MAKING THE MOST OF OUR BIOSOLIDS – WHAT ARE THE OPTIONS?

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ABSTRACT

Excess sludge generated from wastewater treatment plants has been a headache for many utilities and operators in New Zealand and around the world. Traditionally, the excess sludge has long been viewed as a waste, requiring waste management (i.e. to be disposed of). The disposal routes often include ocean disposal, landfilling of dewatered sludge (with or without stabilisation), incineration and agricultural application.

Stringent legislation, perceived risks of emission and public opinion has made the option of incinerating undigested sludge very unpopular. Similarly, land application for agricultural use has been a subject of negative public perception over odour and pathogens. Landfilling excess sludge has been a common practice for past decades but it is difficult to build new landfills in large metropolises and the cost of transporting dewatered sludge to landfill has been progressively increased. Thus, new management practices need to be identified.

During the last decade, the fossil fuel crisis has resulted in developing new initiatives and technologies to minimise/replace fossil fuel uses. As a result, biosolids are increasingly being recognised a fuel to generate electricity after being dried or via combustion of biogas which originates from anaerobic digestion, as well as its nutrient value as an attractive alternative fertiliser source.

Moreover, a range of process technologies have since been developed and commercialised to improve the current biosolids management practice with an objective of "greener future".

This paper presents an overview of these new technologies and how they can be applied in the New Zealand context to deliver the desired outcomes.

KEYWORDS

Biosolids, Sludge Treatment, Resources, New Approaches

1 INTRODUCTION

Modern wastewater treatment plants in urban New Zealand areas are predominantly secondary and tertiary processes, which invariably generate excess sludge as a result of biological treatment. Traditionally, this excess sludge has been viewed as a waste stream, requiring management and disposal.

The most common sludge management and disposal routes in New Zealand include:

(i) onsite sludge dewatering and landfill disposal

(ii) onsite sludge digestion (stabilisation), dewatering and landfill.

US and many European countries, sludge incineration and land application for agricultural uses are commonly employed in addition to digestion, dewatering and landfill disposal.

Landfill disposal of sludge not only adds pressure to the existing landfills, but also incurs high transport costs due to increasing fuel cost and transportation distance between wastewater treatment plants and landfills.

Conventional sludge digestion reduces the volatile fraction in sludge by 20 to 40%, thus reducing the quantity of sludge to be dewatered, transported and disposed. In addition, the digestion process also generates biogas (~60-65% methane) which can be used for power / heat generation on sites depending on site specific economics.

2 BACKGROUND

2.1 CURRENT SLUDGE DISPOSAL IN NEW ZEALAND

From the figures provided by Ministry of Environment, approximately 240,000 tonnes of treated sewage sludge are generated by the treatment plants in the country each year. (Environment New Zealand 2007, MfE) Of which, about 37,000 tonnes are being used for beneficial reuse in New Zealand every year, which includes land application in forests and composting. This implies that about 84% or 200,000 tonnes of excess sludge is being buried in landfills or specific disposal sites each year. This volume of sewage sludge increases the total amount of solid waste disposed into landfills, which in turn shortens the lifespan of landfills. Sludge quantity from wastewater treatment plants is expected to increase as more and more treatment plants are being upgraded to increase its capacity and higher quality (e.g. from oxidation ponds to activated sludge process).

For example, the waste digested sludge from the two main wastewater treatment plants (Mangere WwTP and Rosedale WwTP) in Auckland is landfilled. The dewatered sludge from Mangere WwTP is disposed in a dedicated disposal site within the treatment plant area and the dewatered waste sludge from Rosedale WwTP is transported to Hampton Downs landfill for disposal.

2.2 NEW ZEALAND BIOSOLIDS GUIDELINES

Biosolids is often viewed as a more acceptable term of sewage sludge, but there are noticeable differences in technical definition. Based on the New Zealand Biosolids Guidelines, Biosolids is defined as "*sewage sludges or sewage sludges mixed with other materials, that have been treated and/or stabilised to the extent that they are able to be safely and beneficially applied to land*." Therefore, untreated /unstabilised sewage sludge or sludges originated from industrial processes do not fall into the category of biosolids.

There are two grades in the Biosolids Guidelines, the first letter denotes the stabilisation grade of the biosolids (Grade A or B) and the second letter denotes the contamination levels of heavy metals and pesticides in the biosolids (Grade a or b). Grade A stabilisation requires a quality assurance program to be in place in addition to a robust pathogen reduction process (e.g. thermal treatment, lime stabilisation and composting). Grade B stabilisation requires the biosolids to be processed via an acceptable vector attraction reduction (VAR) method. Biosolids that satisfy the contaminant Grade "a" are expected to have very low concentrations in metal and pesticides. Refer to the Biosolids guidelines for details on the derviations and the limits of the stabilisation and contamination grades.

2.3 NEW ZEALAND BIOSOLIDS CHARACTERISTICS

Sludge treatment at wastewater treatment plants dictates the stabilisation grade (Grade A, B or not graded) of the biosolids while the source of wastewater determines the contamination grade (Grade a, b or not graded) of the biosolids, especially in terms of heavy metals and pesticides.

