KEEP YOUR EFFLUENT POND – BIOSHELLS/MF – CASE STUDY TO IMPROVE QUALITY

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ABSTRACT

The Clutha District Council (CDC) Wastewater Ponds at Kaitangata and Heriot required upgrading to meet new discharge quality requirements. CDC engaged Marshall Projects Ltd (MPL) and Pall Water (PALL) to install Bio-Shells and Microfiltration to improve nitrogen, ammonia, suspended solids, BOD and E-Coli.

The processes implemented for this project are Bio-Shells for the ammonia and BOD reduction installed directly into the existing ponds. The pond effluent was then treated using the Pall Aria Microfiltration system for E-Coli and suspended solids reduction. The Bio-Shells were manufactured by MPL in Invercargill of which 7 are installed in Heriot and 15 in Kaitangata. The Bioshells were developed by the University of Utah, professors Kraig Johnson and Larry Reaveley. Bio-Shells award-winning, patented technology consists of concentrically nested shells that are infused with air from the bottom. They sit on the floor of a lagoon and are completely submerged. As water flows through them, biofilms effectively reduce ammonia-nitrogen, BOD, and TSS in wastewater. The growth of the naturally occurring bio-films is maximised by the way in which oxygen is optimally guided through the domes by their geometry. MPL manufactures and sells patented submergible aerated bio-film reactors under the trade names Bio-Dome & Bio-Shell. For these towns, each Bio-Shell contains an aerated surface designed to remove 1.18kg BOD/Bio-Shell/day and 0.70 kg TSS/Bio-Shell/day, or once BOD and TSS concentrations are below 30 mg/L, 0.11 kg NH_4^+-N /Bio-Shell/day at 6°C. These are the first of the Bio-Shells installed in New Zealand.

The systems were commissioned in February and March 2018 for Heriot and Kaitangata respectively. The microfiltration systems are operating as expected providing the suspended solids and bacterial removal from the 0.1micron membrane.

The Pall aria AP2 and AP4 units installed at Heriot and Kaitangata use 0.1micron PVDF membranes and are identical to those used in water supply in New Zealand. Direct online integrity testing ensures integrity of the membranes and provides surety that the E-Coli requirements are being achieved. Whilst pond effluents are often considered high fouling waters for MF, the Pall MF system is not experiencing a high fouling tendency and with time cleaning regimes may be able to be reduced. The paper explores the operational costs in more detail with sustainable operational parameters presented.

The paper will compare historical performance of the ponds verses upgraded performance from proving period laboratory testing.

KEYWORDS

Effluent Pond, Bio-Shells, Microfiltration, Ammonia

PRESENTER PROFILE

Tom Marshall is a civil engineer with 28 years' experience including 20 years in the installation and commissioning of membrane based water and wastewater treatment plants. Tom is the project manager for these projects and the business owner of Marshall Projects Limited and managing director of Marshall Industries Limited. Prior to 2005 Tom was a consultant with BCHF and CH2M HILL.

1 INTRODUCTION

Clutha District Council has eleven sewage treatment facilities, ten of which incorporate oxidation ponds. The ponds were built between 1974 and 1994 and are typical of those constructed at the time, providing the only treatment of the effluent. Discharge consents for the ponds began to expire in the mid-2000s, with the last to expire in 2018. As new consents have been obtained more stringent discharge requirements have been imposed. The Council has therefore added treatment into and downstream of the ponds in order to achieve compliance.

Heriot and Kaitangata were granted consents in 2014 with new consent limits to apply from early 2018. Council adopted a design build procurement process, eventually negotiating a contract for additional treatment based on Bio-Shells and membrane filtration. Bio-Shells are a technology new to New Zealand which originated in Utah. They are placed directly into the pond to reduce BOD, Suspended Solids (SS), and once SS and BOD are < 30 g/m^3, nitrogen concentrations in the pond effluent.

Commissioning of the new Heriot plant was completed in February 2018 and Kaitangata in March 2018. This paper sets out the design criteria and expected results. Some preliminary results are presented and the paper presentation should provide further analytical information on performance.

