Farm dairy effluent treatment

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ABSTRACT

With the recent expansion of dairy farming the disposal of Farm Dairy Effluent (FDE) has become increasingly important. Current practice within the dairy farming sector is to dispose of this effluent either through storage in effluent ponds and sporadic irrigation to land or through continual irrigation to land. Neither of these methods impact on the nutrient content of the wastewater and the nutrients are applied to land in a controlled manner for beneficial reuse.

Feedback from regulators and the dairy sector has revealed that approximately 20-25% of dairy farms face difficulties with applying this nutrient load sustainably. This can be due to a number of factors including soil drainage properties, topography, proximity to water ways, and elevated ground water to name a few. The development of a cost effective high rate biological treatment system has been under way for a number of years. Both Sequencing Batch Reactor (SBR) and Membrane BioReactor (MBR) technology has been trialled with encouraging results.

Recent research work in this area employs the use of a multi-stage treatment system targeting the removal of organic matter, nutrients and solid matter. The different technology steps investigated by these research trials encompass SBR technology for removal of organics and nitrification followed by sand filter contact, modified zeolite and denitrification beds for solids, phosphorous and nitrogen removal respectively.

This system was recently trialled at laboratory scale, and is currently in a prototype design stage with a view to testing it at full scale during 2010.

INTRODUCTION

Dairy shed wastewater, if not adequately treated, presents a significant pollutant load on New Zealand's rural environment. Both Central Government and Regional Councils have identified the disposal of dairy shed wastewater as a major pollution control issue.
The dairy industry is one of the largest export earners for the New Zealand economy. Retaining the clean, green image that is currently enjoyed will depend on effective pollution control measures. The Resource Management Act (RMA) 1991 requires Regional Councils to develop policies and plans that provide for sustainable disposal of wastewaters.
Given the requirement under the RMA for sustainable management of natural and physical resources, and the importance of New Zealand's clean, green image and the dairy industries large contribution to the economy, improved treatment techniques will become increasingly necessary.

Until recently, treatment and disposal techniques such as pond or barrier ditch systems were seen as adequate measures for management of Farm Dairy Effluent. Wetlands have sometimes been added to provide an additional treatment step. Over the past 15 years however, Regional Councils have encouraged the land spraying of effluent through regional plans and policies and this has been successful in many cases. However this application involves significant capital and operating costs, and is not suited to all environmental conditions (i.e. this is not always a sustainable option), in particular where soils drainage is poor and when soils are saturated, topography is unsuitable or ground water nutrient levels are elevated.

Traditional treatment and disposal technologies

Traditional treatment and disposal techniques often incorporated barrier ditches and oxidation ponds prior to disposal to the local stream, river or estuary. The traditional pond and barrier ditch systems provide a degree of organic load removal (e.g. BOD_5 or COD) from the wastewater before being released into the receiving environment. There is however minimal removal of nutrients across these systems due to the difficulties of enhancing the biological mechanisms for nutrient removal within a pond or barrier ditch system.

Developments over the past 30 years with domestic and industrial wastewater treatment technologies for nutrient removal can be applied to dairy shed wastewater treatment.

Trials using a prototype Sequencing Batch Reactor (SBR) (Elwood and Mason 1999; Couper 2001) and Membrane Bioreactor (MBR) systems have shown these high rate processes to be an effective means of treating FDE, significantly reducing organic matter, ammonia, suspended solids and removal of nutrients (total nitrogen and total phosphorus). Newer technologies, such as the modified Zeolite technology make even higher levels of treatment possible. Modified Zeolite was originally developed by Scion to control phosphorus release from contaminated lake sediments. This could be applied in a flow through application to strip phosphorus from effluent flows as an additional treatment option where necessary.

Effects of discharges

The discharge of ammonia from dairy shed effluent can have significant adverse effects on small inland waterways by causing toxicity to New Zealand aquatic biota (Hickey and Vickers 1994). The discharge of nitrogen and phosphorous can also have an eutrophication effect through the growth of nuisance plants and algae. The discharge of dairy shed wastewater is also believed to be causing increased incidences of campylobacter infections in New Zealand.

FARM DAIRY EFFLUENT (FDE) CHARACTERISTICS

Effluent from three different dairy farms has been used as feed into three different high rate biological treatment processes. The first was a SBR trial carried out in 1998-1999, the second a MBR run between 2005 to 2007 and, the most recent, a laboratory scale SBR trial in 2009.