The 1998 national biosolids characterisation survey[1] identified that most biosolids from most wastewater treatment plants would comply with the metal limits specified by Grade b biosolids guidelines.

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[1] *National Study for the Composition of Sewage Sludge 1998 (NZWWA)*

Table 1: Sludge Monitoring Data in 1998 National Study of Sewage Sludge

	Biosolids Guideline		**Data Presented in 1998 National Study for the Composition of Sewage Sludge (in mg/kgDS)**									
	Grade a	**Grade b**	**Dunedin**	**Christchurch**	**Invercagill**	**Hutt Valley**	**North Shore**	**Tokoroa**	**Mangere**	**Paraparaumu**	**New Plymouth**	**Rotorua**
Arsenic	<20	<30	3	18	13	1	5	10	25	6	4	8
Cadmium	<1	<10	2	4	1	2	2	2	2	2	1	1
Chromium	<600	<1500	90	1000	46	40	93	50	470	35	200	40
Copper	<100	<1250	300	460	200	400	450	350	480	260	480	220
Lead	<300	<300	180	200	140	70	85	90	110	55	60	60
Mercury	<1	<7.5	2	3	3	7	4	6	3	3	1	3
Nickel	<60	<135	25	90	30	20	250	30	75	14	130	23
Zinc	<300	<1500	600	1300	670	600	820	**1500**	1300	660	**1860**	1000

2.4 FERTILISER MANUFACTURE

The success of the strong New Zealand agricultural sector has been built on modern farming practices including applying synthetic fertilisers. Most of the ingredients for fertiliser manufacture are sourced from overseas and they are predominantly non-renewable resources.

For example, urea is one of the common forms of nitrogen fertilisers, which is manufactured from natural gas via Haber process before ammonia is synthesised with carbon dioxide into urea. The cost of urea fertiliser is highly sensitive to the natural gas price because natural gas presents bulk of its manufacturing cost, thus any price volatility would have a sizeable impact on farmers and their income.

Another common fertiliser used in New Zealand is Diammonium hydrogen phosphate (DAP), which is formed by reacting phosphoric acid with ammonia, which phosphate rocks are the raw ingredient for manufacturing phosphoric. There are finite amount of high quality phosphate rocks on Earth’s crust, thus studies of the potential economic impacts of “Peak Phopshorus” scenarios have been undertaken. It should be noted that the price of phosphate rock has rocketed from USD$50 to 400/tonne in the past few years and would affect the bottom line of farmers and consumers.

It has been recognised that biosolids has a significant value in nutrient supplementing and soil conditioning. There are reports suggesting that addition of biosolids improves and replenishes the soil health thus resulting in better crop growth, organic constituents improves binding of soil resulting in less soil erosion and better water holding capacity, slower release of nutrients reduces leaching of fertiliser into groundwater.

Therefore, substituting artificial fertiliser with nutrients in biosolids would prove to be a sustainable approach to maintain the strength of our agricultural sector, provided that appropriate Biosolids guidelines are met.

3 BETTER UTILISATION OF BIOSOLIDS

3.1 CURRENT BIOSOLIDS MANAGEMENT PRACTICE

There are generally two main sources of waste sludge in a wastewater treatment plant, primary sludge (PS) and secondary sludge (WAS for activated sludge processes). Figure 1 shows a process block diagram of a typical wastewater treatment plant.

