AN ADVANCED BIOSOLIDS TREATMENT PROCESS AND POTENTIAL BENEFICIAL APPLICATIONS OF THE PROCESSED BIOSOLIDS

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ABSTRACT

An innovative and cost-effective biosolids treatment and processing technology was developed and demonstrated at a pilot and full-scale at the Guelph Wastewater Treatment Plant in Ontario. The Lystek process involves a low but optimized application of heat, alkali, and mixing in a batch or semi-continuous system to achieve the desired physical, chemical and microbiological characteristics of the processed biosolids. The resultant processed product is a high solids concentration (12 - 14%), pathogen-free liquid biosolids product which is fully compatible with standard equipment in use for land application of biosolids and liquid manure. The process achieves conversion of Ontario's Nutrient Management Act Class B biosolids to US EPA Class A biosolids. Processed material retains the pumpability needed to reduce the costs of biosolids handling, storage, transport and land application and is suitable for beneficial re-use and application as a fertilizer product even after prolonged seasonal storage at ambient temperature in Canadian weather conditions. Processed materials can be stored for long periods of time at room temperature (17-22^{o}C) without evidence of re-growth of harmful pathogens such as *Escherichia coli*, *Salmonella* and fecal coliforms. Application of Lystek process on raw sewage sludge and other intermediate wastewater solids indicated the versatility of the process that may have a potential to minimize the burden on the existing intermediate biosolids/sludge handling processes within the wastewater treatment facility, increase energy recovery, reduce the total biosolids generated and reduced storage capacity in the plant.

KEYWORDS

Biosolids, Lystek process, recycling, pathogen removal, agricultural utilization, nutrients

INTRODUCTION

Biosolids waste generators continue to face new technical and financial challenges in processing, safe disposal or utilization due to a growing public interest and involvement. Currently, three-quarters of all biosolids processed through wastewater treatment operations in the United States and Canada (>8 million dry tonnes a year) are disposed of by beneficial application to agricultural land in a liquid state (2-3% solids), incinerated or by direct burial at approved landfill sites.

For beneficial recycling and agriculture utilization of municipal sludge, a high level of stabilization and sanitation of organic matter in the biosolids is required to maintain, soil, water and air quality. In Ontario, material applied to agricultural land must meet the prescribed requirements made in the Nutrient Management Act (NMA) 2003. Such materials are classified as "Class B" biosolids. Similarly in the United States, the Environmental Protection Agency (US EPA) establishes standards for beneficial reuse under Part 503 Biosolids Rule (US EPA, 1992). The overall intent of both the NMA and US EPA Part 503 Biosolids Rule is to provide the regulatory framework for the protection of the public and environment associated with beneficial reuse of biosolids. Conventional stabilization methods include drying, chemical treatment, aerobic or anaerobic digestion and composting. Although composting is an effective method for stabilizing biosolids and producing a useful product (Witter and Lopez-Real 1987; Lynch 1993; Epstein 1997), it is difficult to reach and maintain the sanitizing temperature throughout the composting mass for the appropriate time, which often results in only partially stabilized product (Burge et al. 1987; Dumontet et al. 1999). Since application of improperly stabilized biosolids as a soil amendment and source of nutrients for plants poses a serious threat to human and animal health (Straub et al., 1993; US EPA, 1999; Brown et al., 2002), more effective biosolids treatment and management technologies are being continually sought.

An innovative biosolids treatment and processing technology was successfully developed over a 2 year period at bench-scale, pilot tested and further scaled up with the collaborative efforts of Lystek and the City of Guelph, Ontario at the Guelph wastewater treatment plant. The processing requires an optimum application of heat, chemical and mixing in a batch or semi-continuous system to achieve the desired microbiological, physical and chemical characteristics of the processed biosolids. The goal of the Lystek Process is to produce a low-pathogen product that can be used as a soil conditioner without the health and environmental risks associated with the high-pathogen biosolids currently being spread on the farm land.

The objectives of the study included optimization of various process conditions of biosolids treatment to establish a process which can be easily scaled-up and integrated into any existing wastewater treatment system, and evaluation of potential application of the processed biosolids product. This paper presents some of the results of pilot- and full-scale feasibility studies conducted by Lystek at the Guelph Wastewater Treatment Plant and describes the benefits of the process and the beneficial recycling potential of the Lystek processed high solids pathogen-free liquid biosolid product.

