DOSING MPE50 POLYMER TO INCREASE MBR FLUX RATES

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ABSTRACT

Stormwater ingress and infiltration (I&I) into the wastewater reticulation in Te Aroha is high, with the hydraulic capacity of the membrane bioreactor (MBR) being inadequate to treat wet weather flows (WWF). Nalco have developed a polymer, MPE50, specifically for use as a flux-enhancer in MBR plants. The polymer is designed to bind extracellular polymeric substances (EPS) into the floc, reducing the membrane fouling potential.

Laboratory tests were initially undertaken to determine whether MPE50 would be suitable for Te Aroha WwTP, followed by a full-scale trial in winter 2008 after the bench trials proved effective. The laboratory tests indicated the optimal MPE50 dose to be 450mg/l for Te Aroha. An initial bulk dose of 200 litres was required to achieve the required polymer concentration, with a daily polymer dose applied to maintain the desired polymer residual. Particle size analysis confirmed that the polymer addition resulted in an increase in floc size and filterability.

The average flux rate was increased from 19.5 to 28.9 LMH during the period of polymer addition, representing an increase of 48%. This average increase was maintained over a period of 82 days, after which polymer addition ceased as flows reduced.

KEYWORDS

MBR, EPS, SMP, MPE50, flux rate, fouling

1 INTRODUCTION

Te Aroha wastewater treatment plant (WwTP) receives wastewater principally domestic in origin, although it does receive filter backwash water and clarifier sludge from Te Aroha's Water Treatment Plant. Industrial contributions to the wastewater load are minimal. The WwTP was upgraded by Matamata Piako District Council (MPDC) to a membrane bioreactor (MBR) in 2006. The MBR was designed for average and peak flows of 1,800 and 2,300m^3/d respectively, with the existing facultative and maturation ponds retained as balance ponds to buffer wet weather flows. Kaimai Valley Services (KVS) is the Works Business Unit of MPDC, and operates and maintains wastewater infrastructure for MPDC, including the Te Aroha MBR.

During winter 2007, it became evident that the wet weather flows (WWF) greatly exceeded the design capacity of the MBR, even with the 20,000m^3 of theoretical storage available in the balance ponds, with WWF exceeding 7,000m^3/d. As a result, it was not possible for all of the WWF to be treated through the MBR, with a portion of the WWF being treated through the facultative and maturation ponds prior to discharge.

While the resource consent conditions were met by the combined MBR and pond discharges, the existing consent expires in 2010. The conditions of the future consent are not known, therefore it is necessary for MPDC to fully understand the limitations of the MBR and options available for both increasing hydraulic capacity and optimising final effluent quality.

Nalco have developed a cationic polymer, PermaCare MPE50 (MPE50), specifically for use as a flux enhancer in MBR plants. MPDC and KVS explored the opportunities for using this polymer to increase the hydraulic capacity of the Te Aroha WwTP during sustained wet weather periods.

2 BACKGROUND

2.1 MBR FLUX RATE

The hydraulic capacity of a membrane process is limited by the membrane flux rate, quoted as $l/m^2/hr$ (LMH). The critical flux rate is the maximum flux rate that can be achieved without the occurrence of significant fouling. MBR plants are typically operated at sub-critical flux, because if the critical flux is exceeded, fouling occurs rapidly and flux rate is restricted (LeClech et al., 2006).

