate and hence control the membrane flux rate, expressed with the units $m^3.m^{-2}.d^{-1}$. For the pumped regime the pump flow rate would be adjusted to control the membrane flux rate.

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 three key roles:

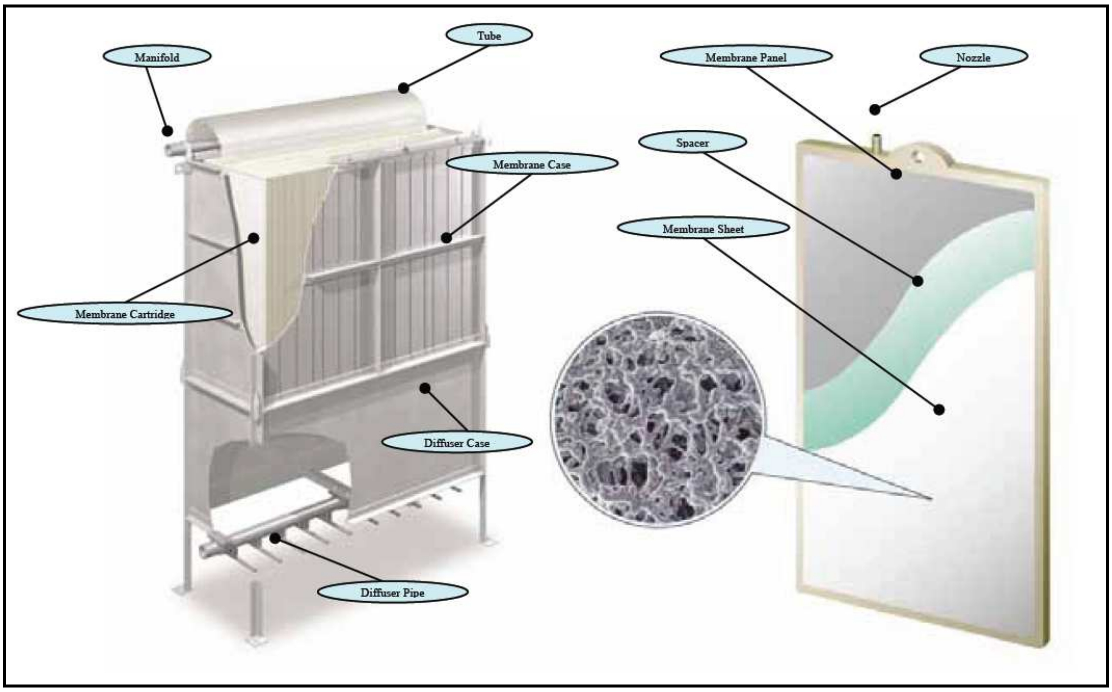
1. To provide oxygen for the biological process

2. To scour the membrane surface to prevent fouling

3. To assist with permeation by creating a specific density difference between the inside and the outside of the membrane unit which induces an MLSS current through the module.

Details of a typical Kubota flat sheet membrane module is shown in Figure 2.

*Figure 2: Kubota Submerged Membrane Unit Details*




### 1.4 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.

## 2 MEMBRANE SHEET SLUDGE CAKING

At each of the three plants considered for the purposes of this paper, 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 observed at the Turangi WWTP was the most prolific and severe.

The sludge caking at its worst was extremely thick and well compacted, forming an almost 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. In Photograph 1 below it can be seen that the sludge cake between the sheets is sufficiently thick in places to displace the neighbouring sheet. Photograph 2 provides examples of some of the more severe sheet fouling observed. Finally, Photograph 3 provides three examples of the spectrum of lesser degrees of sludge caking witnessed, including an example of a sheet with no fouling.

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

*Photograph 2: Examples of severe sludge caking [from left; Te Aroha WWTP (26052010), Te Aroha WWTP (27052010)*

*Photograph 3: Examples of spectrum of sludge caking observed*

# 3 CONTRIBUTING FACTORS TO SLUDGE CAKING

Over the course of the three inspection procedures hypotheses were postulated as to the possible causes of the membrane sheet sludge caking observed. Various observations and comparisons were made to determine the key contributing factors to the sludge caking and a number of conclusions were drawn. The key contributing factors for the presence of sludge caking between the membrane sheets are discussed below.