2 DESIGN BASIS

2.1 CONSENT REQUIREMENTS

The council's primary reason for upgrading the ponds is to comply with new discharge consent quality requirements. As is typical of regional towns in New Zealand, the growth, or lack of, in population means that a capacity upgrade is not necessarily a requirement. A summary of the new consent requirements verses previous and the pre upgrade performance is provided in tables 2.1 and 2.2 for Heriot and Kaitangata respectively. The consent conditions are for 9 out of 10 samples to be less than the limit.

Table 2.1 – Consent requirements - Heriot:

	Consent Requirements		**Pre-Upgrade Performance**	
Parameter	**Old**	**New**	**Average**	**90th %ile**
Dissolved Oxygen (g/m^3)	≥2	≥2	Unknown	Unknown
BOD (g/m^3)	70	20	37	60
pH	6.5-9.0	6.5-9.0	8.0	7.2-8.8
Ammonia N (g/m^3)	40	20	16	23.5
TSS (g/m^3)	100	30	52	87
TN (g/m^3)	No Limit	35	Unknown	Unknown
TP (g/m^3)	15	10	8	10
E-Coli (cfu/100ml)	500,000	260	69,000	116,000

Table 2.2 – Consent requirements - Kaitangata:

	Consent Requirements		Pre-Upgrade Performance	
Parameter	**Old**	**New**	**Average**	**90th %ile**
Dissolved Oxygen (g/m^3)	≥2	≥2	Unknown	Unknown
BOD (g/m^3)	70	20	42	52
pH	6.5-9.0	6.5-9.0	7.6	7.2-7.9
Ammonia N (g/m^3)	35	20	15	20
TSS (g/m^3)	150	30	76	90-120
TN (g/m^3)	No Limit	35	Unknown	Unknown
TP (g/m^3)	15	10	6	9
E-Coli (cfu/100ml)	500,000	260	81,000	194,000

The design performance for the upgraded plants therefore needed to provide the levels of performance (on a 90th percentile basis) as presented in table 2.3.

Table 2.3 – Upgrading Requirements:

Parameter	**Heriot (@ 150m^3/d)**		**Kaitangata (@ 800m^3/d)**	
	g/m^3	**kg/day**	**g/m^3**	**kg/day**
BOD (g/m^3)	40	6	32	26
Ammonia N (g/m^3)	3.5	0.5	0	0
TSS (g/m^3)	67	10	96	77
TN (g/m^3)	?	?	?	?
TP (g/m^3)	0.15	0.02	0	0
E-Coli (cfu/100ml)	116,000	NA	194,000	NA

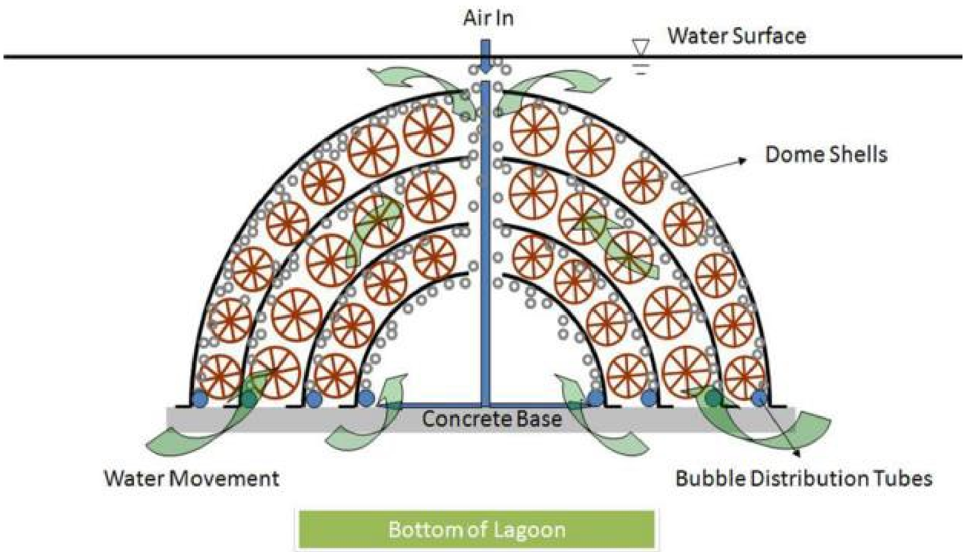
2.1.1 DESIGN PHILOSOPHY

The upgrade design utilises Bioshells for BOD and ammonia reduction within the pond and Microfiltration for further SS and E-Coli reduction.