2.2 TE AROHA MBR

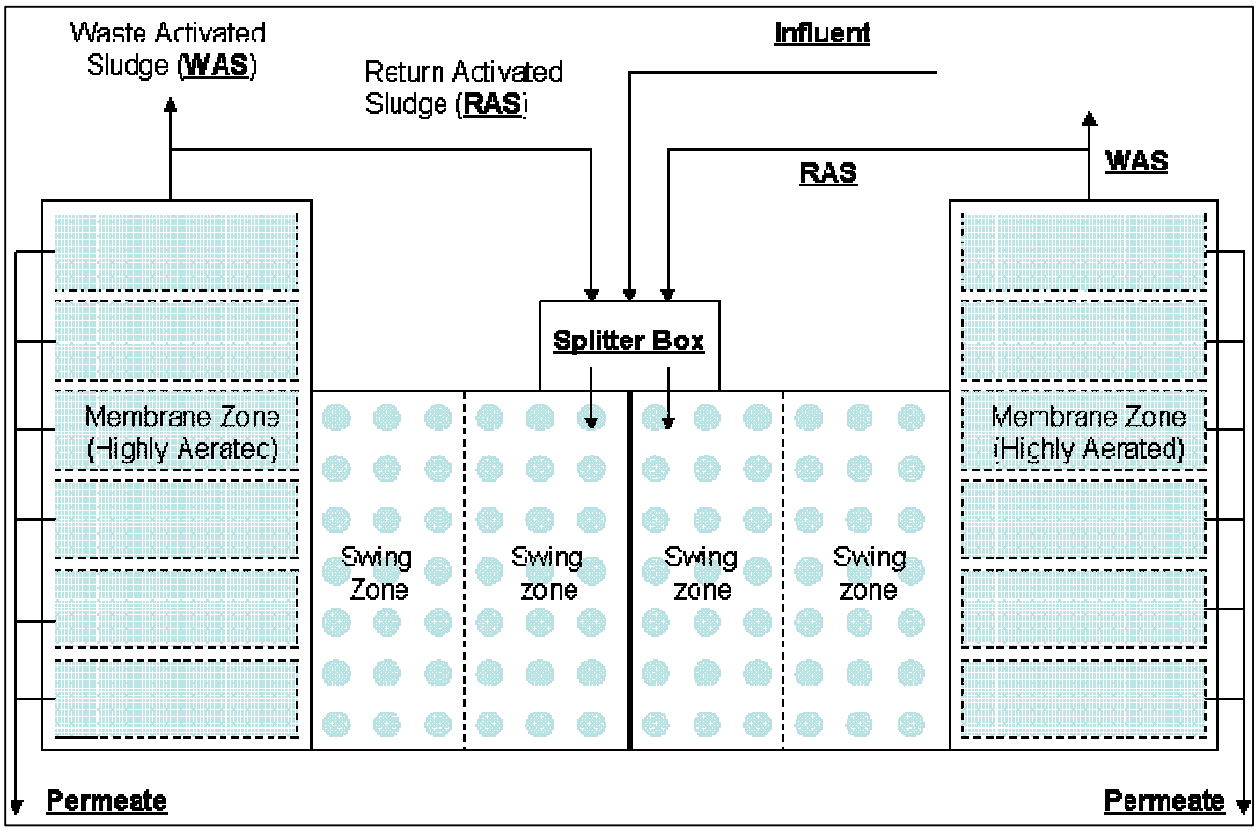
Kubota flat-sheet membranes have an actual pore size of 0.4µm. A total of 4,800 membranes are installed at Te Aroha, each with an area of $0.8m^2$. This gives a total membrane surface area of $3,840m^2$. At a peak design flow rate of $2,300m^3/d$, the membranes have a theoretical maximum instantaneous flux rate of 28 LMH, equating to a maximum average flux rate of 25 LMH over a 24-hour period when taking into consideration that permeation does not occur during relaxation and extended relaxations.

The Te Aroha MBR is configured as two MBR processes in parallel, each comprising an anoxic/aeration "swing" zone and a membrane tank. Return activated sludge (RAS) is returned from each membrane tank back to the splitter box preceding the swing zones. As for any activated sludge based process, it is necessary to remove waste activated sludge (WAS) to maintain the desired mixed liquor suspended solids (MLSS) concentration. At Te Aroha, the target MLSS is typically 10,000 - 12,000mg/l, with the total volume of biomass being $450m^3$. The rate of WAS removal is dependent on the influent loading, averaging $15m^3$/day and giving a typical sludge age of 30 – 35 days.

During the first two years of operation of the Te Aroha MBR, the sustainable average hydraulic capacity was found to be $1,800m^3/d$, consistent with the design. This equates to an average flux rate of 19.5 LMH.

The layout of the MBR at Te Aroha is shown in Figure 1.

Figure 1: Te Aroha MBR Layout



2.3 MEMBRANE FOULING

Fouling is the accumulation of organic and inorganic compounds which act as a barrier to flow through the membrane. Jiang (2007) identified four types of foulants, (1) Particulate fouling, caused by suspended solids and colloids, (2) Organic fouling, caused by adsorption of organic matter, (3) Biofouling, caused by deposition or growth of microorganisms, and (4) Scaling, caused by salt precipitation.

To minimise fouling, coarse air is released at the bottom of the membrane tanks. The rising air provides a cross-flow velocity across the surface of the membranes, designed to move particles away from the membrane surface. For Kubota membranes, a cross-flow velocity of 0.5 m/s is typical.

If the critical flux rate is exceeded, particulate fouling rapidly occurs because the size of the particulates is larger than the membrane pores. Yoon & Collins (2006) commented that the rate of fouling is exponentially proportional to the flux rate, particularly when the critical flux is exceeded. Biofouling and scaling will both occur gradually over time, with the rate of accumulation of these foulants being site-specific depending on environmental factors and chemical characteristics of the wastewater. Organic fouling has been found to be very significant in MBR's, and, where an MBR operates at sub-critical flux, organic foulants are the most significant foulant group.

Significant organic foulants have been found to include extracellular polymeric substances (EPS), in particular soluble microbial products (SMP) which are the soluble components of EPS. EPS and SMP are the by-products of microbial activity, death and lysis, and include a wide range of organic compounds including humic acids, polysacchirides, proteins, nucleic acids, and organic acids (Chipasa & Medrzycka, 2008). When comparing the particle size of biomass from a MBR with conventional activated sludge (CAS), Jiang (2007) found that both exhibited the main particle size peak between 30 – 50 μm, yet the MBR biomass showed a second peak in the 0.1 to 1.0 μm range. Jiang (2007) considered this likely to be bacterial cell fragments which are generally retained by the membranes, but are eliminated from a CAS plant in the final effluent.