## 3.1 INLET SCREENING & LINT BUILD UP

Satisfactory influent screening is vital for the protection of the downstream membrane modules. The membrane sheets themselves 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 inspection of the Turangi WWTP a very high membrane sheet failure rate was observed, in the order of 30%. An investigation was undertaken into the cause of the unexpectedly high failure rate and 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. In support of this theory the plant at Te Aroha which had the correct screen had a sheet failure rate of less than 2% upon its first inspection within a similar timeframe from the initial commissioning of the plant.

However, 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 adequately remove lint and hair from 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. Photograph 4 illustrates an example of severe lint/hair agglomeration at the base of a membrane bank. Significant sludge caking was observed between the membrane sheets above.

*Photograph 4: Example of lint/hair agglomeration at the base of a membrane module (Turangi WWTP)*

At the Tirau WWTP the operators have employed a low cost, innovative approach to reduce the quantity of lint build up within the reactor tanks. The operators are using ‘Copasac’ sacks on the discharge of the screen and grit removal to provide additional screening. Currently the sacks are replaced weekly. The plant has been operated in this manner for over a year and a significant decrease in lint build up was noted at the plants most recent inspection (undertaken April 2010). Photograph 5 illustrates the system in place and also displays the quantity of lint captured on a used sack.

*Photograph 5: Crude additional screening provided at the Tirau WWTP to reduce quantities of ling entering process*

## 3.2 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 therefore 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.

In support of the importance of the correct operation of the coarse bubble aeration system, the case study of the Turangi WWTP is of use. Early in 2009, after nearly three years of operation 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 variable speed drive set points. Upon increasing the aeration to the specified flow rate the plant performance was noted to increase significantly, that is the plant was able to be operated at a high flux rate and achieve similar TMPs.

This was further evidenced by the relatively uniform presence of sludge caking across all sheets at the Turangi WWTP during the first inspection in comparison to the isolated instances of sludge caking seen at with Te Aroha WWTP during its first inspection.

If permeation occurs without coarse bubble aeration the membranes will foul at an accelerated rate. Without coarse aeration there is no air scour or induced MLSS current and as such sludge accumulation of the sheet faces is extremely rapid in this scenario. It is very important that all MBR plants include suitable interlocks to prevent a scenario such as this from occurring i.e. permeate valve cannot be in an open state without coarse bubble aeration system in operation. There were observed instances on the SCADA trending of the Turangi WWTP where very short duration power supply interruptions had caused the course bubble blowers to trip-out, however the plant UPS had not registered a power supply failure, which would have immediately closed the permeate valves. Instead the permeate valves closed after a time delay due to “low coarse bubble air flow” alarm. While this delay was less than 1 minute, the TMP across the un-aerated membrane banks was observed on the SCADA trending to rise very rapidly.

## 3.3 COARSE BUBBLE DIFFUSER BLOCKAGE

Deterioration of the coarse bubble aeration pattern was witnessed at all three plants over the period of operation. 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 cases. As can be seen in Photograph 6 below (left) considerable variation in aeration intensity was evident across each module and from module to module.

*Photograph 6*: *Coarse Bubble Aeration Pattern Pre-Cleaning (left) and Post 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. Photograph 6 (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. Steel rods were used to dislodge the sludge from within the lateral pipes and high pressure water was used to remove blockages from the 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. Photograph 7 illustrates the diffuser cleaning process.

*Photograph 7: 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 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.

### 3.4 OPERATING MLSS RANGE

The membrane supplier recommends a MLSS operating range of between 8,000 and 18,000 mg/l, with optimal performance at approximately 12,000 mg/l. Operating the membranes at MLSS concentrations above and below the recommended range can lead to degradation in the membrane performance, and hence decreased throughput.