Bioshell and Biodome designs are available to be utilised. The key difference in the Bioshells and Biodomes is the available water depth for satisfactory performance. The Bioshells must be completely submerged in the pond to work effectively. The two layer Bioshells were chosen for the upgrade design. These are the smallest of the family and suit a pond depth of 1200mm.

The Bioshells comprise a concrete base, nested shells to direct the air and sewage flow, plastic media and air diffusers at the bottom as depicted in Figure 2.1.

Figure 2.1: Configuration of Bioshells and Biodomes



Proven in the US at temperatures as low as 0.5°C to nitrify and provide ammonia reduction, the Bioshells are a good fit for improving performance whilst maintaining the asset of the wastewater stabilisation pond. A design temperature of 6°C was adopted for the sizing of the number of Bioshells required. Nitrification performance is directly affected by temperature and 6°C was adopted based on temperature monitoring of other Clutha District Council waste stabilisation ponds.

At 6°C, the Bioshells performance characteristics for design purposes are:

- 1.18kg/day BOD reduction; and
- 0.7 kg/day SS reduction; and when BOD and SS are < 30g/m^3;
- 0.11kg/day ammonia reduction.

The Pall Microfiltration plant was installed as the final treatment providing the removal of all solids resulting in an effluent turbidity of < 0.1NTU with non-detectible SS and E-Coli. This is the same type of plant as used in drinking water supplies and with the same membranes validated for 4 log removal of pathogens and verified in excess of 5 log removal.

As future flexibility is also desired with all upgrades, the MF also has the ability to introduce coagulant to chemically remove phosphorus should it be required in the future.

The combination of Bioshells and Microfiltration allows for simple future augmentation. The ability to easily add more Bioshells and membranes to the MF allows the initial design not to be over capitalised, which in turn enables deferral of further capital costs until they are required.

The footprint of the services building to house the MF, Blowers for the Bioshells and supporting services is small. The smaller plant at Heriot was completely pre-fabricated off-site and transported as a complete unit, reducing the time required for the construction and for such remote areas, reduces the onsite costs. The design for the Heriot plant is now standardised and able to be delivered ready for connection on site with capacities up to 350 m^3/day. Further options exist for higher flow requirements.

3 PERFORMANCE - HERIOT

3.1 POND PERFORMANCE

After the upgrade it was quickly learnt at Heriot that the pond was not performing as expected. Results were clear that nitrification was not occurring and it could also be seen that BOD and SS were higher than required for the nitrification to occur in the Bioshells. Investigations into influent, pond effluent and final micro-filtered discharge were undertaken. The analysis averages to date are presented in table 3.1.

Table 3.1 – Upgraded Pond Performance:

Parameter	Influent	Pond Effluent (pre-upgrade)	Pond Effluent (post Upgrade)	Discharge	Consent Requirement
BOD (g/m^3)	122	37	61	8.7	20
Ammonia N (g/m^3)	42	16	42	42	20
TSS (g/m^3)	160	52	106	<6	20
TN (g/m^3)	56	?	58	42	35
TP (g/m^3)	11	8	15	11	10
E-Coli (cfu/100ml)	7,260,000	69,000	214,000	<5	260

In summary, it can be seen that the pond effluent performance is worse than pre-upgrade design data by a factor of 2. The investigations are still ongoing to understand all of the reasons. One reason (if not solely) is that the information used for design did not include a new truck-wash connection to the sewerage system significantly impacting the influent to the plant. It is anticipated that the final solution is likely to be a mixture of treatment at the truck-wash and further augmentation of the pond.