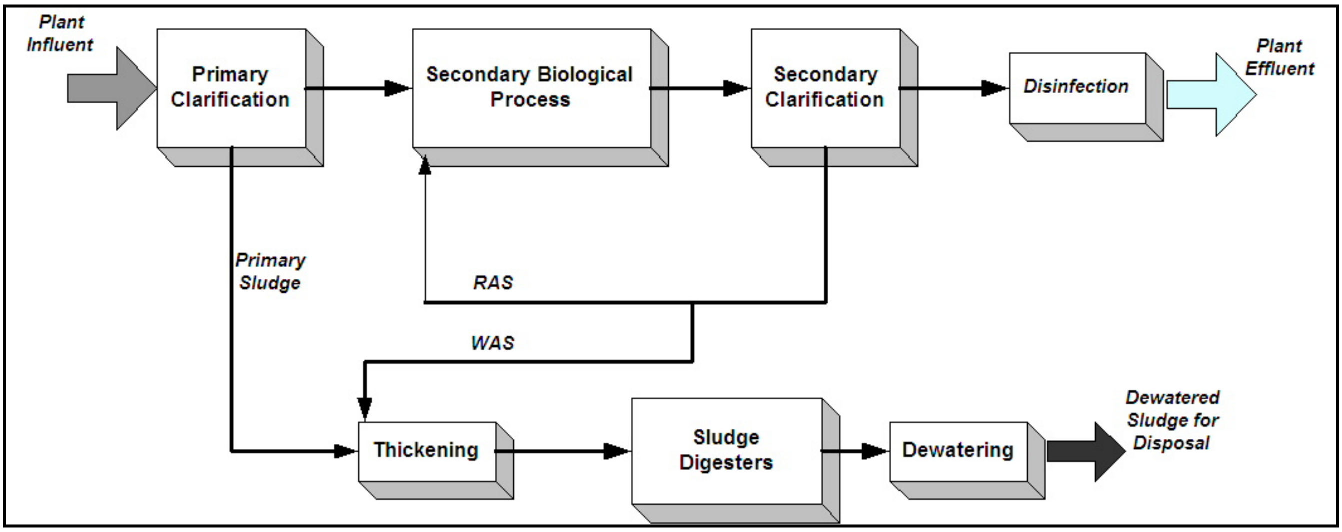

Figure 1: Process Block Diagram for a Typical Wastewater Treatment Plant

Conventional sludge digesters include anaerobic or aerobic digestion. Comparing anaerobic digestion to aerobic digestion, anaerobic digestion requires much larger tanks, but consumes significantly less power (i.e. without aeration) and does not require alkalinity addition. In addition, biogas from the anaerobic process (methanogenesis) can be collected and used for generating electricity and heat (hot water/steam).

A number of process variants of anaerobic digestion had been developed to improve the digestion efficiency, including thermophilic anaerobic digestion (TAD), temperature phased anaerobic digestion (TPAD), two phase anaerobic digestion (acid/methane phase digestion).

3.2 NEW TECHNOLOGY AND NEW OPPORTUNITIES

A number of sludge treatment technologies have been developed in the past two decades, aiming to improve sludge processing, treatment and resource recovery. Some of them have been implemented in full-scale installations.

3.2.1 SLUDGE HYDROLYSIS

Hydrolysis is a break-down of complex particulate matter into dissolved compounds with low molecular weight and it is known as the rate-limiting step in anaerobic reactions, which comprising hydrolysis, acidogenesis, acetogenesis and methanogenesis.

When sludge is hydrolysed, the high molecular weight compounds such as complex carbohydrates, proteins and lipids are converted into soluble sugars, amino acids and volatile fatty acids. As a result, the sludge is more biologically digestable, vast interest and research has been undertaken to apply the principles of sludge hydrolysis in the following areas:

a) Returned Activated Sludge (RAS) Hydrolysis – this breaks down the particulate compounds into soluble forms that can be used as a carbon source for denitrification or biological phosphorus removal (Or known as carbon bioaugmentation).

b) Waste Activated Sludge (WAS) Hydrolysis – this breaks down the particulate compounds in WAS (preferably thickened WAS) into more soluble forms which improves sludge digestability and in turn improves volatile solids reduction and biogas production.

c) Combined Sludge Hydrolysis - this breaks down the particulate compounds in the combined sludge into more soluble forms, which improves the sludge digestability and in turn improve volatile solids reduction and biogas production.

Figure 2 below illustrates the possible locations of installing sludge hydrolysis pre-treatment.

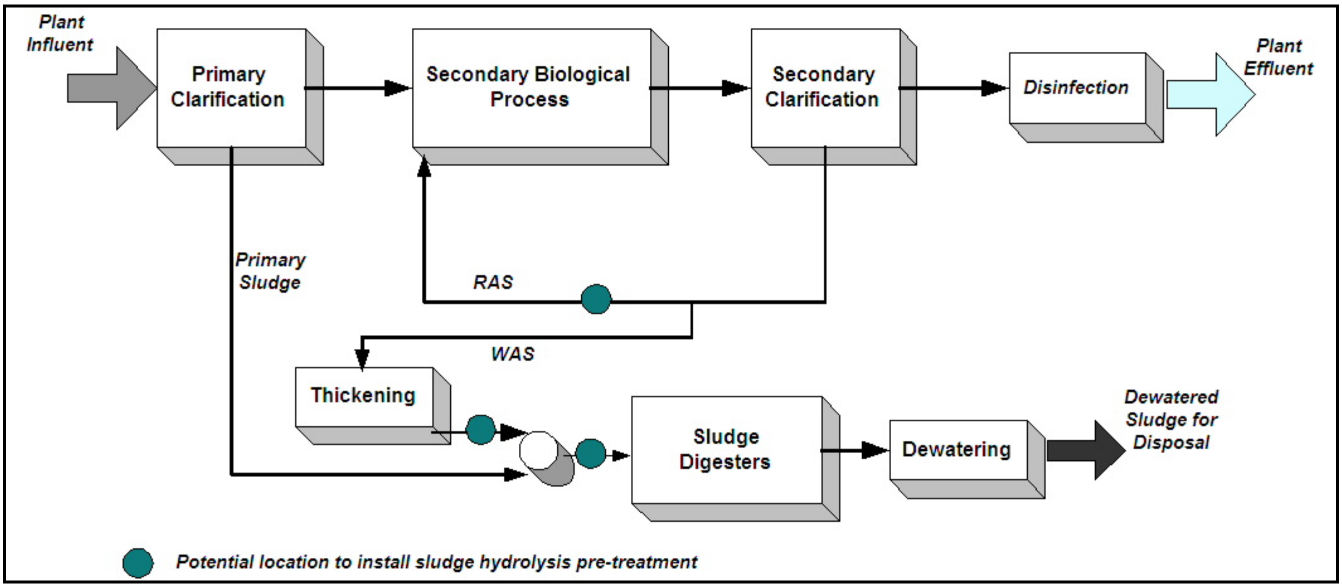

Figure 2: Possible Locations of Installing Sludge Hydrolysis

Sludge hydrolysis can be achieved via the following pathways:

- Thermal and mechanical (e.g. Cambi™ and Biothelys™)
- Mechanical (e.g. Biogest® Crown Disintegrator)
- Physical & Chemical (e.g. MicroSludge®)
- Biological (e.g. Monsal® Enhanced Enzymic Hydrolysis, EEH)
- Ultrasound (e.g. Sonix™ and Ultrawaves)

The table below is a summary of the selected hydrolysis technologies.

Table 2: Summary of Selected Technologies for Sludge Hydrolysis

Methods	**Thermal/Mechanical**	**Mechanical**	**Physical/Chemical**	**Biological**	**Ultrasound**
Selected Example	Cambi™THP	Biogest®	MicroSludge™	Monsal EEH	Ultrawaves
Process in Brief	Heat sludge with live steam at 5-6barg before cell rupture (hydrolysis)	Pressurise homogenised sludge before cell rupture	Alkaline adjustment upstream of homogenise sludge before cavitation at	Multiple reactors in series to promote hydrolysis and acidification	Apply ultrasound to achieve cell rupture

Methods	Thermal/Mechanical	Mechanical	Physical/Chemical	Biological	Ultrasound
			very high pressure		
Process Configuration	Each process train: Pulper 1x Reactor 2 to 5x Flash Tank 1x	Each process train: Macerator Pressure Pump (12barg) Pressure Mixer Disintegration nozzle	Each process train: Caustic pH adjustment Chopper pumps Microscreen Homogeniser (800barg)	Each process train: 3 reactors in series (42°C) 3 reactors in series/ semi-batch (55°C)	Each process train: An ultrasound unit consisting 5 sonotrodes
Approx. Retention Time	3 - 4 hours Reaction: 30-60mins at 155- 165^{3}C	Continuous system	Data not available	Reactors 1 to 3 1.5 days Reactors 4 to 6 1.5 days	75 – 90 sec
Application	WAS Hydrolysis CSF Hydrolysis	RAS Hydrolysis WAS Hydrolysis CSF Hydrolysis	RAS Hydrolysis WAS Hydrolysis CSF Hydrolysis	WAS Hydrolysis CSF Hydrolysis	RAS Hydrolysis WAS Hydrolysis CSF Hydrolysis
Example Installations	Dublin (Ireland) Oxley Creek (Aus)	Rosedale (NZ)	Pilot Trial (Des Moines WRF)	Great Billing (UK)	Bamberg (Germany)
Installation Base	Europe & Around the World	Mostly Europe	Pilot Trial	England only	Mostly Europe
Benefits claimed by vendors	Biogas Production ↑ VSR% ↑ Dewatered Cake Consistency ↑	Biogas Production ↑ VSR% ↑ Carbon augmentation for BNR	Biogas Production ↑ VSR% ↑ Carbon augmentation for BNR	Biogas Production ↑ VSR% ↑ Dewatered Cake Consistency ↑	Biogas Production ↑ VSR% ↑ Carbon augmentation for BNR

However, it should be noted that all sludge hydrolysis pre-treatmaent processes upstream of digesters will increase ammonia concentration in centrate streams, which will in turn increase the nitrogen load returning to the biological process. This is because particulate protein is converted into more soluble compounds like amino acids and ammonia as part of hydrolysis reactions.

Cambi™ Thermo-hydrolysis process (Cambi THP)

Cambi™ T HP is developed by a Norwegian company, Cambi. The first full scale installation is located at Hamar, Norway since 1996. Since then, there are over 23 installations plus a few in detailed engineering/construction phase around the world, pre-dominantly in Europe and UK. There are a couple of installations outside Europe, including Oxley Creek WwTP near Brisbane, Australia.

Cambi™ THP consists of three process steps, Pulper, Reactors and Flash Tank. Cambi™ THP can be arranged in a number of parallel process trains, for example the Stage 1 THP in Ringsend STW, Dublin (1.6millions PE) included 2 lines of Cambi™ THP, each with four reactors. It is understood that the Stage 2 THP upgrade in Dublin, which includes the third stream, is currently being commissioned.