SMP's are generally smaller than the membrane pores, and cause fouling by accumulating on the membrane surface and within the pores. The relationship between the SMP's and the membrane is influenced by a number of factors, such as pH, charge, ionic strength, hydrophobicity and membrane morphology (Jiang, 2007).

2.4 MEASUREMENT OF FOULING

Key monitoring tools for MBR plants are trans-membrane pressure (TMP) and permeability. TMP is the headloss across the membrane, and is often used as a surrogate measurement of fouling. A membrane will exert a headloss, even when clean, and as the membrane fouls, so the TMP will increase. When operating at sub-critical flux, the TMP increase over a normal permeation cycle will be minimal. Over a period of weeks or months of sub-critical flux operation, the TMP will slowly increase. If an MBR is operated above critical flux, TMP will increase much more rapidly as particulate fouling occurs.

However, if used in isolation, TMP can be a slightly misleading fouling indicator. TMP is affected not only by fouling, but by the membrane flux rate. As the flux rate increases, so the TMP will increase, irrespective of fouling. A more reliable surrogate fouling measurement is permeability, which is a function of both TMP and flux rate. Permeability is calculated using Equation 1. At any given flux rate, the permeability will reduce as fouling occurs.

$$Permeability(LMH/bar) = \frac{Flux(LMH)}{TMP(Bar)} \qquad (1)$$

2.5 MEMBRANE CLEANING

There are a number of ways of minimising fouling and maintaining the TMP at manageable levels. These measures include relaxations and extended relaxations during a normal permeation cycle, and clean-in-place (CIP). Relaxations are typically programmed for periods of 30 to 120 seconds every 15 to 60 minutes, during which permeation ceases and the cross-flow velocity of air scour increases. Relaxations target the removal of particulate fouling from the surface of the membranes. Extended relaxations are similar to relaxations, however

are less frequent and for longer durations. Extended relaxations would typically occur every 6 to 12 hours, for 30 minutes duration.

CIP's are designed to target the removal of organic fouling, biofouling, and scaling. A dilute sodium hypochlorite solution bled back through the membranes removes organic fouling and biofouling, with sodium hypochlorite CIP's undertaken every 6 months. Scaling is not removed by sodium hypochlorite, therefore a dilute citric acid clean is undertaken to remove inorganic precipitates. The frequency of a citric acid CIP is very dependent on the nature of the wastewater. At Te Aroha, the first citric acid CIP was undertaken after 2 years of operation.

2.6 PERMACARE MPE50

MPE50 is a cationic polymer. Microbial flocs predominantly have a negative surface charge, so MPE50 adsorbs to the flocs and binds EPS and SMP into the floc. The result is an increase in floc size which reduces particulate fouling, and reduced free SMP in solution which reduces organic fouling. Koseoglu et al. (2008) determined that dosing MPE50, and 6 other chemicals, effectively reduced SMP, reduced fouling rates, and increased permeability. Koseoglu et al. (2008) determined that MPE50 was the most effective of the chemicals tested, with a dose of 500mg/l enhancing the critical flux by 46% and reducing fouling by 96%, although some of the other chemicals were more effective at reducing SMP concentrations. This suggests there are other factors which are significant in determining the rate of fouling.

Yoon & Collins (2006) applied MPE50 on a full-scale plant at a dose rate of 200mg/l, and determined that flux rates could be increased by 50% over a period of 3 or 4 weeks. They also found that MPE50 application resulted in lower COD concentrations in the permeate, and that the polymer was effectively bound in the flocs and did not pass through the membranes with the permeate. Analysis of permeate for MPE50 showed concentrations were below the limit of detection of 0.5mg/l.

MPE50 is removed from the MBR process in two ways; through microbial degradation, and removal in the WAS. Prior to the full scale trial at Te Aroha, Nalco suggested the degradation rate would be in the order of 1% per day, as measured by Nalco during laboratory studies (Wilson, 2009).

3 METHODOLOGY

3.1 CONTROL

Ideally one-half of the Te Aroha MBR plant would have been dosed with MPE50, with the other kept polymer free and used as a control. However, the RAS from the two treatment trains is returned to a common splitter box, therefore if MPE50 is dosed in one half of the MBR, it rapidly becomes mixed through the whole plant. It was not, therefore, possible to carry out a full scale control while the polymer trial was in progress.

The Te Aroha MBR had been operated for 18 months before the full scale polymer trial was undertaken. Process limitations had been determined through operational experience, so data was available from winter 2007 when the MBR was operated without MPE50. In winter 2008 after MPE50 dosing, where possible the MBR was operated under the same conditions as it had been during winter 2007 to allow data from 2007 to be used as a control. While not ideal, operating conditions in 2007 and 2008 are considered similar enough to allow this comparison to be made.