METHODOLOGY

A process flow diagram is presented in Figure 1. The full-scale Lystek's biosolids management facility consisted of the following components:

- A conveyer belt system connected to the conveyer system of Guelph Plant's dewatering unit for transfer of the dewatered biosolids
- Storage tank (~10 m3) for temporary storage of dewatered biosolids
- A progressive cavity pump for handling of dewatered biosolids

- Specialty process tank or reactor units with about 2-m^3 and 5-m^3 working volume fitted with sampling ports, a mixer/shear unit, and appropriate electronic controls for temperature, pH and level sensors.
- An electric boiler with 300,000 BTU capacity to provide desired heat to the system
- A pre-heating tank (~1 m3) to hold warm filtrate water for initial dilution of the dewatered biosolids
- A pneumatic transfer pump to transfer hot water to the processing reactor
- A product discharge pump
- A storage tank for temporary storage of the processed material
- A PLC unit for the electronic instrument controls

To operate the system in a batch mode, a progressive cavity pump is used to pump the dewatered biosolids from an existing biosolids storage tank to the processing reactor. An appropriate amount of warm filtrate water obtained from the dewatering plant is added to dilute the dewatered biosolids to the processing range of 12-15% solids in the reactor. The temperature and pH of the feed biosolids are adjusted to the optimum operating range and mixed for 40 - 60 minutes to complete the batch process.

For a semi-continuous system in the 5-m^3 reactor with 5-25% volume removal and replacement, a batch of Lystek process at the optimum process conditions was prepared using approximately 3500 L dewatered biosolids, 1000 L warm water and appropriate amount of alkali solution. Remaining make up water to the batch was added through steam to obtain desired temperature. The processed material was removed using a diaphragm pump and replaced with dewatered biosolids (17-19% solids), water and alkali solutions. This process was repeated every 4-8 minutes. The desired process conditions were consistently achieved over the course of investigation.

Frequently samples were collected and analyzed for viscosity, pH, temperature, and solids concentration. Treated and untreated control samples were collected for microbiological testing (*Salmonella*, fecal coliforms, *Escherichia coli* and cyst forming pathogens) and chemical (metals and general chemistry) analysis using standard methods by an independent certified laboratory, Maxxam Analytical, Mississauga, Ontario. The effect of long-term storage of the Lystek processed material has been evaluated by storing samples over a 24-month period at room temperature (17-22^oC) and conducting repeat testing and analysis for pH, viscosity, and pathogens at different time intervals in addition to physical appearance and any odors.