If the MLSS concentration is too low the wastewater’s ability to flocculate decreases and as such the material the membrane is required to filter becomes finer. It is thought that the increase in fine materials leads to blockage of the membrane pores, further decreasing the effective pore size and as a result decreasing the throughput. The reduction is effective pore size also causes an increase in the collection of sludge on the sheet. This collection of sludge will form caking if the scour is insufficient to remove the solids build up. The shear forces imparted on the surface of the membranes is a function of the coarse bubble air flow and the viscosity of the MLSS. At low MLSS concentrations the MLSS viscosity is low and hence the shear forces for membrane scouring are reduced.

It has been observed that if the MLSS concentration is too high the permeate flux decreases (Judd S.). This phenomenon has been attributed to the rapid formation of a fouling cake layer at the higher MLSS concentrations. It is thought that this cake layer provides additional protection to the membrane whilst also improving the degree of filtration. The additional filtration layer ultimately restricts the potential flux of the membranes.

## 4 OPERATIONAL WARNING SIGNS

### 4.1 COARSE BUBBLE AERATION PATTERN

As discussed previously, the correct and optimal operation of the coarse bubble aeration system is critical to prevent the build up of sludge caking and as such the overall operation of the MBR plant. One of the key indicators of potential membrane sludge caking is a reduction in the intensity of the observed aeration pattern or the appearance of ‘dead’ zones or unevenness in the aeration pattern.

Unfortunately in practice the aeration pattern is a difficult parameter to observe and quantify whilst the tank is in operation. The coarse and turbulent nature of the flow means that visually assessing the pattern from the surface level does not provide a true representation of the performance of the aeration system beneath until there is a significant level of blockage and caking occurring.

### 4.2 PLANT PERFORMANCE

Over time the TMP at a given flux rate will slowly increase as the membrane sheets foul. This slow membrane sheet fouling is a normal aspect of operation and the membrane supplier recommends routine maintenance procedures to restore the performance of the membrane sheets. When dealing with membranes for wastewater applications fouling is typically divided into three categories:

1. ***Reversible*** Fouling Reversible by mechanical cleaning mechanisms, such as back pulsing with permeate or membrane relaxation

2. ***Irreversible*** Fouling Irreversible by mechanical cleaning mechanisms but reversible by chemical cleaning

3. ***Irrecoverable*** Fouling Irreversible by any form of cleaning

At the three MBR plants discussed in this paper the membranes undergo frequent relaxation periods where permeation is suspended and the coarse bubble air flow rate is increased for a short period. At the time of writing:

- At Turangi WWTP relaxation occurs for 1 minute in every 10 minutes.

- At Te Aroha WWTP relaxation occurs for 1 minute every 30 minutes.

- At Tirau WWTP relaxation occurs for 2 minutes every 30 minutes.

In addition to this the Te Aroha WWTP also incorporates an extended relaxation period once per day. These phases are the same as the normal relax phases except undertaken for a longer duration (at Te Aroha WWTP half an hour every six hours). The relaxation operations are intended to reverse the *reversible* fouling.

To prevent and maintain the level of *irreversible* fouling Kubota[1] recommends a schedule of *recovery* chemical cleans. Kubota recommends a six monthly clean in place (CIP) with sodium hypochlorite (hypo) and a bi-yearly citric acid clean. Hypo is used to remove biological growth from within and on the surface of the membrane sheets. Citric acid is used to remove any inorganic build-up on or within the membrane sheets. Kubota also recommend that additional cleans be undertaken if the TMP reaches a critical high level.

After undertaking either of the cleaning procedures mentioned above a decrease in TMP should be observed. As the membranes age it may be observed that even following the cleaning procedures the membrane are unable to return to their original operational performance levels. This observation will tend to indicate one of two things (or a combination of both); *irrecoverable* fouling or the presence of sludge caking.

Sludge caking is a form of *reversible* fouling that is unable to be removed through the conventional in-situ cleaning methods. Both *irrecoverable* fouling and sludge caking will present in the same manner, as an increase in TMP which is not restored through in-situ physical or chemical cleaning procedures.

The only method to determine whether the cause of the decrease in plant performance is due to sludge caking is to draw down the tank level and visibly inspect the sheets for sludge build up within the interstitial space. However, as a rule of thumb it is likely that unexpected signs of *irrecoverable* fouling early in the membrane life (< 5 years) would be more likely to be as a result of sludge caking.