3.2 MPE50 DOSING

3.2.1 BENCH TESTS

Nalco undertook bench tests to determine the optimal MPE50 dose rate. The bench tests comprised a series of jar tests, diluting the polymer to 0.1% before adding it to the MLSS. Polymer effectiveness was determined initially through visual observation of floc size and structure, then confirmed through determining filterability of the MLSS. The standard filterability test is to pour 50ml of MLSS into a concertinaed Whatman #42 filter paper in a funnel, allowing filtration under gravity for 5 minutes, then measuring the resulting permeate volume.

Initial bench tests suggested the optimal dose was 350mg/l, however this increased to 450mg/l with further bench tests.

3.2.2 MPE50 DEGRADATION

Nalco were not able to measure the residual polymer concentration in the MBR, therefore the actual polymer concentration through the course of the trial cannot be known for certain. However, assuming the optimal polymer concentration remained constant through the trial at 450mg/l, it is possible to estimate the microbial degradation rate of MPE50 using Equation 2.

$$Degradation(kg/d) = PolymerAdded(kg/d) - \left[WAS(m^3/d) \times Concentration(g/kg)\right] \qquad (2)$$

3.3 OPERATING PARAMETERS

During the course of the trial, relaxations occurred for 60 seconds every 30 minutes, and there were 4 extended relaxations per day, each of 30 minutes duration. A full sodium hypochlorite and citric acid CIP was undertaken between 14 and 17 July 2008 when initial results from the trial suggested membrane fouling was adversely affecting the performance.

The operating MLSS was typically within the range 10,000 – 12,000mg/l, with the minimum and maximum MLSS during the trial period was 8,600 and 14,000mg/l respectively. The average daily MLSS temperature slowly increased from 14°C at the beginning of July to 18°C in the middle of October, and the average daily pH was 7.0 during the course of the trial.

3.4 FLUX RATES

The flux rates are PLC controlled, with the target flux rates being an Operator adjustable set-point. Due to periods of relaxation and extended relaxation during which no permeation occurs, the actual average flux rate is less than the target flux rate. At Te Aroha it has been found that TMP's can be controlled more effectively if the flux rates are dropped by approximately 10% for one or two days per week to give the membranes a rest.

As mentioned in Section 3.3, a full CIP was undertaken two weeks after MPE50 dosing commenced due to the instability of the TMP's. Shortly afterwards, the SCADA computer crashed which caused a further delay to the trial. It wasn't until July 31, some 4 weeks after polymer dosing commenced, that flux rates were significantly increased. When flux rates were increased, the target flux rate was incrementally increased every two or three days and the effect on TMP monitored. It was found that the permeate pipe work limited the maximum flux rate to 34.5 LMH, equating to an average flux rate of 30.5 LMH being achieved. The MPE50 did not completely eliminate fouling, and the maximum flux rate slowly fell to 33 LMH over a 3 week period, after which the target flux rate was lowered by approximately 10% for one day per week to give the membranes a rest.

Due to a limitation with the capacity of the inlet pumps, it was necessary to reduce the flux rates through MBR2 to allow the MBR1 flux rates to be increased. Table 1 below shows the pertinent flux rates for Te Aroha during normal operation and during the MPE50 trial.

Table 1: Flux Rate Set-points

Flux Rate Set-point, LMH	Average Flux Rate, LMH(1)	MBR1 Permeate Flow, m^3/d
22.1	19.5	900
28.3	25.0	1,150
32.9	29.1	1,350
34.6	30.5	1,400

1. Average flux rate is less than set-point due to relaxations and extended relaxations

When the MPE50 dosing ceased on 22 October 2008, the flux rate set-points were returned to normal levels. However, close monitoring of the process continued to determine any after effects from the polymer dosing.

3.5 DATA COLLECTION

The SCADA at Te Aroha WwTP automatically creates a daily report of operational parameters from midnight to midnight. All flows and TMP's are recorded in this way, and are therefore totals or averages over an entire 24-hour period, irrespective of operational status. The average daily TMP, and the average daily flux rate calculated