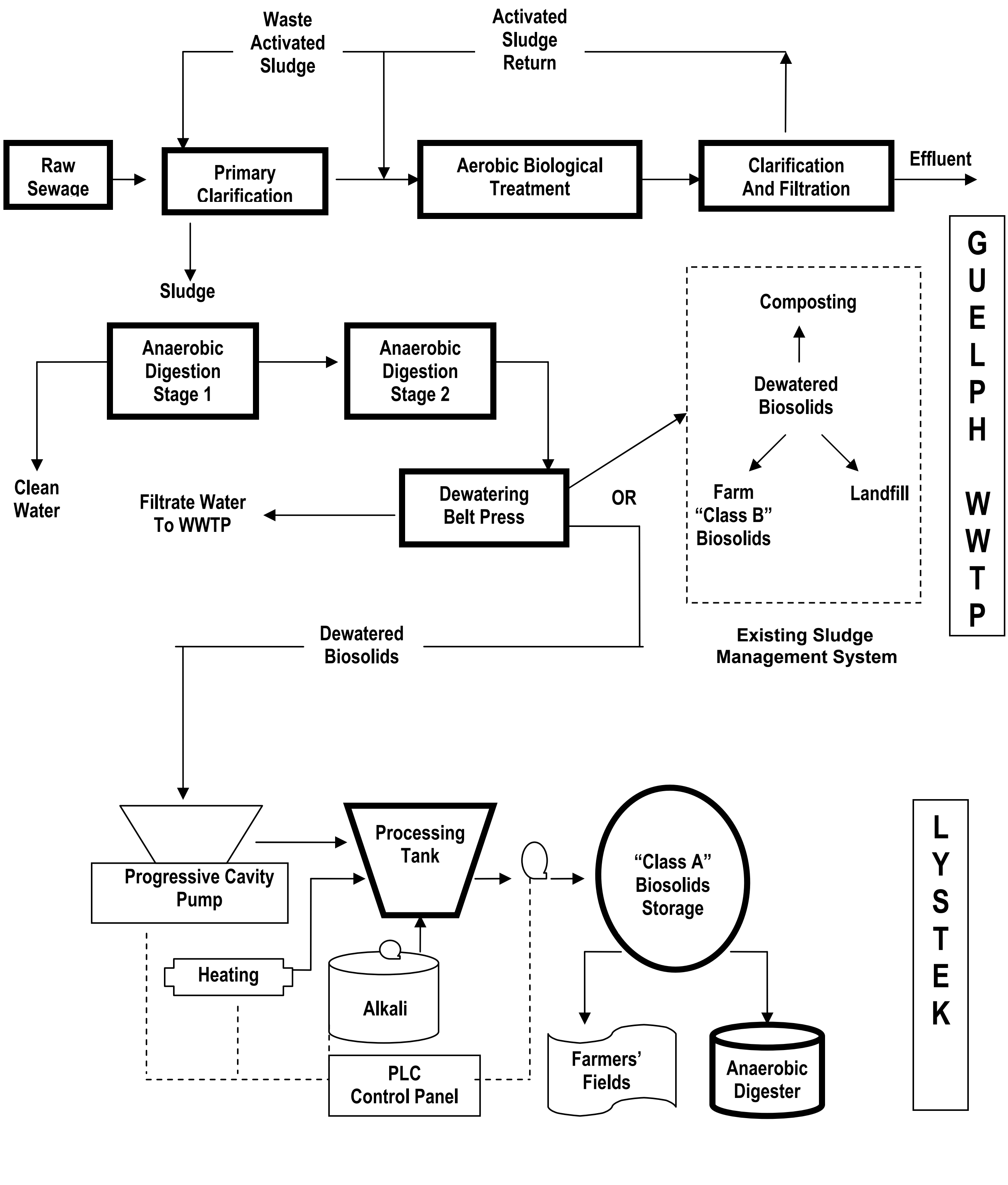

Figure 1. Process flow diagram of Guelph WWTP and Lystek system

A drying oven (Quincy Lab) was used for total solids determination. Temperature and pH were measured using a portable Accumet 1001 (Fisher Scientific). The viscosity of treated samples was determined using a Brookfield digital viscometer, model DV-E. Microbiological analysis for the levels of Salmonella, fecal coliforms and *Escherichia coli* were carried out by Maxxam Analytical Laboratory, Mississauga, Ontario. Analysis of fecal coliforms and *E. coli* were carried out using a 5 Test Tube method (Ont. SOP 0196), where *Salmonella* was determined using a Presence-Absence method (Ont. SOP 0189). Unprocessed and Lystek processed samples were analyzed by Maxxam Laboratory for metals and general chemistry parameters to determine any changes in the characteristics of the dewatered biosolids. Maxxam follows laboratory methods Ont. SOP 0072, 0101 and 0100 for the analysis of metals, ammonia and nitrite, respectively.

In order to study the USEPA Class A pathogen quality standards, seed samples of enteric virus (*Poliomyelitis* virus) and helminth ova (*Ascaris* eggs) were obtained from Hoosier Microbiological Laboratory (HML), Muncie, Indiana, USA. Dewatered biosolids were inoculated with these pathogens and then treated under optimum process conditions in a 10 L reactor under controlled laboratory conditions. The control and treated samples were analyzed by HML using EPA/625/R-92/013 and ASTM D4994-89 methods for helminth ova and enteric virus, respectively.

RESULTS

Chemical characterization of various sludge streams generated in the Guelph WWTP is shown in Table 1. The Guelph WWTP currently produces approximately 4,000 dry tonnes of Class B biosolids annually. Second stage anaerobically digested material is mechanically dewatered using belt filter presses to produce a 17-19% by weight dewatered cake. Dewatered biosolids can then be land applied or further processed in the facility's in-vessel composting system.

The results of batch processing of dewatered biosolids from a 2 m^3 pilot reactor and a 5 m^3 full scale reactor are presented in Table 2. The processing of dewatered biosolids showed dramatic reductions in the viscosity of the processed materials. In feed material to the process is secondary stage anaerobically digested biosolids at a total solids content up to 17-19% dry weight with a viscosity exceeding >2,000,000 cP. The resultant product of the process is a liquid biosolids product (12-14% solids) with a viscosity of <1,800 cP that is fully compatible with conventional equipment in use for land application as apposed to dewatered biosolids which requires expensive specialized pumps or equipment for handling. It was also established that the Lystek process for the dewatered biosolids treatment using a 5 m^3 capacity reactor in batch mode can process about 30 - 35 m^3 (4 - 5 dry tonnes) of biosolids per 8-h day.