# 5 MEMBRANE CLEANING AND INSPECTION

Kubota[1] recommend that the membrane modules are inspected once every three years. It is recommended that this inspection include; replacing the retaining rubbers, replacing the permeate tubes and replacing the membrane sheets as required (estimated life span three to seven years).

The Turangi, Te Aroha, and Tirau MBR plants recently undertook the recommended inspection. This section of the paper summarises the details and logistics of the procedure, whilst making recommendations as to how future inspections could be undertaken more efficiently to reduce the operational cost and impact of the procedure.

## 5.1 INSPECTION OBJECTIVES

The objectives of the procedure were for the most part common across the three plants. The objectives of the clean and inspection procedure are listed below:

- To undertake a condition assessment of the membrane assets, including individual inspection of each sheet to identify any failures that could degrade effluent quality

- To remove any sludge caking from between the membrane sheets and restore the modules to an ‘as new’ condition

- To replace the permeate tubes (not undertaken at the Tirau WWTP)

- To inspect the coarse bubble aeration diffusers for signs of wear, damage or decreased performance (not undertaken at the Tirau WWTP

- To inspect the fine bubble aeration diffusers for signs of wear, damage or decreased performance

- To clean out the reactor tanks of any accumulated settled solids

- To restore the plant performance to as close to the original levels as possible

## 5.2 PLANNING

Undertaking the inspection process presented a number of logistical and operational challenges as the procedure had to be undertaken on live treatment plants. As a result it was vital to ensure the process was sufficiently planned to enable the procedure to be undertaken efficiently therefore minimising the plant down time. Fortunately as all three of the plants operate a two train configuration and have influent flow balancing (all) the ability to discharge from oxidation ponds while meeting resource consent requirements (Te Aroha only) it was possible to undertake the inspection on one process train while maintaining 50% treatment capacity through the MBR with storage or alternative treatment of the balance of incoming flows.

The inspection process at Turangi presented greater challenges than encountered at the other plants due to the strict resource consent conditions. The conditions meant that discharge from the existing oxidation ponds (now only used for flow balancing) would be prohibited. To accommodate this a significant period of time was allowed between the inspection of the two trains to allow the plant to draw down the balance pond level to maximise the storage volume available in preparation for the second stage of inspection.

At the Tirau WWTP the complete inspection of one process train could be completed within a single day. As such the excess inflow was able to be safely buffered within the plant’s balance tank without concern of non-complaint discharge.

A detailed project plan document specific to each site was prepared for the inspections undertaken at Turangi and Te Aroha. The document stepped through each aspect of the inspection, from module removal to reinstallation and commissioning.

This detailed level of pre-planning allowed time to be saved through the intelligent allocation of resources and use of time.

## 5.3 METHODOLOGY

The methodology for the clean and inspection process can be divided into six key tasks. The tasks are somewhat generalised for the purpose of this paper as each plant had slight differences and requirements. These tasks are discussed below.

1. ***Plant Preparation***

   To allow one of the reactor trains to be taken offline temporarily it was necessary to ensure that the MLSS stock could be retained. To achieve this, the MLSS concentration in the plant (both process trains) was decreased into the range of 8,000 – 9,000 mg/l. This then allowed for one process train to be isolated and the contents slowly pumped into the other train without exceeding the recommended maximum MLSS concentration. The objective was to hold sufficient MLSS for both process trains in a single process train, such that upon completion of the inspection the plant can be quickly returned to full capacity without the need to bring in external seed sludge.

2. ***Membrane Module Removal***

   A purpose built man cage was lifted and manoeuvred, by crane, into the reactor tank and suspended above the membrane modules. From the man cage the membrane module’s permeate header pipe could be disconnected from the plant's permeate pipework. Lifting chains were then connected to the four lifting eyes on the module and the module removed from the reactor tank. Each module (at Turangi and Te Aroha WWTP's) is made up of two banks of 200 sheets (one stacked on top of the other), as such the lifting process was repeated twelve times to remove the six upper and six lower banks.