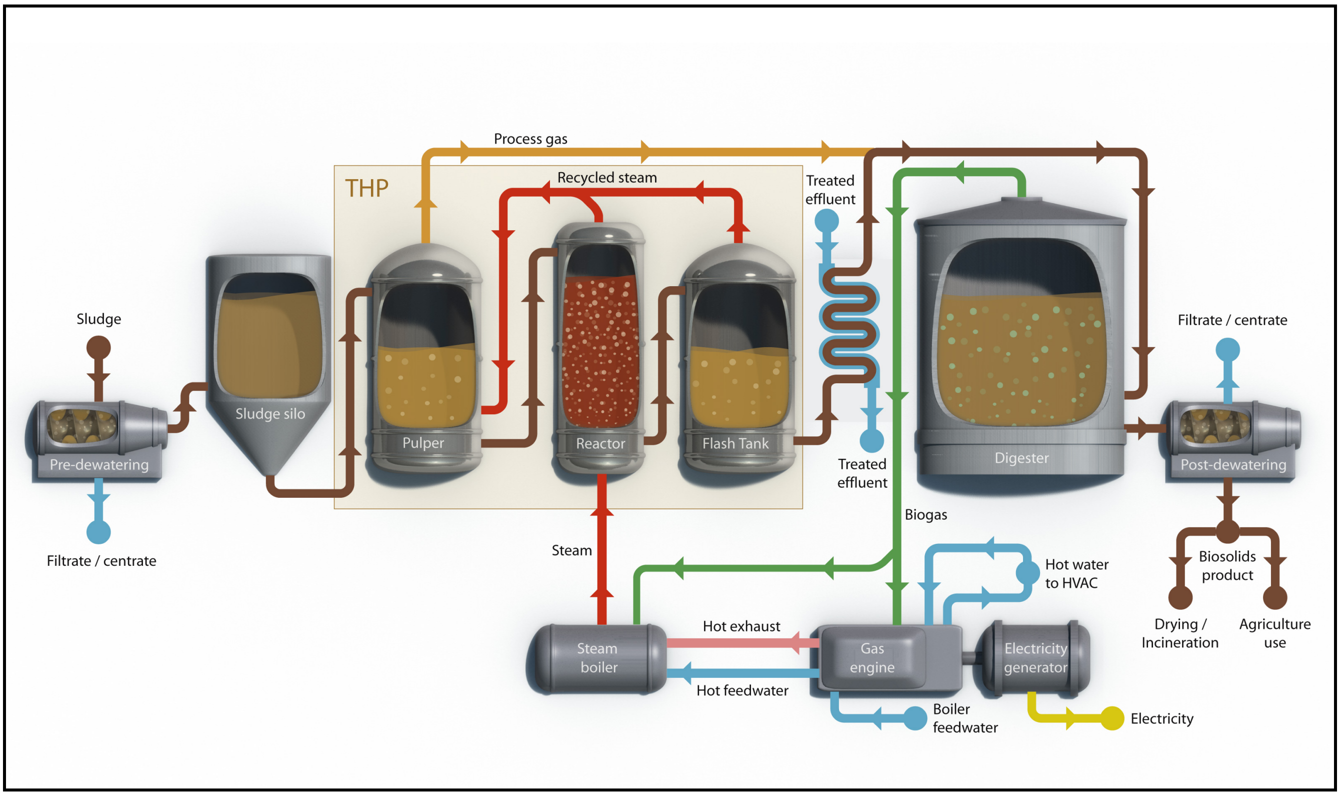

Figure 3: Cambi™ THP Process Schematic (courtesy of Cambi, only 1 reactor is shown)

Pulper tank in the Cambi THP receives pre-dewatered sludge at 15%DS in which it will contact with recycle flash steam from the Reactors and Flash Tank. Reactors are operated in batches and they receive heated sludge from the Pulper Tank from its cycle setting. Live steam is injected into the Reactors to reach its target temperature (155-165°C) and pressure (5 to 6 barg). Reactors will then be de-pressurised as flash steam is directed to the Pulper followed by hot sludge is sent to the Flash Tank where steam explosion and cell rupture occurs. Dilution water is then added in-line to the THP sludge (not shown in Figure 3) before passing through the heat exchanger upstream of mesophilic digesters. Biogas from the digesters will be used for generating electricity and steam. It has been reported that an odourless, higher consistency dewatered sludge cake (>30%DS) can be produced.

Biothelys® is another sludge thermo-hydrolysis technology, represented by Veolia Water. Although it belongs to the category of thermo-hydrolysis, the system set-up and operational characteristics are vastly different to those for the Cambi™ THP. At present, there are about four full-scale Biothelys® installations, and all of them are in France.

Biogest / Crown Disintegrator

Biogest$^{®}$ / Crown Disintegrator is developed by Biogest$^{®}$ AG in Germany. Most of its full-scale installations are in Europe with an installation in Rosedale WwTP, New Zealand. This hydrolysis technology can be applied as RAS treatment for carbon augmentation or a pre-treatment step upstream of sludge digesters.