Table 1. Chemical characterization of various sludge streams at Guelph Wastewater Treatment Plant

Parameters	Raw sludge (mg/L)	Secondary digester (mg/kg)	Dewatered biosolids (mg/kg)
Metals			
Arsenic	0.1	0.1	2
Cadmium	0.5	0.5	5
Chromium	2.2	1.9	124
Cobalt	0.5	0.5	2
Copper	14.7	12.2	639
Lead	5	5	27
Mercury	0.014	0.017	2
Molybdenum	2	2	13
Nickel	2	2	20
Phosphorus	572	519	28,570
Potassium	100	100	1004
Selenium	0.2	0.1	2.5
Sodium	312	305	2,021
Zinc	29	21	988
General chemistry/microbiology			
pH	5.4	7.4	7.1
Conductivity (µmhos/cm)	NA	7040	9100
Total solids (%)	2.9	1.7	17.0
VSS (%)	75.0	62.4	63.0
Total NH_3-N	NA	666	6,128
Total NO_3-N	NA	2	4.8
Total NO_2-N	NA	2	NA
TKN (mg/kg)	NA	963	31,953
E. coli (CFU/g)	NA	1,000 – 6,000	10,000 – 40,000
Fecal coliforms (MPN/g)	>1600	>1600	>1600
Salmonella (P-A/25g)	POS	POS	POS

Note: Data from City of Guelph; NA, no analyzed; POS, positive

Table 2. Treatment of dewatered biosolids in 2-m^3 and 5-m^3 reactors using batch process and processed product storage results*

Processing Reactor / Parameters	Fresh processed samples	4 Months after storage at room temperature	8 Months after storage at room temperature	24 Months after storage at room temperature
Untreated dewatered biosolids				
Total solids (%)	17.0-19.0	17.0-19.0	17.0-19.0	ND
Viscosity (cP)	>2,000,000	>2,000,000	>2,000,000	ND
Salmonella (P-A/25 g)	POS	POS	POS	ND
Fecal coliforms (MPN/g)	>1600	>1600	>1600	ND
Escherichia coli (MPN/g)	>1600	>1600	>1600	ND
Processed biosolids in 2 m^3 Reactor				
Total solids (%)	12.6-14.1	12.6-14.1	12.6-14.1	12.6-14.1
Viscosity (cP)	1220-1590	1910-2450	1890-2570	1740-2200
Salmonella (P-A/25 g)	NEG	NEG	NEG	NEG
Fecal coliforms (MPN/g)	<1.8	<1.8	<1.8	<1.8
Escherichia coli (MPN/g)	<1.8	<1.8	<1.8	<1.8
Processed biosolids in 5 m^3 Reactor				
Total solids (%)	11.5-14.3	11.5-14.3	11.5-14.3	ND
Viscosity (cP)	1025-1400	1740-2830	1580-2130	ND
Salmonella (P-A/25 g)	NEG	NEG	NEG	ND
Fecal coliforms (MPN/g)	<1.8	<1.8	<1.8	ND
Escherichia coli (MPN/g)	<1.8	<1.8	<1.8	ND

*The results are range from several batches; ND, not determined; POS, positive; NEG, negative. The pH of untreated biosolids ranged from 7.3 to 8.0; whereas average final pH of the product was around 10.5.

The primary microbiological parameters of concern in the demonstration tests were *Escherichia coli*, fecal coliforms and Salmonella. All the unprocessed control samples showed the presence of *E. coli* and fecal coliforms at greater than 1600 most probable number (MPN) per g of sample. In addition, *Salmonella* was positive in all the non-Lystek processed control biosolids sample. While all the Lystek-processed samples submitted to date have shown below detection level of *E. coli* and fecal coliforms (<1.8 MPN/g sample) and negative for *Salmonella*.

An increase in viscosity by 50-100% was observed in the processed samples stored at room temperature (17-22^{o}C) conditions. However, slight mixing for few minutes brings the viscosity levels very close to the original values. Storage properties are a reflection of the pH and microbial characteristics of the final product. Achieving a specification similar to the one of batch process the continuously produced product will remain microbiologically stable. Storage stability in terms pH, viscosity and pathogen regrowth were determined after prolonged storage at room temperature.