Feed effluent for the 1998 and 2005 trials was taken from the first pond in a two pond system while in the 2009 trial effluent was taken from the second pond in a two-pond system. The characteristics of the different effluent streams are presented below in Figure 1.

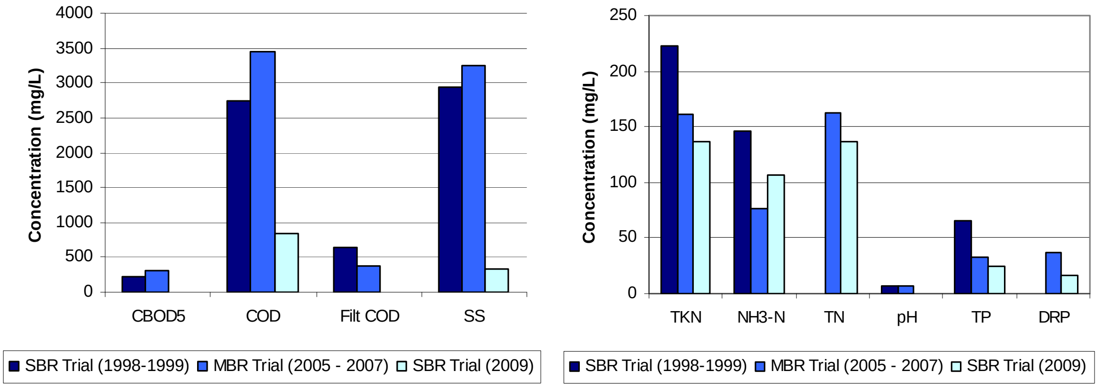

Figure 1. FDE influent characteristics for the three dairy farm trials.

The above results show that while the suspended solids and associated COD is greatly reduced as the effluent passes through to the second pond, the nutrient content in particular nitrogen remains high across the pond systems. A comparison of effluent from the first and second ponds during the 2009 trial is shown below in Table 1.

Table 1. Comparison of pond characteristics for the 2009 SBR trial.

		Pond 1	Pond 2	Reduction
COD	mg/L	6314	809	87%
SS	mg/L	17022	384	98%
VSS	mg/L	8286	344	96%
TKN	mg/L N	395.9	160.7	59%
NH3-N	mg/L N	162.7	111.6	31%
TN	mg/L	417	162	61%
TP	mg/L	51	23.7	54%

The characterisation data for the 2009 trial show that there is a substantial removal of solids across the first pond in a two pond system. Other pollutants associated with the solids are also removed to varying degrees.

This solids removal is typically evidenced by a substantial "crust" or floating solids layer on the first pond with the liquid phase flowing through to the second pond below this surface crust. In addition heavier solids will settle to the base of the first and second pond.

FDE has been investigated by others and typical daily volumes and pollutant loads for dairyshed wastewater have been previously published (Heatley et al. 2006). The above data shows that the typical "text book" characteristics are comparable to the results that we have experienced in our experimental work.

One of the key aspects to note is the high nitrogen concentration relative to the organic carbon in particular the biodegradable fraction (BOD). This creates challenges for conventional biological nitrogen removal within a high rate process as a supplemental carbon source is required to ensure effective denitrification.

FDE TREATMENT SYSTEMS

Ponds

Typical practice is for FDE to pass through a two pond treatment system. In the first pond anaerobic conditions will typically exist. Most of the solid matter, and the portion of organic compounds that is associated with this, is captured by the two ponds and the treated effluent passes through to be irrigated to land or discharged.

The first anaerobic stage, which receives the high strength wastewater from the shed, provides a reducing environment where biodegradable organic nitrogen will be converted to ammonia, and organic carbon will initially be hydrolysed to intermediates and organic acids, and ultimately to methane or carbon dioxide. In addition to these removal mechanisms for the organic carbon, a significant portion of the removal is simply through sedimentation (physical solids-liquid separation) and accumulation at the base of the pond. The organic component of this sediment will also undergo biodegradation through cold digestion.

Due to the conditions in the anaerobic pond and the fact that the dairy shed wastewater contains a significant mass of nitrogen (either as ammonia or organic nitrogen), the effluent from the anaerobic pond is typically high in ammonia. Values in excess of 150 mg/l are not uncommon and this is 3-4 times the ammonia concentration typically present in raw domestic sewage.