The membrane sheets lose their (hydrophilic) filtration properties if the membrane surface is allowed to dry out[1]. As such it was vital to ensure the membranes remained wetted at all times. To achieve this, temporary sprinklers were set up to wet the modules once removed from the tank.

Photograph 8 below presents the man cage in operation, with one of the upper module banks attached in the left hand photograph and on the right the configuration of temporary sprinklers can be seen ensuring the membranes remain wet.

*Photograph 8: Membrane Module Removal and Temporary Storage*

### 3. Membrane Clean and Inspection

Once removed from the tank the permeate tubes were disconnected and disposed of, the retaining plates and rubbers removed and cleaned and each membrane sheet extracted for cleaning and inspection. Sludge was cleaned from the sheets by a water blaster operating at low pressure prior to sheet inspection. The inspection process involved partially filling the sheet with clean water (via a trickling hose), sealing the outlet nipple and holding the sheet up in the air and titling and rotating the sheet to check for leaks along the seams and both membrane faces. Damaged sheets were documented and replaced with new ones.

Upon completion of the inspection process the sheets were re-installed into the cleaned module casing, the retaining plates and rubbers replaced and fastened and new permeate tubes connected. The modules then remained in temporary storage outside the tank under the temporary sprinklers until they could be reinstalled. At Turangi the anoxic tank was cleaned out, partially filled with permeate and utilised for wet storage of the upper banks while the inspection was undertaken on the lower banks.

### 4. Tank and Diffuser Cleaning

In conjunction with the membrane clean and inspection activity the reactor tank was prepared for the reinstallation of the membrane modules. This involved the complete clean out of all process tanks. It was noted that there was a significant build up of a fine settled (primarily inorganic) sludge (silt) in the process tanks. The absence of mixing energy beneath the diffusers appears to such that sufficiently calm conditions are present to facilitate sludge settlement. Difficulty was noted at both the Turangi and Te Aroha sites in clearing the settled solids from the tank as no fall was incorporated into the tank floor to facilitate de sludging.

The pattern of both the fine bubble diffusers and the coarse bubble diffusers was inspected by partially filling the tank(s) with permeate to above the diffuser face. In the case of the fine bubble diffusers, diffusers exhibiting reduced or no flow were investigated and components replaced as required. For the coarse bubble diffusers the inspection was undertaken to enable a comparison to be made for the performance before and after diffuser cleaning. Following the aeration pattern checks the water was drained and the reactor tank accessed to undertake the coarse bubble diffuser cleaning. As mentioned previously this was undertaken using high pressure clean water and a steel rod.

Once the diffuses had been thoroughly cleaned the tank was refilled with clean water to approximately 300 mm above the diffusers and the diffuser pattern was retested. It was found on retesting that some ports were still not operating correctly and to clear these ports both the duty and the standby coarse bubble blowers were operated at full speed to provide additional airflow and pressure to clear the remaining debris from the defective ports.

Finally the tank underwent a thorough clean with an industrial wet and dry vacuum cleaner to ensure no foreign objects were left in the tank that could potentially cause damage to the membranes.

***5. Module Reinstallation and Integrity Testing***

Upon completion of the membrane module cleaning and inspection process the lower module banks were reinstalled into the reactor tank. Again this was undertaken using the purpose built man cage. Upon reinstallation and reconnection of the permeate pipework a simple test was performed to confirm the integrity of the membrane modules. To undertake this all of the downstream permeate valves were all closed and the tank filled with water. The philosophy of this test is to ensure the modules maintain air pressure, should holes be present in the sheets (top half only will be picked up during the integrity test) or the permeate tubes or pipework a stream of air bubble would be noted. Kubota recommends the pressure is held for two to four hours and then released (via the downstream sample valves), if the pressure was satisfactorily held over this time a notable ‘whoosh’ of air will be noted upon opening the sample valve.

This process was then completed for the upper module banks. During this process a number of leaks were noted due to damaged sheets that were missed in the inspection process. These sheets were removed and replaced as a result.