A semi-continuous process approach was implemented in 2-m^3 and 5-m^3 reactors by removing 10-25% of the total volume and replacing that volume every 4-8 min with a mixture of dewatered biosolids, water and alkali solution after completion of the first batch and when all the product specifications for the batch process quality (pH, temp, and viscosity) were met as determined by frequent representative samples. Samples were collected at every replacement cycles and analyzed for solids, pH, viscosity, pathogens, general chemistry and metals. Results are shown in Table 3. The results showed consistent viscosities and solids concentration through various cycles indicating that a semicontinuous process is feasible in biosolids processing with Lystek process.

Using semi-continuous process strategy in a 5-m^3 reactor, about 48 m^3 (~7 dry tonnes) per 8-h day, whereas about 20 m^3 (~3 dry tonnes) biosolids per 8-h day can be processed using a 2-m^3 reactor. The results presented above indicated that a semi-continuous process can effectively be applied at full-scale without compromising the desired process parameter and product quality in the Lystek system in terms of viscosity and pathogens.

Table 3. Test results for semi-continuous system using a 2-m^3 and 5-m^3 reactors*

Description	Total solids (%)	Viscosity (cP)	*Salmonella (P-A/25g)*	Fecal coliforms (MPN/g)	*Escherichia coli* (MPN/g)
Untreated dewatered biosolids	17.5-18.3	>2,000,000	POS	>1600	>1600
Average results for 10-25% Removal Cycle with 4-8 min hold time in 5-m^3 reactor					
Cycle – 1	12.9	1275	NEG	<1.8	<1.8
Cycle – 2	13.0	1270	NEG	<1.8	<1.8
Cycle – 3	13.6	1345	NEG	<1.8	<1.8
Cycle – 4	12.6	1220	NEG	<1.8	<1.8
Cycle – 5	13.2	1340	NEG	<1.8	<1.8
Average results for 10-25% Removal Cycle with 4-8 min hold time in 2-m^3 reactor					
Cycle – 1	12.8	1180	NEG	<1.8	<1.8
Cycle – 2	13.0	1190	NEG	<1.8	<1.8
Cycle – 3	13.1	1170	NEG	<1.8	<1.8
Cycle – 2	13.0	1150	NEG	<1.8	<1.8
Cycle – 3	13.1	1180	NEG	<1.8	<1.8

*The pH of untreated biosolids ranged from 7.3 to 8.0; whereas average final pH of the product was around 10.5

General chemistry and metal analysis of processed biosolids from 2-m^3 and 5-m^3 reactors are presented in Table 4. Chemical characteristics of the processed material were not expected to be different from the unprocessed material, except for the levels of potassium and sodium that were added during processing for pH adjustment. Following Canadian and US guidelines for the general chemistry parameters of interest such as various metals, ammonia, nitrate and nitrite, both the processed and unprocessed material are suitable for land application. However, the physical characteristics of the processed material exhibit some very interesting feature; the material is very homogeneous and does not separate significantly even after prolonged storage.

Table 4. Chemical characterization of biosolids processed in 2-m^3 and 5-m^3 reactors in batch process

Parameters	Dewatered biosolids mg/kg	Lystek Process			
		2-m^3 Batch mg/kg	2-m^3 Semi-continuous mg/kg	5-m^3 Batch mg/kg	5-m^3 Semi-continuous mg/kg
Metals					
Arsenic	3.0	3.0	3.1	4.2	4.4
Boron	ND	ND	ND	24.7	25.5
Cadmium	2.0	5.2	5.3	2.8	3.0
Chromium	110	127.4	127.4	142.5	157.5
Cobalt	5.4	1.8	2.7	7.2	8.3
Copper	740	700.7	691.6	1050	1125
Lead	29	25.4	27.3	44.3	45
Mercury	1.01	0.2	0.1	0.2	0.2
Molybdenum	16	18.2	18.2	24.7	27
Nickel	24	20.9	21.84	29.3	33
Phosphorus	32,000	30,303	30,394	52,500	51,000
Potassium	800	76,440	72,800	150,000	157,500
Selenium	6.0	2.5	2.4	4.2	4.6
Sodium	2,000	16,380	15,470	45,000	49,500
Zinc	1100	1183	1183	1575	1650
General chemistry					
Total conductivity (μmhos/cm)	NA	25,000	27,100	34,800	39,600
Total NH_3 - N	6,128	3620	3720	4222	4248
Total NO_3/NO_2-N	4	3.1	3.2	2	2
TKN (mg/kg)	40,200	29,550	38,050	26,250	36,000
BOD (mg/L)	-	23,600	27,100	-	-

*Dewatered biosolids data from City of Guelph; NA, no analyzed; ND, not detected above method detection limit

The comparison of results of supplementary testing of enteric viruses (*Poliomyelitis* virus) and helminthes ova (eggs from *Ascaris* species) in the pre-seeded biosolids material indicated that all Lystek processed samples met the 2-log reduction required by the US EPA for enteric virus and helminths ova (Table 5). All optimized process batch samples tested for microbiological performance criteria met and exceeded the Class A requirements.