As the pond is not achieving a reduction in BOD and SS to less than 30 g/m^3, there is no surprise that the ammonia is not being reduced. It can be seen that the MF is removing the insoluble nitrogen leaving total nitrogen (TN) to be approximately the same concentration as ammonia N.

The data used for design is quite different to that experienced after upgrading the plant; therefore it is not possible to draw any conclusions on the performance of the Bioshells. However it is fully expected that they are assisting in BOD and SS reduction as proven in the United States and at Kaitangata.

3.2 MF PERFORMANCE

The performance of the MF is providing full removal of insoluble N, insoluble BOD, SS and E-Coli. The original design did not rely on improvement from the MF for BOD and TN reduction but they are useful performance outcomes for the treatment plant as a whole.

The performance of the MF in these extreme influent conditions (the pond effluent being far worse than design) is both sustainable and effective. Key operating parameters at the flows that are being treated are presented in table 3.2.

Table 3.2 Heriot Microfiltration Key Operating Parameters

Parameter	**Operating Condition**
Feed Quality	• Turbidity >150NTU continuous • TSS >100 g/m^3 • Temperature Winter <5deg C
Flux Rate (LMH – Litres per m2 membrane per hour)	• Design 40 • Operating 12
ASRF (backwash)	• Every 20 Mins
Chemical Cleans	• Daily with Caustic and Hypochlorite • Every 6 weeks full CIP – Caustic and Hypochlorite followed by Citric

The design flux rate is assessed not to be sustainable at the current pond performance conditions and has as yet been unable to be tested with expected turbidity and suspended solids loadings.

The MF plant is showing significant resilience when operating at these low flux rates, which is matching influent flows therefore providing a sustainable operation and full compliance with BOD, SS and E-Coli, even when the pond performance is poor.

4 PERFORMANCE - KAITANGATA

4.1 POND PERFORMANCE

After the upgraded plant was commissioned, the overall performance was very good and effectively performing as designed. Table 4.1 summarises the performance of the pond.

Table 4.1 – Upgraded Pond Performance:

Parameter	**Influent**	**Pond Effluent (pre-upgrade)**	**Pond Effluent (post Upgrade)**	**Discharge**	**Consent Requirement**
BOD (g/m^3)	79	42	26	<6	20
Ammonia N (g/m^3)	19	15	18	18	20
TSS (g/m^3)	133	76	43	<6	20
TN (g/m^3)	27	?	25	20	35
TP (g/m^3)	3	6	4	2	10
E-Coli (cfu/100ml)	743,000	81,000	16,000	<5	260

From the data obtained to date, it can be seen that the pond performance has improved in terms of BOD, TSS and E-Coli.

However, as the pond is not at all times achieving a reduction in BOD and SS to less than $30g/m^3$, there is limited or no ammonia reduction occurring at this stage. It can be seen that the MF is removing the insoluble N leaving TN to be approximately the same concentration as ammonia N.

Current performance of the Bioshells is apparently successful in BOD and SS reduction compared to pre-pond upgrade with an improvement of approximately $16g/m^3$ BOD and 33 g/m^3 of TSS performance. Based on an average flow of $600m^3$ per day, this equates to approximately 9.6kg/day BOD and 19.8kg/day TSS. For the number of Bioshells installed (15 in total), this equates to 0.65kg/day BOD and 1.3kg/day TSS. Design for the Bioshells is 1.8kg/day BOD and 0.7kg/day TSS.

As part of the upgrade, the pond was de-sludged, and baffles installed to prevent short-circuiting. Together with a limited data set on pond effluent (approximately 3 months being April through June 2018) and no pre-upgrade data on pond influent, it is not possible to currently determine the true performance of the Bioshells for BOD and TSS reduction. However on face value it is reasonable to assume that they are responsible for BOD and TSS improvements.

Nitrification is not obvious from the data gathered to date. This is most likely attributable to the higher than required TSS with the average being 42 g/m^3 which is significantly higher than the required 30 g/m^3 for nitrifying biomass to be stable within the Bioshells.