The second aerobic or facultative pond is usually shallow so as to allow for the diffusion of oxygen from air into the pond water and also light penetration to encourage algae growth which will also contribute to the oxygen input via photosynthesis. The term facultative refers to the fact that the bottom portion of the pond is likely to be anaerobic thus much of the biomass within the second pond is capable of survival under both sets of conditions.

The facultative pond provides further pollutant removal through biological oxidation, near the surface, and sedimentation and digestion at the base of the pond. However dairy shed wastewater typically contains a high degree of colour, which is the result of dissolved and colloidal cellulose, lignins, tannins and other organic compounds such as humic acid. This provides an effect similar to that of decaying vegetation in a stagnant pond by producing a high degree of colour and can significantly reduce the light penetration into the pond water (Wang et al. 2004). In addition to these light attenuating substances there is usually a high concentration of fine suspended solids, which can further impede light penetration into the pond. Thus the oxygen contribution from algal photosynthesis in dairy shed wastewater ponds is likely to be less when compared to ponds treating domestic wastewater. The majority of the oxygen contribution will therefore be from atmospheric diffusion. This light attenuation phenomenon has not been taken into consideration in the design of many ponds and thus pollutant removal has been limited. Light penetration is also of fundamental importance for the removal of pathogens (Curris et al. 1994). Therefore the reduction of pathogens and subsequent bacteriological quality of the wastewater will be reduced.

The design for pond systems for treating FDE has often been based on guidelines developed for municipal wastewater treatment. Several examples of two pond design guidelines exist and these guidelines usually assume oxygen contribution from photosynthesis as well as passive diffusion.

With low dissolved oxygen levels, poor light penetration and relatively low biomass concentrations within a pond system the removal of pollutants, in particular ammonia is limited.

Land treatment

Land application of Dairy Shed wastewater is the preferred method of treatment by most regional councils for the following reasons:

- A lack of cost effective alternatives currently available.
- Nutrient benefits to be gained from the wastewater.
- Environmental effects are generally less than a direct discharge to surface water.

For land discharge the soil acts as the treatment unit and removes suspended solids through filtration, nutrients through sorption and bio-assimilation, and organic matter through biodegradation by soil micro-organisms.
For land treatment the nutrient value of the effluent is realised by application to the pasture, however application rates must be well managed, and nutrient loads per unit pasture area need to be calculated and assessed on a regular basis. Poor application of dairy shed effluent can lead to:

- Nutrient leaching into the ground water.
- Surface run off and non point source discharges to water.
- Surface ponding.
- Nuisance odours and spray drift.

Land treatment systems can provide a successful disposal method for dairy shed wastewater as well as a recovery of fertiliser costs if applied and managed effectively. Alternative irrigation to a variety of tree species has also identified other options for land treatment and reuse of the nutrients (Roygard et al. 2001). Land treatment may not however be suitable in every case or under all conditions and is often dependent on weather, soil conditions, proximity to water courses and the ground water table. Land treatment also represents a significant capital and ongoing operational cost.

High rate systems

All biological wastewater treatment processes are simply an acceleration or intensification of naturally occurring processes. The treatment of wastewater prior to release into the environment must therefore lower the assimilative requirements and thus improve the state of the environment.

The addition of a secondary (high rate) treatment option, (such as an SBR or MBR), further breaks down the amount of organics that pass through the system. It also is capable of utilising and removing nutrients, in particular nitrogen and phosphorous, that are present in the FDE. These systems transform these nutrients, for example ammonia is converted to nitrate and subsequently nitrate to nitrogen gas, if sufficient organic carbon is available.

EXPERIMENTAL WORK

The prime objective of this project was to develop a suitable, cost effective high rate wastewater treatment process for the treatment of FDE targeting the removal of organic matter, and in particular the removal of nitrogen (specifically ammonia), but also total nitrogen and if possible phosphorous.

A greater degree of treatment provides more flexibility for disposal/reuse such that the effluent can in some cases be directly discharged to the receiving environment or potentially reused as washwater. Set out in Figure 2 below is a “typical” pond system and a simple flow sheet for each of the three trials. Note: The sand filter and denitrification bed were not used in the laboratory trial but are planned for the field loads.