***6. Clean Water Flux Tests***

In order to benchmark the performance of the refurbished membrane modules and to allow comparisons to be drawn with the original performance of the membranes, clean water flux tests were undertaken. These tests involve permeating clean water at a range of flux rates and recording the TMP. Each test was repeated for each membrane module individually and across all modules operating simultaneously.

## 5.4 COSTS

It is estimated that to undertake a full clean and inspection for a MBR plant with 12 x Kubota EK400 membrane modules the total project cost would be in the order of \$120k – \$150k. This assumes a period of six weeks and does not allow for the replacement cost of any damaged sheets. From experience an allowance for a failure rate of 5% would be conservative, however much higher failure rates could be experienced if sewage debris is able to pass through the inlet screen (Turangi). At current prices replacement sheets are in the order of NZ\$180 - \$200 each depending on the number ordered and the freighting method.

## 5.5 POTENTIAL IMPROVEMENTS TO INSPECTION PROCESS

Following the inspection undertaken at Te Aroha, a plant that was operated correctly with the correct inlet screen size, it is suggested that some improvements could be made to reduce the impact and cost of the inspection process.

It is suggested that the frequency of the inspection procedures is increased and the scope of the inspection decreased, in an attempt to maintain the membranes at a suitable condition rather than trying to rehabilitate the membranes after significant deterioration in membrane performance. The Tirau WWTP has undertaken yearly inspections commencing after the second year of operation and has found this to be a successful approach.

At Te Aroha annual inspections of the membranes and diffusers are being recommended. However, as a result of the low failure rate the inspection of each membrane sheet individually is not seen as worthwhile considering this takes a substantial amount of time to complete. Instead the membrane sheets will only be inspected with the sheets in place. Visually checking the interstitial space between the sheets will provide indication of the level of sludge caking and sheets which have been compromised and filled with sludge will also be evident. Hosing from above should in most cases be sufficient to dislodge sludge caking from between the sheets if caking is only minor. Individual permeate samples from each membrane bank should be taken and analysed for suspended solids and indicator bacteria prior to the inspection taking place. If higher than normal suspended solids or bacteriological break through are noted a more thorough inspection of that membrane bank would be warranted.

The main purpose of the drain down and inspection would be to remove excess quantities of solids and lint from within the tank and on the membrane modules and to undertake a comprehensive clean of the coarse bubble diffusers.

It is predicted that this regime of inspection and cleaning would allow operation to continue without the need to undertake a comprehensive inspection until the membrane sheets are due for replacement (predicted useful life of membrane sheets 7 – 10 years).

It is estimated that the cost to undertake this more rudimentary inspection process would be approximately $20k for a MBR plant with 12 x Kubota EK400 membrane modules.

# 6 POTENTIAL OPERATIONAL IMPROVEMENTS

Based on the observations made over the first four years of flat sheet MBR plant operation in New Zealand and the findings from the recent plant inspections undertaken at Turangi WWTP, Te Aroha WWTP and Tirau WWTP a number of potential improvements are suggested that could improve plant performance and operability. Some of these proposals have the potential to be retrospectively incorporated into operational plants, but all should be considered at the design stage of any future MBR plants.

## 6.1 IMPROVED INFLUENT SCREENING

The observed quantities of lint and hair in the reactor tanks indicate that the rotating screw type perforated plate screens are ineffective at capturing this material. The cause of this ineffectiveness is twofold; firstly fine fibres such as hair tend to align with the flow and as such flow directly through screens of this type and secondly the brush cleaning action of the screen has a tendency to push soft material through the screen. Due to the apparent negative effects the lint has on the membrane plant operation the suitability of the rotating screw type perforated plate screens for MBR plants must be questioned.

It is recommended that screening equipment capable of removing this fine fibrous material is utilised, either in addition to or in place of other types of screening equipment. For example fine aperture rotary drum or band screens which induce a 90° flow direction change through the screening element and a backwash in the reverse direction of flow to remove the screenings from the screening element are significantly more effective in capturing hair and fine fibres.

It also appears that the greater the screenings capture rate the better the performance of the plant. As such benefits are likely to be seen from utilising a fine screen aperture size. It is recommended that a 1 mm screen aperture is preferable for MBR plants. Further still due to the criticality of the influent screening and the severe effects inadequate screening can have on the downstream process, it is recommended that wherever feasible a standby screen of equal specification is provided.