Table 5. Microbiological analysis of unprocessed dewatered and Lystek processed biosolids

Pathogens	MDL	Class A Criteria	Unprocessed dewatered biosolids	Lystek processed biosolids product
Fecal coliforms (MPN/g)[1]	1.8	< 1,000	> 1,600	< 1.8
Escherichia coli (MPN/g)	1.8	-	> 1,600	< 1.8
Salmonella (P-A/25 g)	1	< 3 MPN/4g	POS	NEG
Polio virus (pfu/4g)	1	< 1	776	< 1
Ascaris eggs (numbers/4g)	1	< 1	130.8	< 1

*For Class A criteria, fecal coliforms and *E. coli* must be less than 1000 MPN per g total solids dry weight. *Salmonella* must be less than 3 MPN per 4 g total solids dry weight; Polio virus and *Ascaris* eggs were seeded in the dewatered biosolids before processing

Studies related to the raw sludge were carried out in 2-m^3 reactor in batch processing mode. Raw sludge contained about 3.7% dry weight solids (Table 6). Two batches of dewatered biosolids processing with 10% and 20% raw sludge to replace the filtrate water as diluent of dewatered biosolids. Two batches of raw wastewater (3.9-4.4% solids) on its own were also carried out under standard Lystek process conditions. Appropriate samples were collected for further analysis. The results indicate that the Lystek process can effectively treat the raw sludge as diluent to dewatered biosolids or on its own to obtain the same product quality as Lystek-processed dewatered biosolids.

Table 6. Processing of raw sludge in 2-m^3 reactor

Description	Solids (%)	Viscosity (cP)	*Salmonella*	Fecal coliforms	*Escherichia coli*
Untreated dewatered biosolids	17.5	>2,000,000	POS	>1600	>1600
Untreated raw sludge	3.7	330	POS	>1600	>1600
Processed biosolids with 20% raw sludge as diluent	13.6	1390	NEG	<1.8	<1.8
Processed biosolids with 10% raw sludge as diluent	14.1	1410	NEG	<1.8	<1.8
Processed raw sludge only	4.4	270	NEG	<1.8	<1.8

*Average pH for raw sludge pH 5.4; dewatered biosolids and processed biosolids were 5.4, 7.3 and 10.5, respectively.

DISCUSSION

Treatment of municipal liquid wastes results in the production of large quantities of sludges that requires environmentally safe disposal or reuse (Chernicharo, 2006). Anaerobic digestion degrades organic matter and makes the resultant residue more stable. This protects the environment from the uncontrolled degradation of the waste. Thus, it reduces the impacts from environmental aspects such as odour, flies and vermin and helps to reduce the plant and animal pathogens that can be spread by wastes (O'Flaherty et al., 2006). Co-disposal of this sludge at solid waste landfills is not a viable long-term alternative and the clear tendency in North America is to minimize the disposal of biodegradable wastes to landfills and promoting the options of recycling, composting, energy production and recovery. In the case of municipal sewage sludge, a major reuse method is the agricultural utilization of biosolids as soil conditioner and fertilizer (Warman and Termeer, 2005). Wastewater treatment plants hardly produce effluents that comply with usual discharge standards established by government environmental agencies (Andreadakis et al., 2002). Therefore, usually a post-treatment step is required as a means to adapt the treated effluent to the requirements of the environmental legislation. Conventional methods are usually not very effective and hence new methods are continually being sought.

The primary goal of this pilot- and full-scale study of the Lystek technology was to develop a low-cost energy-efficient process that produces a high solids concentration (12-14% solids) and pathogen-free stable biosolids product that can be beneficially used for land application using conventional equipment commonly used for handling regular liquid 3% biosolids to meet or better stringent public health and environmental concerns including odor issues. After completion of a two-year multistage bench/pilot scale studies and review of the data confirming process reliability and product quality that exceeds Class A requirement, the Lystek process has been scaled-up, optimized and successfully demonstrated in a full-scale facility at the Guelph Wastewater Treatment Plant in Ontario, Canada.