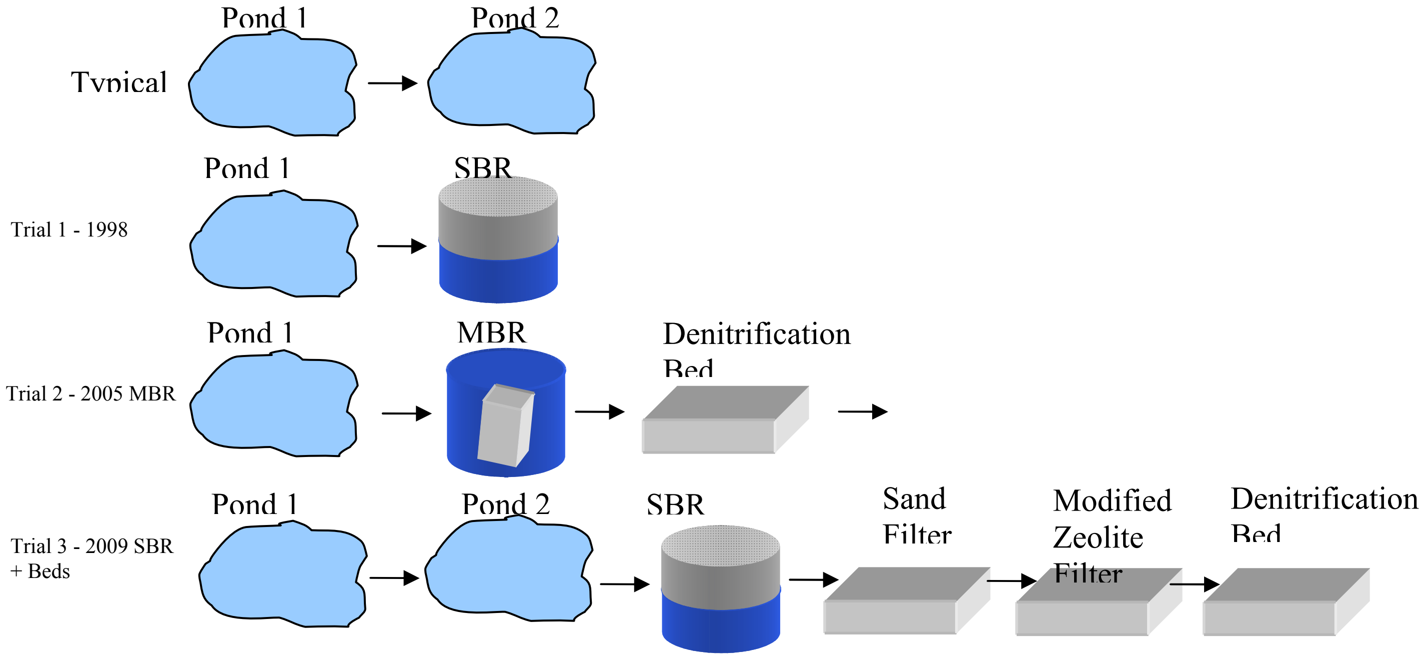

Figure 2. Comparison of FDE treatment options evaluated.

Typical results for a pond treatment system and trial 1 (SBR) and trial 2 (MBR and denitrification bed) are presented in Figure 3 below.

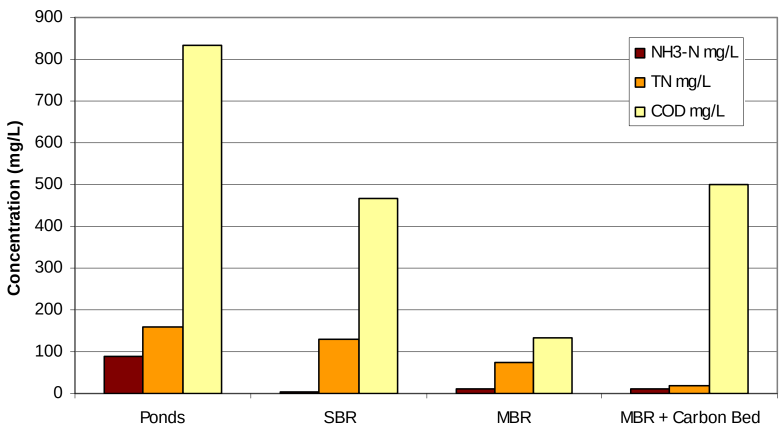

Figure 3. Effluent quality from the different treatment trials.