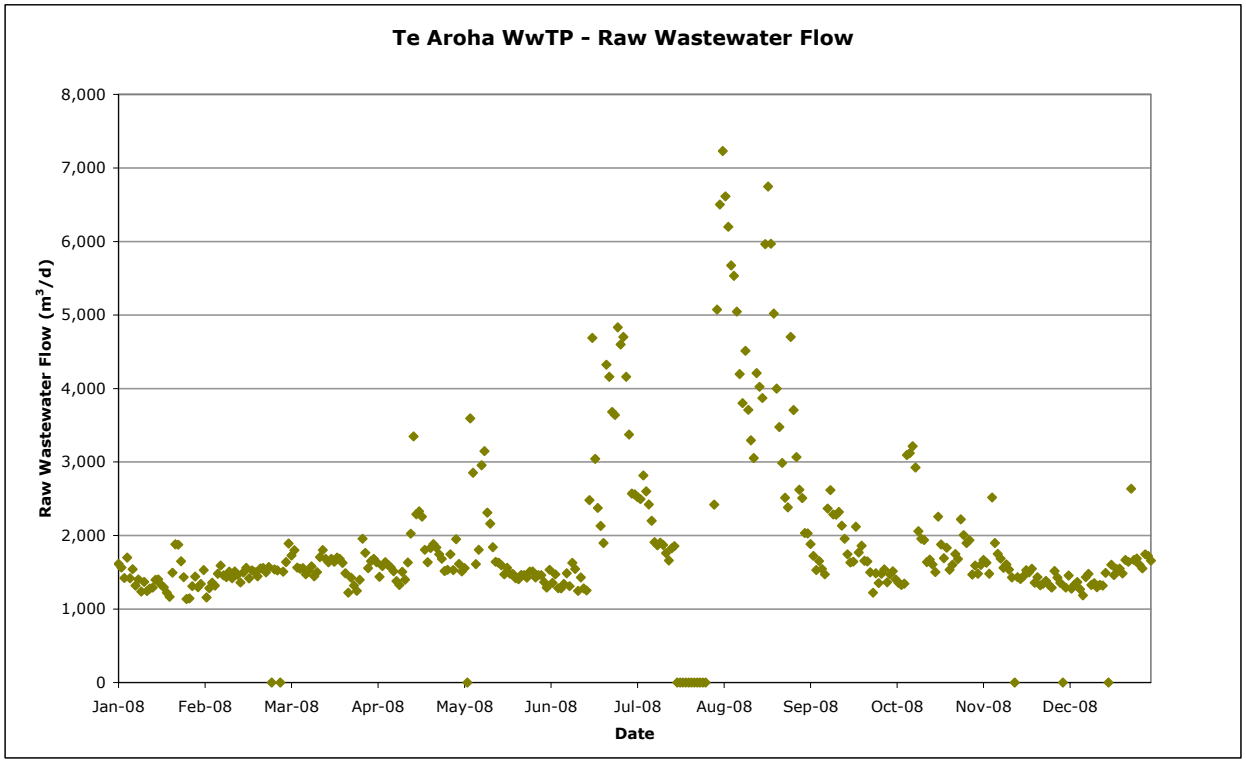
from the totalised daily flow, are average values from periods of permeation, relaxation and extended relaxation combined. The actual flux rate during permeation would, therefore, be higher than the average flux rate shown in the results.

4 RESULTS

4.1 WINTER 2008 IN TE AROHA

Predictably, winter brought some short, high intensity storms, and more prolonged, lower intensity, wet weather periods. The WWF peaked at 7,230m^3/d, with raw wastewater flows during the month of August averaging 4,360m^3/d. While raw wastewater characteristics were not routinely measured during the trial period, it is considered safe to assume that the wastewater would have been very dilute during this period given the increase in flow rate. The raw wastewater flows during 2008 are shown in Figure 2. Note; this is the total flow to Te Aroha WwTP, not necessarily the flow to the MBR process.

Figure 2: Te Aroha WwTP Raw Wastewater Flows



4.2 MPE50 POLYMER DOSING

A bulk dose of 200 litres of MPE50 was added to the MBR on 1 July 2008 to achieve a polymer concentration of 450mg/l across the MBR. The polymer was dosed over a period of approximately 60 minutes, poured slowly into the intensely aerated membrane tanks to aid mixing. MLSS filterability was tested after approximately 60 minutes of mixing to confirm that the dose had been effective.

Based on a WAS rate of 15m^3/d and the expected degradation rate of 1% per day, the daily maintenance dose was initially set at 8 l/d to maintain the desired residual MPE50 concentration of 450mg/l. However, through a combination of day to day filterability measurement and intermittent jar tests, it was determined that it was necessary to increase the daily maintenance dose to maintain the optimal residual polymer concentration.

Towards the end of the trial, it became more and more difficult to maintain a high filterability, so the daily maintenance dose increased on a number of occasions. This was at least partly due to lower wastewater flows which meant more of the wastewater load was being treated through the MBR, resulting in higher WAS rates and corresponding polymer loss. It is also hypothesised that filterability becomes naturally depressed during dry

weather. Therefore, based on dosing and degradation rates, it is considered likely that the residual polymer concentration at the end of the trial period was actually in excess of 450mg/l as dose rates were increased in an attempt to maintain high levels of filterability. The daily maintenance dose subsequently averaged 15 l/d over the course of the trial.

4.2.1 MPE50 DEGRADATION

The average degradation rate of MPE50 through the trial was calculated to be between 3 and 4% per day, significantly greater than the 1% per day suggested by Nalco. When taking into consideration the operating MLSS, this equates to a degradation rate in the order of 1.2 – 1.6 gMPE50/kgMLSS.d.