This sludge hydrolysis consists of the following components:

- Balance Tank – Buffer sludge flow
- Macerator and Mixer – Homogenise feed sludge
- Positive displacement pump – Pressurise sludge to 12barg
- Crown Disintegrator (nozzle) – Sludge hydrolysis

Ultrawaves

Ultrawaves is a hydrolysis process based on the principles of cell lysis (rupture of membrane cells) by applying ultrasound. The operating ultrasound frequency is typically between 30 to 100kHz.

The reactor design follows a serpentine arrangement for maximum flow path with 5 sonotrodes.

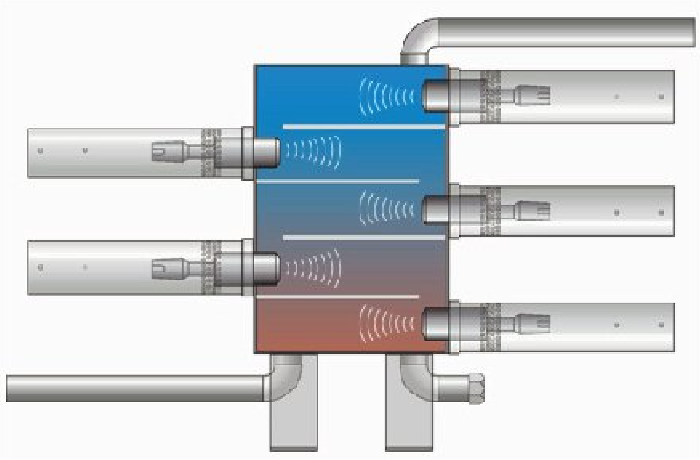

Figure 4: Ultrawaves Reactor Schematic provided by the supplier

From vendor's literature, the standard reactor size is 28L and each is capable of treating up to 30m^3/day of sludge flow. The reactor typically receives between 30 to 40% of the full flow (RAS flow or digester recirculation flow) to promote hydrolysis reaction. Vendor information indicated that the best efficiency is achieved for a sludge consistency of 4% Dry solids.

Most of its installations are in Europe and some are in China. A trial of Ultrawaves reactor has recently commenced in the West Camden STP in Sydney.

3.2.2 SOLIDS REDUCTION TECHNOLOGIES

Cannibal® is a solids reduction technology developed and represented by Siemens Water. There are a number of full scale installations in the United States since 1998. Cannibal® is not a sludge treatment pre-treatment or digestion process.

Compared to conventional wastewater treatment plants (Figure 1), sludge digesters are replaced with a side-stream biological process which aims to eliminate excess sludge generation and associated disposal. Figure 4 below depicts a wastewater treatment plant incorporating Cannibal® process.

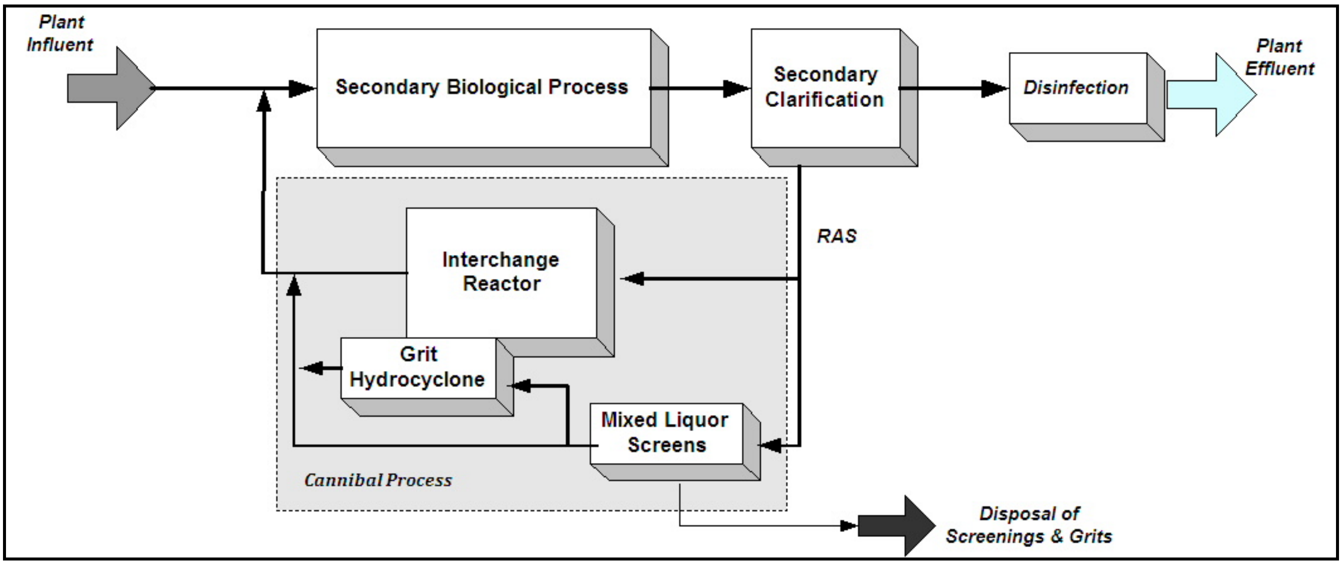

Figure 5: Process Block Diagram of a Wastewater Treatment Plant Incorporating Cannibal® process

The Cannibal® process includes the following components:

- A portion of RAS from the biological process is sent to a side-stream interchange reactor in which the sludge is exposed to anaerobic and anoxic condition. This quiescent condition in this reactor reduces the aerobic bacteria in the sludge and encourages facultative bacteria to be developed. The treated sludge from the interchange reactor is returned to the biological process tanks where facultative bacteria is out-competed by aerobic bacteria. As the sludge stream is interchanged between the main biological process and the interchange reactor, solids are being reduced to inert solids resulting a significantly lower sludge yield of the biological process.