In summary, the Bioshells at Kaitangata are reducing BOD and TSS. Further work on reducing TSS is being investigated and additional Bioshells are an option.

4.2 MF PERFORMANCE

The performance of the MF is providing full removal of insoluble N, insoluble BOD, SS and E-Coli.

The performance of the MF at Kaitangata has seen two distinctly different phases of pond performance and therefore feedwater entering the MF. Initially on start-up, feed turbidity and SS were 30-40NTU and 25-40 g/m^3 respectively. This first phase was during April 2018. Subsequently, the pond performance deteriorated which corresponded with two major factors. The first factor was an excessive storm event which then combined with a massive drop in temperature from approximately 12-15°C to <5°C pond liquid temperature.

After these events, the feed turbidity into the MF increased to 70-75NTU with a corresponding increase in TSS to an average of 55 g/m^3.

The MF performance in these two different conditions has been stable with a reduced capacity being noted with the increased solids loading and the reduced temperature. Key operating parameters at the flows that are being treated are presented in table 4.2.

Table 4.2 Kaitangata Microfiltration Key Operating Parameters

Parameter	**Operating Condition**
Feed Quality	Condition 1: • Turbidity <40 NTU continuous • TSS <40 g/m^3 • Temperature >10deg C Condition 2: • Turbidity 70-75 NTU continuous • TSS 55-60 g/m^3 • Temperature <5deg C
Flux Rate (LMH – Litres per m2 membrane per hour)	• Design 40 • Operating Condition 1: 30 • Operating Condition 2: 18
ASRF (backwash)	• Condition 1: Every 20 Mins • Condition 2: Every 12 Mins
Chemical Cleans	• Condition 1: Daily with Caustic and Hypochlorite • Condition 2: 18 hourly with Caustic and Hypochlorite • Every 6 weeks full CIP – Caustic and Hypochlorite followed by Citric

The MF plant is operating at design flux rates when pond effluent TSS was in the order of 35 g/m^3 and temperatures were >10°C. When the TSS increased and the temperature decreased, stable operating flux rates are < 20lmh.

5 PERFORMANCE SUMMARY

5.1 BIOSHELLS

Proven to nitrify at low temperatures in the USA they are seen as a very good option to reduce ammonia from ponds with simple augmentation as they are installed in operating facilities without the need to drain ponds.

They are successfully reducing BOD and SS at Kaitangata and it is expected that they will also be achieving similar performance at Heriot. The data is not sufficient to provide any definitive conclusion at Heriot.

To date, the concentrations BOD and SS less than 30 g/m^3 to allow nitrification have not occurred. However it is fully expected they will provide nitrification when these conditions are achieved.

Bioshells are cost effective with the air requirements being only 1.7Nm^3/hr at a pressure to overcome static and pipe losses. At Heriot and Kaitangata, pressures required are approximately only 20-30kPag. The blowers used are the same side-draft blowers at each site are only 2.2kW. Operating continuously this is approximately $10 per day.

Further investigations are continuing at Heriot and it is likely more Bioshells will be installed or the influent load from the truckwash will be removed or reduced. A combination is likely.

Whilst Kaitangata is meeting it's requirements, to provide a better quality feed to the MF, further Bioshells may also be considered.

The Bioshells are made locally in New Zealand and are a good augmentation option for those treatment plants that are looking for an option on how to improve quality whilst keeping their existing waste stabilisation pond.

5.2 MICROFILTRATION

The Pall Microfiltration system installed at the back end of the ponds is working well achieving quality at all times with respect to TSS, insoluble BOD, E-Coli and insoluble nitrogen.

The design of the plant was initially at a fluxrate of 40lmh. The temperature drop to <5°C was not expected. At the beginning of June, ice had formed on the surface of the ponds and effluent temperatures were as low as 2.5°C. At these lower temperatures, it is assessed that the additional viscosity of the water warrants a reduction in fluxrate of up to 30%.