As a result of the previous trial work and associated effluent quality results the team identified the SBR system to be the most suitable option for the further development of a high rate FDE treatment system.

We highlight the following reasons for this:

- Minimal moving parts thus the process is mechanically and electrically simple for operation on a farm.
- SBR process will cope with shock solid loads better than an MBR system.
- SBR does not have the hydraulic limitations of an MBR process.
- Materials and equipment are substantially less expensive for an SBR system.
- Ammonia removal (nitrification) is similar for both systems.
- Utilisation of a conventional two pond system for pre-treatment results in a significant reduction in required level of treatment over a single pond.

Trial 3 – 2009 laboratory scale SBR and modified zeolite filter

The remainder of this paper is focussed on recent laboratory trials and comparing the effluent quality results with the previous field trials.

For this third trial two laboratory scale SBR reactors were operated with a view to determining the optimum operating conditions for full-scale design specifications to be developed. In addition, the SBR effluent was used to trial the use of a modified Zeolite filter for the removal of the residual phosphorus. The set up is presented in Figure 4 below:

SBR Reactor 1 (right) and 2

Modified Zeolite Filter

Figure 4. SBR reactors and modified zeolite filter.

Under the initial start-up phase these reactors were run identically, but, after several months of operation, the contents from Reactor 1 were subjected to conditions that would promote the formation of rapid settling aerobic biomass granules. The potential for granulation was identified in the previous trials and if successful will result in a considerably more efficient full-scale design. The experimental work followed the program set out below.

Day	**Reactor 1**	**Reactor 2**
0	Reactor Seeded and Started	Reactor Seeded and Started
60	Feed to 2L/cycle	Feed to 1L/cycle
90-110	Reduce settle 15 – 1 minute	

RESULTS

Results from trial 3 are set out and compared to the results from the previous two trials in Table 2 below.

Table 2. Results from trials 1, 2 and 3.

Trial			CBOD5	COD	SS	TKN	NH3-N	Nitrate	TN	pH	Alkalinity	TP	DRP
		Units	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	-	mgCaCO3/L	mg/L	mg/L
SBR Trial 1 (1998-1999)	Influent	Mean	214	2749	2947	222	147	0		7.5	3061	65.2	
		90%	280	3787	4912	259	168	0		7.8	7100	89.6	
	Number of Samples		*10*	*9*	*8*	*9*	*7*	*2*	*0*	*7*	*5*	*5*	*0*
	Effluent	Mean	35	717	586	31	3	129		7.1	94	71.7	
		90%	45	835	1046	46	4	152		7.4	111	90.5	
	Number of Samples		*11*	*11*	*10*	*10*	*11*	*11*	*0*	*9*	*3*	*6*	*0*
MBR Trial 2 (2005 - 2007)	Influent	Mean	302	3438	3255	161	76	0	162.3	7.2	518	33.2	36.2
		90%	526	4020	11027	206	124	0	209.3	7.5	803	45.2	55.6
	Number of Samples		*16*	*26*	*39*	*33*	*48*	*1*	*32*	*11*	*13*	*26*	*5*
	MBR Effluent	Mean	3	132	5	21	12	49	74.5	7.4	165	16.9	12.6
		90%	8	194	7	70	46	97	147.2	7.7	452	25.6	35.2
	Number of Samples		*15*	*21*	*15*	*34*	*47*	*45*	*33*	*9*	*11*	*19*	*5*
	Carbon Bed Effluent	Mean	101	498	15	25	13	0	18.0	6.1	133	20.5	21.6
		90%	153	896	20	52	37	1	30.8	6.9	225	38.5	42.6
	Number of Samples		*14*	*16*	*10*	*28*	*41*	*41*	*23*	*5*	*5*	*24*	*5*
SBR Trial 3 (2009)	Influent	Mean		833	330	137	107	2	136.7			25.0	16.0
		90%		953	420	160	130	3	160.0			25.0	16.0
	Number of Samples		*0*	*12*	*19*	*6*	*7*	*15*	*6*	*0*	*0*	*1*	*1*
	Reactor 1 Effluent	Mean	9	428	194	16	3	122	137.3	6.54		22.0	16.8
		90%	9	528	284	19	4	132	154.0	5.92*		23.6	18.2
	Number of Samples		*1*	*9*	*9*	*7*	*10*	*9*	*7*	*34*	*0*	*9*	*9*
	Reactor 2 Effluent	Mean	21	247	134	13	2	113	124.4	6.31		15.3	12.3
		90%	34	400	210	26	5	120	132.0	5.86*		20.0	18.0
	Number of Samples		*4*	*11*	*11*	*9*	*12*	*11*	*9*	*34*	*0*	*11*	*11*
	Modified Zeolite Filter	Mean										5.5	3.7
	Number of Samples											*3*	*3*