Under optimum processing conditions, there was >99% reduction in the viscosity of the materials. The viscosity of the unprocessed biosolids (17-19% solids) is not truly quantifiable due to the limited equipment range, i.e. 2,000,000 cP. It was confirmed in the supplementary testing that from a practical standpoint, inexpensive centrifugal pumps are adequate for use to pump this material in the viscosity range of 0 - 4,000 cP. This represents a reduction in viscosity of more than 99.5% from the unprocessed condition of the biosolids. However, a target viscosity of 1,800 cP would be adequate to meet all of the practical requirements related to the effective handling, storage and application of the processed materials.

The main function of the shear unit is to reduce particle size, thereby at higher temperature and pH than normal, general mass transfer is increased. Assuming homogeneous mixing, the major factors responsible for destruction of pathogens are heat and pH and even if a small proportion of microbes do not have an adequate residence time in the shear reactor, destruction would continue in the hot, high pH liquid product.

Based on the results of our existing batch and semi-continuous process, it is expected to considerably enhance the overall process productivity. The unique feature of this semi-continuous process is that operating conditions can be optimized and maintained constant at the optimized levels. Since the average biosolids shear time for semi-continuous runs were similar to the batch with superior mixing characteristics during continuous process, product viscosity remained more or less constant. This should also significantly affect the load on the motor and is expected to save energy usage of the mixer unit. Indeed there is likely an opportunity to reduce average holding time by increasing rotor speed in the low viscosity medium. However, a cost benefit analysis will be required to calculate the energy usage and benefits achieved in lowering viscosity and increasing process productivity. Once in continuous mode labour input should also be minimal.

Except for the adjustment of pH either through sodium hydroxide or potassium hydroxide, the Lystek Process does not require the addition of any chemicals, therefore, no significant changes in the general chemistry of the processed material are expected. The general chemistry parameters of interest in the unprocessed material were metals, ammonia, nitrate and nitrite. When compared the general chemistry parameters of the Lystek processed or unprocessed biosolids with the Canadian guidelines presented in the "Guidelines for the Utilization of Biosolids and Other Wastes on Agricultural Land" (MOE 1996) as well as the United States guidelines presented in "A Plain English Guide to the EPA Part 503 Biosolids Rule" (US EPA 1994), both the processed and unprocessed material met both the Canada and United States guidelines from the perspective of general chemistry. The Lystek Process does not affect the total quantity of inorganic materials that are found in the biosolids but it does have some very important positive implications. The processed biosolids are considered to be very homogeneous and can be processed as a much more controlled product for land application, particularly with respect to the control of nutrient addition to the lands. The reduced moisture content of Lystek processed materials from typical manure or unprocessed sludges makes hydraulic and loading application rates for lands much easier to regulate and control.

With respect to the balance of the organic and other general chemistry parameters, the Lystek process may yield a slight loss in ammonia nitrogen but the reductions in the other general chemistry parameters noted in Tables is attributed primarily to the improved homogeneity of the processed materials versus the grab sample heterogeneity of the influent sample.

One of the issues associated with sludge dewatering and handling is the trade-off between processing costs and disposal/transportation costs. Typically any liquid or partially dried material above about 6% solids by volume requires more expensive pumping and handling systems. This factor represents one of the Lystek Processes greatest benefits because subsequent to process treatment, the liquefied high solids (12-14%) Lystek processed material handling, storage and transportation requires just conventional and much less expensive equipment. The design of the demonstration project was intended to showcase the various positive features of the Lystek Process and to develop the operating basis for a full-scale facility at the Guelph WWTP.

A consistent decrease in viscosity with increasing mixing time has been repeatedly demonstrated in the Lystek process. When the temperature increases the viscosity decreases and at a constant temperature as mixing time increases the viscosity decreases. The magnitude, in which the viscosity is lowered, increases with decreasing temperature. There is also a non-linear relationship between mix time and viscosity. This relationship indicates that longer retention times in the shear mix vessel will tend to yield a lower viscosity but the relative difference in performance results tend to converge at higher processing temperatures.