When the TSS loading is > 40 g/m^3, a further reduction should be applied when treating pond effluent. At low temperatures, stable operation at <20lmh is being achieved with higher solids loading; and design flux rates are achievable at 12°C with the design solids loading.

Based on operational parameters observed to date, design for treating pond effluent needs to be considered carefully and should allow for pond treatment upsets and low temperatures. The design for the MF should be undertaken as normal and then a risk mitigation factor for frequency of acceptable partially treated discharges verses pond storage buffer and reduced capacity should be taken into account. Designing for pond upset conditions and extremely low temperatures which may well coincide is recommended.

Stable operation in high solids effluent from these ponds at low temperatures of <5°C is being achieved at 30-50% of original design fluxrate with design performance being achieved when ponds are operating as designed.

The MF plant mechanical and membrane reliability is excellent with no membrane fibre breakages nor any increase in pressure decay during the daily integrity testing.

6 UPGRADE COSTS

The Council evaluated the options for the upgrade on whole of life costs including capital and operating chemical, power, membrane replacement costs (based on 7 years) and labour. The chosen option was based on the basis of surety and whole of life costs with the chosen option being mid-range in the whole of life costs.

6.1 CAPITAL

The overall contract costs for the capital upgrade were $1.20m for Kaitangata and $0.73m for Heriot. This excludes Council costs and de-sludging the ponds.

6.2 OPERATIONAL

Chemical consumables during the operational period compared to design are 77%. Operational costs for three months operation are summarised in table 6.1.

Table 6.1: Operational Cost Summary

Item	Description	Amount
Heriot:	Volume	5,900m^3
Chemicals	3 months operation	$727
MF Power	Estimated based on experience	0.1kWh/m^3 @ 25c/kWh $148
Bioshells Power	Calculated from current draw	$820
Chemical/Power	Total per m^3	$0.29/m^3
Kaitangata:	Volume	50,000m^3
Chemicals	3 months operation	$3,950
MF Power	Estimated based on experience	0.1kWh/m^3 @ 25c/kWh $1,250
Bioshells Power	Calculated from current draw	$820
Chemical/Power	Total per m^3	$0.12/m^3

In addition to the direct consumables, the plant requires periodic labour input and a supervisory contract has also been entered into with MPL and Pall. In summary, the Council labour requirement is one visit per week, averaging two hours plus up to 4 hours per month for a full CIP. At $65 per hour this equates to approximately $800 per month plus the supervisory cost of $2,900 per month per plant. The supervisory cost will reduce within 18 months to approximately $1000 per month.

In summary, compared to other options, the plant capital and operational costs are favourable and are far less than a new facility that does not maintain the key waste stabilisation pond asset. The solution is one of the cheapest ways to improve quality whilst maintaining the existing asset and is likely to be suitable for many regional towns in New Zealand.

7 CONCLUSIONS

The upgraded plants at Heriot and Kaitangata are commissioned and operating as expected accounting for the differences in design data and real operational data. One key lesson is to ensure design data is based on comprehensive information to allow the design to be accurate.

The Bioshells are simple, easy to install into an operational pond and operate effectively reducing BOD and SS and will be proven to nitrify at these plants as has been proven in the United States at very low temperatures.

Microfiltration as the final treatment provides surety of compliance with E-Coli, SS, and BOD. With the pond reducing ammonia to acceptable levels the MF will likely ensure total nitrogen is also within desired performance outcomes.

Careful consideration needs to be provided on the impact of the performance of the pond during extreme events and decisions made to appropriately size the MF so that capacity during potential upset conditions match the acceptable level of risk for achieving full treatment.

Overall the two plants are performing with improvements to be made as the operational characteristics become clearer with time. Further augmentation of upgrades to ponds with this technology means it is easy to augment further due to the modular nature of the Bioshells and MF, providing flexibility for future needs if or when even tighter discharge quality improvements are required.

Small towns with small flows can have their plant completely pre-fabricated off-site minimising capital costs associated with on-site construction in remote areas reducing capital costs meaning this technology cab be cost favourable for regional New Zealand towns.

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