Based on a microbial degradation rate of 4% per day, and loss of polymer through the WAS, the residual MPE50 concentration can be estimated after polymer dosing ceased. Table 2 shows the estimated residual concentration for 2 months after dosing ceased.

Table 2: Estimated Residual MPE50 Concentration

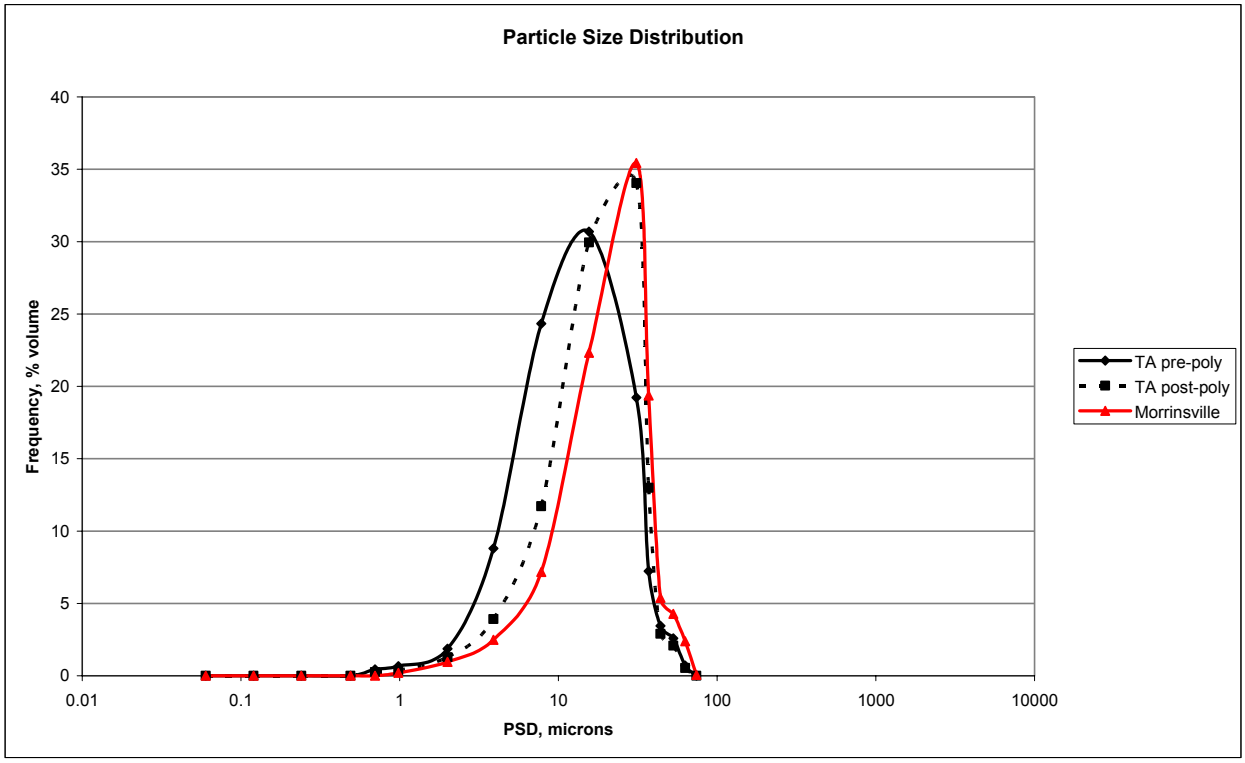
Date	MPE50, mg/l	Date	MPE50, mg/l
22 October	739(1)	26 November	42
29 October	399	3 December	24
5 November	215	10 December	13
12 November	117	17 December	7
19 November	71	24 December	3

1. Concentration >450mg/l due to elevated dose rates in final days of trial

4.3 PARTICLE SIZE

The particle size was not measured in 2008. However, when dosing commenced again in the winter of 2009, mixed liquor samples were submitted for particle size distribution (PSD) analysis to the University of Waikato. These samples included Te Aroha mixed liquor both before and soon after polymer dosing commenced, allowing adequate time for mixing, and from Morrinsville WwTP as a comparison with a CAS process. The results of the PSD analysis are shown in Figure 3.

Figure 3: Particle Size Distribution



4.4 FLUX RATE & PERMEABILITY

Table 3 compares the actual flux rate during the period of the MPE50 trial in 2008 with the corresponding period in 2007.