## 6.2 CONTINUOUS MLSS SCREENING

An alternative to improved inlet screening would be continuous side stream screening of the MLSS. This would involve separating and screening a proportion of the return activated sludge flow to continuously remove hair and lint from the MLSS. This was considered to be less preferable to improved influent screening which would reduce the hair and lint entering the system in the first place.

## 6.3 ALTERNATIVE DIFFUSER FLUSHING METHODS

The degree of coarse bubble diffuser blockage noted during the plant inspections identifies potential deficiencies in the effectiveness of the current diffuser cleaning method. Two alternatives are suggested that may provide more agreeable results:

1. ***Removal of Diffuser Flush Sequence from Normal Operation***

   It is possible that the venturi effect created during the flush operation, with the intention to clean the diffusers, may in fact be a contributing factor for the diffuser blockage. A simple approach to remedy this is to remove the diffuser flush sequence from the plants normal operation. With the coarse bubble aeration system operating continuously, diffuser fouling should be negligible. Experimentation may be necessary with one process train continuing to undergo diffuser flushing and the parallel process train operating with no diffuser flush with observation of any differences in aeration and membrane performance between each process train noted to confirm if abandonment of the diffuser flushing sequence is beneficial or detrimental to overall plant performance.

2. ***Diffuser Flushing Using Pressurised Water/Permeate***

   An alternative diffuser flushing regime, which would provide the same function as the current operation without introducing the risk of blockage, would be to back-flush the diffusers using high pressure clean water or permeate. In such a configuration permeation would stop, the coarse bubble blower would be shut down, automated valves on the aeration droppers would be closed (to protect the blower) and the air line to the coarse bubble diffusers would be pumped with high pressure clean water/permeate. The high velocity of water flow through the diffusers should provide sufficient force to dislodge any solids from within the diffusers.

## 6.4 FAIL SAFE SYSTEMS

As discussed in section 3.2, permeation without coarse bubble aeration leads to an extremely accelerated rate of membrane sheet fouling. To prevent this most plants incorporate various software/hardware interlocks. However, in many cases the plant can still be vulnerable in the event of power or equipment failure.

One way to further mitigate against the risks arising from this situation is to incorporate fail safe equipment where possible. The use of fail to closed pneumatic actuators on the permeate line (either spring return or with a back up air reservoir), or battery back up for electrically actuated valves is a good way to add additional protection to the system.

## 6.5 MONITORING OF COARSE BUBBLE AERTION FLOW RATES

Due to the importance of the coarse bubble aeration system in maintaining adequate plant performance the incorporation of on-line air flow monitoring would enable for early detection of insufficient scouring air. Configuring alarms based on the flow measurement would enable the plant to automatically take corrective action should deficient aeration be detected, hence protecting the membranes from excessive fouling and sludge caking.

## 6.6 DESIGN OF FACILITIES FOR EASY TANK DRAINAGE AND CLEANING

As regular tank drain down is a part of routine maintenance, allowances made at the design phase can significantly improve the efficiency with which the task can be completed. Incorporating a suitable fall in the tank floor, leading to an easily accessible sump will allow collected solids to be removed from the tank with substantially greater ease.

# 7 CONCLUSIONS & RECOMMENDATIONS

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 design teams optimise the technology.

Routine inspections at three of the first community scale MBR plants in New Zealand highlighted a number of areas where the MBR system, in the configuration designed, was not performing adequately. It was noted in all three cases 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 under perform 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 membrane.

The following actions are recommended to improve MBR plant operation:

- Inlet screening down to a fine aperture (recommend screening 1 mm in all directions) undertaken in a screen with a high capture efficiency for lint and hair

- Undertaking annual inspections of the membrane modules and physical cleaning of the coarse bubble aeration diffusers during this operation.

- Increased allowance during design phase to improve ease with which tank drain down and cleaning can be completed

- Incorporation of fail safe systems to ensure permeation in the absence of coarse bubble aeration is not possible.

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