- A portion of RAS is sent to the Solids Separation Module which consists of mixed liquor screens and grit hydrocyclones. The fine screens and the hydrocyclones remove trash and grit accumulated in the sludge as a result of the interchange reactions. These materials typically contain 90% volatile materials and can be dewatered between 30 to 40%DS before being disposed to landfill.

- In addition to the above, a biological system purge will take place between once every 1 to 2 years to remove accumulated solids.

The design criteria data provided by the vendor and their literatures is summarised in the table below.

Table 3: Comparison of Cannibal® & a typical BNR Activated Sludge Process

Parameters	**Cannibal® Process**	**BNR Activated Sludge**
Expected Solids Generation	0.2 – 0.3 kgTS/kgBOD/day (Claimed by the vendor)	0.5 – 1 kgTS/kgBOD/day (depending on sludge age)
Solids Generated	Trash and Grit from fine screens and grits	Biological sludge to digesters
Feed DS% to Interchange Reactor or Sludge Digesters	Typically <1% (as RAS stream from clarifiers or SBR tanks)	Typically <2-3% for non-thickened WAS Typically <4-6% for thickened WAS
Interchange Reactor SRT	10 to 12 days	N/A
Interchange Reactor Operation	24 hours cycle, intermittent aeration	N/A

As seen from above, the Cannibal® process may appeal to smaller wastewater treatment plants as it reduces its operating costs relating to sludge processing and disposal, especially if they have aerobic digesters which are more expensive to run.

3.2.3 NUTRIENT RECOVERY

As discussed earlier, the fertiliser and soil conditioning values of sludge are increasingly being recognised while at the same time, the feed materials for synthetic fertilisers are becoming increasingly scarce. Hence, technologies have been developed to increase nutrient recovery in biosolids including phosphate precipitation and struvite crystallisation and substitution of phosphate rock with dried biosolids ash in phosphate fertiliser manufacture.

Out of these nutrient recovery processes, struvite crystallisation appears to be one of the most promising routes to recover nutrients. Struvite deposition is often experienced by the plant operators at wastewater treatment around digesters and centrate pipework. Struvite deposition occurs when the concentrations of constituents reach the level of supersaturation and the reverse reaction (dissolution) is very slow.

$$Mg^{2+} + NH_4^{+} + PO_4^{3-} + 6H_2O \rightarrow MgNH_4PO_4(H_2O)_6$$ (Neethling, JB, 2004)

Although struvite deposition can be an operational issue for wastewater treatment plant operators, it also provide an opportunity for wastewater treatment plants to harvest struvite crystals as a fertiliser products under controlled environment. This is often achieved by adding magnesium hydroxide or magnesium chloride with caustic dosing to adjust pH to around 9 to 11. Strongly alkali pH and magnesium solution addition promote struvite crystals to form.

In addition to create a fertiliser by-product, magnesium-ammonia-phosphate (MAP), struvite crystallisation also reduces the ammonia and phosphate loads returning to the main treatment process, thus resulting in lower ammonia and phosphate concentrations in the final effluent.

Ostara is one of the struvite crystallisation processes which are now available in full scale installations. Centrate from final dewatering is mixed with magnesium chloride and caustic solution before entering the Ostara Crystalliser. Ostara Crystalliser is an upflow fluidised bed reactor with multiple zones of increasing diameters, this increases the size of struvite crystals. Struvite crystal is marketed as "Crystal Green" fertiliser and there are about four full scale installation in North America.

The other approach is to use biosolids ash (after incineration) to manufacture fertiliser mixing with chlorine additives, thermal treatment (removal of metal contents from ash) before it is converted into fertiliser. This technology is being transferred from pilot scale to full-scale installations.

3.2.4 BETTER INCINERATION /DRYING TECHNOLOGIES

Sludge incineration has been practised for a long time, mainly overseas. Un-digested dewatered sludge is fed into a burner in which the organic materials are burnt and oxidised to form water, carbon dioxide and residual ash. Incineration achieves maximum reduction of sludge volume but it has its limitations and undesirable effects including high capital and operating costs, skilled operators to run and maintain these complex systems, concerns over public health effects associated with exhaust gas and disposed ash.

Recent advances have been made in incineration technology to improve economics, operation and performance. Examples include Pyrofluid, which is represented by Veolia Water, and STERM, which is represented by Enviro-Energy Limited. STERM, for instance, has reported that negligible gaseous emission of particulates, heavy metals (mercury and arsenic) and organics.