Table 3: Flux Rates

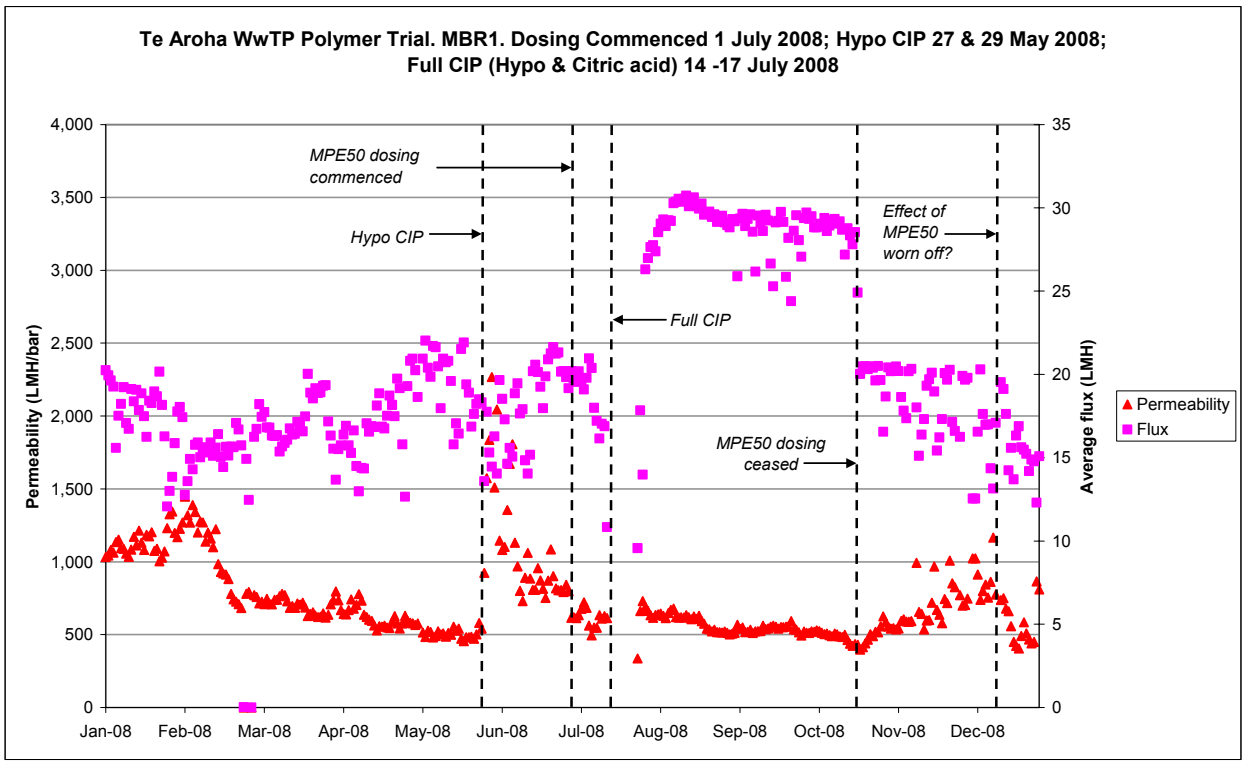
Parameter	31 July – 21 October 2007 (normal operation)		31 July – 21 October 2008 (with MPE50 dosing)		Increase
	LMH	m^3/d	LMH	m^3/d	
Maximum daily	23.2	1,070	30.7	1,416	32%
Average daily	19.5	900	28.9	1,331	48%

Figure 4 shows the actual flux rate and permeability through the course of 2008, and highlights notable points through the trial. It is evident that the CIP in May improved the permeability, as would be expected, following which the permeability started to fall as fouling of the membranes occurred. When the start-up dose of MPE50 was added, there was no increase in permeability although on-site laboratory tests had shown an improvement in filterability. Similarly, there was no improvement in permeability following the full sodium hypochlorite and citric acid clean in July, although this may have been masked by the SCADA failure.

As the trial progressed through August, both the flux rate and permeability slowly reduced as fouling of the membranes occurred. The rate of fouling was apparently reduced through September when the membranes were given a rest one day per week by reducing the flux rate set-point.

When the polymer dosing stopped and the flux rate was reduced, a gradual increase in permeability was observed over the following 6 weeks. It is hypothesised that this was due to lower membrane flux rates while the residual polymer concentration was still sufficient to bind SMP's to the floc, resulting in an apparent reduction in fouling. When the residual MPE50 concentration fell below what appears to be a critical concentration in early December, the permeability dropped rapidly to the point where a CIP was required.

Figure 4: Flux Rates & Permeability



4.5 AFTER EFFECTS

In November 2008 and February 2009, MBR's 2 and 1 respectively were drained for inspection. An accumulation of sludge cake was found to have built up between approximately 10 - 25% of the individual membrane sheets in each module, in some cases completely blocking the space between adjacent membranes. Polymer could be felt in this accumulated sludge cake, however as no inspection had been undertaken before the polymer dosing commenced, it is unknown whether this sludge accumulation was at least partly due to the polymer dosing. It is understood that other MBR's which have not dosed MPE50 have had a similar build up of sludge cake between membrane sheets, however the possibility of the MPE50 contributing to this sludge cake accumulation should not be discounted.

Sodium hypochlorite CIP's were undertaken over a five day period at the end of December 2008 and early in January 2009. After the CIP's, the TMP's returned to normal (pre-polymer) levels, and stayed at such levels through until June 2009 when the next CIP was due. This suggests the CIP was effective in removing fouling which occurred at the higher flux rates during the MPE50 dosing period, although it did not remove the accumulation of sludge cake between individual membranes.