** these show the lower 10th percentile limit rather than the high 90th percentile.*

The results show the following:

- **Organic Load** – COD and BOD_5 – There was consistent removal of both COD and BOD_5 across the various treatment system trials. As expected the MBR trial showed the greatest percentage removal. The carbon (denitrification) bed clearly adds additional organic carbon to the effluent stream this is evidenced by the increase in COD across the bed.
- **Solids** – Solids were substantially reduced during the 1st SBR trial and as expected almost 100% across the MBR system. The 3rd trial had significantly lower feed solids concentrations due to feed originating from a 2 pond system. However, the final solids concentrations compared favourably with the previous first SBR trial.
- **Nitrogen** – In all stages the system was capable of effective nitrification with many low ammonia values reached on the 1st and 3rd trials. No denitrification mechanism was in place for trials 1 and 3. For trial 2 the MBR was coupled to a carbon bed and this system shows substantial total nitrogen removal and almost no nitrate in the trial effluent. A side effect of the carbon bed however, is elevated COD in the effluent.
- **Phosphorous** – There was minimal phosphorous removal across the 1st trial and removals across trials 2 and 3 appear to be related to standard biological requirements for growth, as opposed to any enhanced biological removal mechanism. The Modified Zeolite filter demonstrated high levels of phosphorus removal in the final effluent.
- **pH and Alkalinity** – For the first two trials the wastewater did not appear to be alkalinity limited with minimal pH drop across the process. In the third trial however pH drops as low as 4.8 were experienced without any obvious impact on nitrification.

Further details of the experimental work are presented in the following figures. Figure 5 shows the mixed liquor solids concentrations in Reactor 1 and 2 as a function of time from start up through to the end of the 130 day trial. Also presented are the target operating lines for the mixed liquor solids in both the 1st SBR trial and the MBR trial. These results show that the system is capable of building and maintaining a viable biomass even with a low solids influent from the second pond.

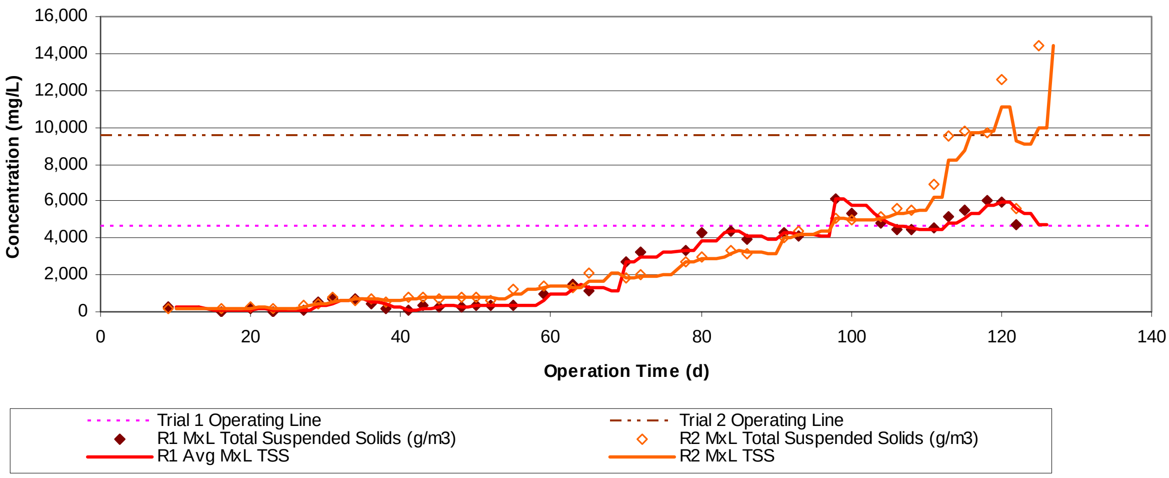

Figure 5. Mixed liquor solids concentrations.