As New Zealand has much lesser experience with incineration technology compared to other countries, it is likely that these advanced incineration technologies may be more difficult to implement.

Sludge Drying is an alternative pathway which significantly reduces the sludge volume. Bromley WwTP in Christchurch has recently lodged a resource consent application to construct a thermal biosolids drying facility to achieve 90% dry solids. The key objective of this project is to minimise the quantity of biosolids to be disposed into landfill.

3.2.5 INDUSTRIAL ECOLOGY APPROACH

Further to using biosolids ash in manufacturing fertilisers, there are other uses and applications of using biosolids based on industrial ecology approach. For instance, biosolids (dewatered or dried) and incinerated ash are being used in cement manufacturing overseas as a supplementary fuel as well as a filler material.

There are also case studies in overseas of using dried sludge as a feedstock in brick manufacturing.

4 BIOSOLIDS ROADMAP

Biosolids represents an important resource in terms of its nutrient and calorific values. Nutrient benefits can be realised if the biosolids can be directly applied to land as a soil conditioner/fertiliser, or extracted from incinerated ash or centrate. Calorific values of biosolids are harvested by anaerobic digesters coupled with onsite power and heat generation. In addition, advances in digestion technologies reduce the quantity of sludge to be disposed, thus resulting a significant cost saving for larger treatment plants.

For small to medium wastewater treatment plants, there are opportunities to reduce their supplementary carbon dosing demand (for nitrogen or phosphorus removal) or enhance energy recovery from the digesters through hydrolysis processes. Centralised biosolids management may be beneficial for smaller communities to reach a critical mass for implementing some of these advanced technologies at a centralised sludge process facility. Nevertheless, land application of biosolids where possible is the least expensive and generally blends well with the rural setting. These options require an extensive evaluation with inputs from community consultations to identify the best–fit solution for a particular community or a cluster of communities.

For medium to large wastewater treatment plants, there could be limitations of direct land applications of biosolids due to the presence of industrial contaminants e.g. heavy metals as well as lack of suitable sites. However, these treatment plants are generally equipped with anaerobic digesters which would allow more effective energy recovery through enhanced digestion techniques (e.g. sludge hydrolysis) and possibilities of implementing nutrient recoveries via centrate or incinerated ash. Although sludge drying or incineration is less popular due to higher capital and operating costs and general public perception, they are likely to be technically and economically feasible for large wastewater treatment plants to significantly reduce biosolids disposal volume. As there are numerous potential improvement options for these larger treatment plants, a robust evaluation of option-screening followed by preliminary engineering costing is necessary to identify the optimum solution for a particular situation.

Furthermore, considerations of using dried biosolids and ash in other manufacturing industries (e.g. cement and bricks) should be given if such opportunity is possible.

On the other hand, Cannibal® presents an alternative pathway to reduce operating costs relating to sludge processing and associated disposal for smaller wastewater treatment plants via solids minimisation mechanisms.

Needless to say, the objectives and drivers are unique for every project in terms of economic (CapEx, OpEx and NPV), technical (e.g. acceptable plant complexity, operator skills), social, cultural (e.g. incineration) and sustainability factors and issues. However, the right solution should answer the following questions:

- How much does it cost? Is the preferred option economically viable?
- Does the option meet the expectations set by the asset owner and the community?
- Does the option satisfy the desired environmental and cost indicators?
- Does the option significantly increase the plant operation complexity?
- Are the operation staff adequate trained for this option?
- Are there markets for utilising the treated biosolids? (e.g. fertiliser or other industries)
- Is co-digestion with municipal solids waste or industrial waste sludge feasible?

5 CONCLUSIONS

This paper outlines a number of new technologies that enable better utilisation of the biosolids. Better utilisation of biosolids can be obtained via higher energy recovery through enhancing digestion efficiency and biogas production, better sludge drying/incineration technologies and nutrient recovery via technologies like struvite crystallisation.

The current practice of disposing undigested / digested biosolids in landfills needs to be re-considered given that there are a number of potentials and future limitations including increase in sludge volume due to tighter resource consent requirements, increase in fertiliser cost, increase demand for renewable energy, lower public acceptance of sludge disposal into landfills and increased difficulties to obtain consents for new landfills.

From our previous experiences, smaller wastewater treatment plants are likely to be benefited from enhanced sludge digestion processes including hydrolysis pre-treatments and alternative sludge minimisation technology such as Cannibal™ if direct land application of biosolids is not possible. Providing centralised biosolids management may enable small communities to obtain sufficient synergy to implement enhanced anaerobic digestion technologies. Larger wastewater treatment plants will be benefited by enhanced anaerobic digestion processes and struvite crystallisation to recover more energy and nutrients from the biosolids.

While sludge drying and biosolids incineration have not been widely practised in New Zealand, they may yield economic benefits in terms of reducing biosolids disposal cost for large metropolitan centres.

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