5 DISCUSSION

5.1.1 PARTICLE SIZE

The PSD of the Te Aroha MBR biomass was quite different to that measured in the CAS biomass at Morrinsville, although the differences were not entirely the same as those reported by Jiang (2007). The modal group of the pre-polymer sample from Te Aroha was 15-31µm, while for the Morrinsville sample the corresponding group was 31-63µm. No second, smaller, peak was observed in the <1µm size range in the pre-polymer sample from Te Aroha. On addition of MPE50 at Te Aroha, the number of particles <15µm decreased markedly, with a corresponding increase in particles >31µm. As shown in Figure 3, the PSD trend of the Te Aroha biomass after polymer addition showed more similarity to the Morrinsville sample than the pre-polymer sample from Te Aroha.

The PSD data confirms that MPE50 has the effect of binding smaller particles into the floc. This would reduce the fouling potential because fewer particles are in the size range of the membrane pores, and the resulting larger particles would be more readily removed from the membrane surface by the air scour.

5.1.2 FLUX RATE

The maximum average daily flux rate achieved during the polymer trial was 30.7 LMH, some 32% higher than had been achieved in 2007 when MPE50 wasn't dosed. However, it is necessary to take a couple of factors into consideration when assessing the maximum average daily flux rate. Firstly, pipe work limitations meant that higher flux rates were physically not possible during the MPE50 trial and, secondly, without polymer dosing the fouling rate at higher flux rates was excessive, so the peak flux rates obtained were not sustainable.

Comparison of the average daily flux rate during the polymer trial with the corresponding period in 2007 is considered a more appropriate measure of the actual increase in flux rate. This takes into consideration the sustainability of operating at a given flux rate – if it was not sustainable, such a flux rate would only be possible for a relatively short duration. Therefore, a sustainable increase in flux rate of 48%, from 19.5 LMH to 28.9 LMH, is considered to be the most appropriate representation of the data. This increase is similar to the findings of Koseoglu et al. (2008) and Yoon & Collins (2006), although was achieved over a more sustained period.

5.1.3 MPE50 EFFECTIVENESS

While the results of this trial indicate that a sustainable increase in flux rate can be achieved through the addition of MPE50, it is not known whether this would be true under all conditions. In Te Aroha, significant stormwater I&I results in considerable dilution of the wastewater during winter, and it is possible that the efficacy of MPE50 is at least partly attributable to the dilute nature of the raw wastewater.

The PSD results do, however, confirm that the MPE50 is effective at binding smaller activated sludge particles into the floc.

5.1.4 MPE50 DEGRADATION

The microbial degradation rate of was calculated to be between 3% and 4% per day, significantly greater than the 1% per day suggested by Nalco. This meant that the daily maintenance dose required to maintain an effective residual polymer concentration was greater than initially estimated, increasing the cost of the polymer dosing.

5.1.5 COSTS

During the trial at Te Aroha, 2,000 litres of MPE50 were used between 1 July and 22 October 2008, representing an operational cost of ~NZ$20,000 for nearly 4 months operation during which the hydraulic capacity of the MBR process was increased by close to 50%. When compared to the capital-intensive alternative of installation of additional membrane sheets and associated infrastructure, the operational cost is considered good value while MPDC addresses the stormwater I&I issues in Te Aroha.

6 CONCLUSIONS

MPE50 has a measurable effect on the floc characteristics by altering the PSD, thus improving filterability and reducing fouling potential. Following addition of the polymer, smaller particles in the <15µm range bind together to form larger flocs. As a result, flux rates at Te Aroha were sustainably increased by 48% over a 16 week period during winter 2008 when stormwater I&I into the sewer reticulation was high.

An accumulation of sludge cake between individual membrane sheets was found following dosing MPE50, however no pre-polymer dosing inspections were undertaken. It is therefore not possible to determine whether the cake accumulation was at least partly due to MPE50 dosing, but the possibility should not be discounted.

ACKNOWLEDGEMENTS

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NOMENCLATURE

Critical flux	Maximum flux rate achieved before significant particulate fouling occurs
EPS	Extracellular polymeric substances; the by-products of microbial activity, death and lysis, including a wide range of organic compounds including humic acids, polysacchirides, proteins, nucleic acids, and organic acids
Flux	Rate of permeation through a membrane, volume/area.time
Fouling	Blocking of membrane pores by organic and inorganic compounds
I&I	Stormwater ingress and infiltration
LMH	Standard flux rate units, $l/m^2.h$
MLSS	Mixed liquor suspended solids; measurement of biomass concentration
RAS	Return activated sludge; biomass returned from the solids separation zone back to the start of the process
SMP	Soluble microbial product; the soluble components of EPS
TMP	Trans-membrane pressure; surrogate measurement of fouling
WAS	Waste activated sludge; excess biomass removed from the process to maintain the desired biomass concentration