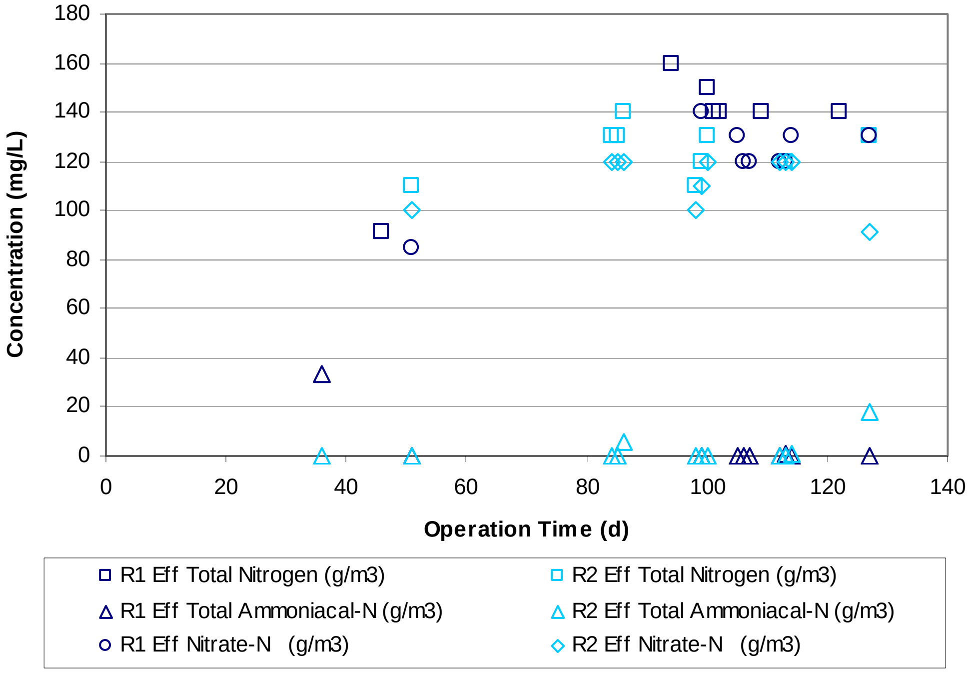

Figure 6. Nitrogen removal.

Figure 6 presents the final effluent ammonia, nitrate and total nitrogen concentrations over time for both reactor 1 and 2 in the third trial. The graph highlights that the SBR system is capable of effective nitrification within a short period of time from start up. The data also shows the concentration of nitrate over time.

CONCLUSIONS

FDE is a significant pollutant load to the rural environment and its discharge/disposal is now coming under increasing scrutiny by Regional Council regulators.

The characterization data measured as a result of the field and laboratory trials shows similar characteristics for FDE and is comparable to text book or guideline values. Of particular importance to the effective treatment of FDE is the extremely high solids concentration in the raw effluent and the subsequent removal of solids across a two pond system. The concentration of nitrogen is substantially higher than municipal wastewater and this coupled to the low concentrations of biodegradable carbon creates difficulties for total nitrogen removal.

Most of the COD load appears to be of low degradability and associated with the solids and color in the effluent.

None of the traditional treatment systems are capable of effective nutrient removal from the wastewater, irrigation has been encouraged throughout New Zealand as the most sustainable option for disposal of FDE as this provides beneficial reuse, uptake of some nutrients by crops, and a buffer between application and the receiving environment. Land treatment may not be sustainable in every case and poor management or certain climatic or land conditions can lead to nutrient runoff and leaching to surface or ground water.

High rate biological treatment systems provide a potential opportunity for treatment of FDE to a higher quality including the removal of nutrients. The field trials and recent laboratory work have confirmed that such systems are technically viable and potentially affordable.

System operational challenges remain, however the SBR process has been identified as the most robust and simple to operate of the high rate systems evaluated and recent laboratory trials have provided design data and operational information that can be used to design a further field SBR trial.

FUTURE WORK

Following on from the recent laboratory trials it is proposed to design a SBR system to be tested in the field and to assess what suitable down stream process can be coupled to the SBR system to provide a final effluent suitable for both irrigation and/or direct discharge. This work is planned for 2010 – 2011.

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