For conventional land application injection of liquid biosolids and manure, the typical nozzle sizes are larger than those used for the gravity test noted above (up to 5 cm in diameter) and the materials are injected at a pressure of approximately 5 psi. The Lystek processed material was found to be very suitable for land application with this type of equipment and would require no changes or modifications to any conventional equipment. Further verification of land application of processed material at different agricultural sites was conducted using a Terragator from Terratec Environmental Ltd, Ontario. The homogenous nature of the processed materials provided for uniform control of application.

The benefits of biosolids as soil amendments are provision of important plant nutrients and organic matter (deFreitas et al., 2003; Shober et al. 2003). Biosolids contain significant amount of N and P but very small amount of K. The presence of potassium and slight alkalinity of the processes due to the potassium hydroxide used in Lystek process provides an important agricultural nutrient which otherwise municipal biosolids lack. The benefits of increased organic matter in agricultural soils include (Stehouwer, 1999):

- Improved soil tilth and friability
- Improved soil structure and aggregate stability
- Improved nutrient retention and slow release of nutrients
- Increased water infiltration, retention and availability
- Increased cation exchange capacity
- Increased microbial activity and diversity

The high shear mixing step in the process provides an excellent opportunity to add other nutrients that could further enhance the quality of the resulting product for land application. Based on the soil characteristics, the Lystek processed material can be customized to add specific nutrients. Thus in addition to benefiting soil fertility and organic matter, biosolids also provide an economic benefit to farmers.

The type of pathogens commonly present in wastewater biosolids depend on state of health of the population, as well as the presence of hospitals, meat and food processing plants, and tanneries. The common pathogens which are usually present in sewage biosolids are bacteria (*Salmonella*, fecal coliforms, *Escherichia coli*), fungi (*Aspergillus*) cyst forming protozoa (*Cryptopsoridium* and *Giardia*), helminth (*Ascaris*) and enteric viruses (Dumontet et al. 1999). Since application of untreated sewage biosolids can pose serious threat to the environment as well as human beings, Canadian and US regulators have created certain standards where material applied to agricultural land must meet the prescribed requirements that classify Class "B" biosolids in Ontario (MOE, 2003) and Class "A" and "B" biosolids in USA (USEPA, 1992). All the testing to date has indicated that the Lystek processed biosolids meets the applicable requirements to be classified as Class "A" biosolids.

In order to evaluate broader applications of the Lystek technology in the wastewater treatment plants, the potential of the process to directly use on raw wastewater sludge was investigated.

Since Lystek process requires dilution of 17-19% dewatered biosolids to bring it down to the effective processing range of 12-14% biosolids in Lystek reactor, filtrate water is used to achieve the desired dilution. It was expected that the raw wastewater can replace the filtrate water for dilution of dewatered biosolids produced at the Guelph WWTP. This would potentially help further minimize the burden on the existing digesters and also reduce volumes of biosolids produced at the facility.

Thermal, chemical and mechanical pretreatment of wastewater biosolids to improve solubility of organic matter and improved anaerobic digestion of waste activated sludge (WAS) has been studied by different groups at temperature range of 60-175^{o}C (Lin and Noike, 1992; Tanaka and Kamiyama; Vlyssides and Karlis, 2004), chemical solubilization (Lin et al., 1997; Penaud et al., 1999), and ultrasonic (Chiu et al., 1997) and mechanical disintegration (Baier and Schmidheiny, 1997; Camacho et al., 2002). Appropriately processed biosolids material from the Lystek process may be more conveniently digested during the anaerobic process. This application will particularly be useful during the winter season for smaller plants and all year around for larger plants having gas to energy recovery system. However, detailed investigations are needed to test the processed material for application in anaerobic digestion system.

CONCLUSIONS

The following conclusions and next steps have been identified during laboratory-, pilot- and full-scale tests on dewatered biosolids:

- Confirmation of the Lystek process to consistently achieve the conversion of Class B biosolids to Class A biosolids at different processing scale including lab, pilot and full-scale;
- The processed biosolids material is fully compatible with standard equipment in use for land application of biosolids and animal manure even at high solids (12-14%) concentrations.
- Reduced handling and volume for storage requirements versus conventional liquid biosolids practices is evident;
- The processed materials can be stored for long periods (>24 months) without regrowth of harmful pathogens and/or loss of the capacity to be pumped, transported and applied as a controlled liquid fertilizer following seasonal storage.
- Potential for a broader application of the technology to treat other in feed products either used as diluent or on its own (raw settled sewage, manure); and
- Identified opportunities for further optimization of the process technology and the potential to customize end products of additional nutrient value for land application

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