EMERGING PROCESSES IN BIOSOLIDS TREATMENT 2003

Harlan G. Kelly
Dayton & Knight Ltd.
P.O Box 91247
West Vancouver, B.C.
V7V 3N9
Canada
hkelly@dayton-knight.com

ABSTRACT

Achieving Class A treatment is becoming potentially desirable. Most emerging new and improved processes are being promoted to meet Class A treatment objectives. Acquaintance with these processes is also desirable to allow improved understanding of their current status and suitability. This paper reviews both digestion and reduction technologies and provides examples, advantages and disadvantages for each.

KEYWORDS

Class A biosolids treatment, emerging technologies, Digestion: hydrolysis, thermophilic, pre-pasteurization; Reduction: gasification, fuel from sludge, wet air oxidation, super critical water oxidation, hydrothermal

INTRODUCTION

Pre-existing and emerging treatment processes are refocusing on the ability to achieve a Class A product. This is in response to a perceived need to show greater protection to the public.

In the following discussion, processes are categorized and briefly reviewed to provide comparison and clarity of purpose. The processes identified include only those that decrease the dry mass of biosolids through digestion or reduction. This excludes pseudo-stabilization processes such as thermal-chemical, chemical and drying. Where processes overlap in general design and operation differing only in specifics of their construction, one only is described. The purpose of this evaluation is to delineate the available technologies in terms of the claims and to provide a general dialog for categorizing processes. WEFR (1998) innovative process assessment is used as a framework for this work. The WERF study describes *embryonic* processes as laboratory or bench scale, *innovative* as demonstration and limited use, and *established* as operating in several full-scale operations. Information from demonstration studies was obtained from the King County (1998) technology assessment. Operating information was obtained from personal and reported experience.

FACTORS DRIVING EMERGING PROCESSES

Is there a need to be acquainted with emerging treatment solutions? Future issues and trends will affect the selection of biosolids processing. These not only include traditional engineering views of efficiency and cost but will include sociological issues of acceptance and reuse that are less identifiable. Sociological issues include public perceptions of protection and acceptability.

Smith (1999), indicated that there is a move to Class A only since the public perceives that the higher quality product if obtainable should be the requirement. In a recent press release, the Center for Disease Control (CDC) has recommended that, “all sludge be treated to Class A standards because of the risk that disease could be transmitted thorough Class B sludge.” Although the EPA are not convinced that new regulations are needed, public pressure may not be so easy to change; even some EPA scientists are reportedly unconvinced that Class B is sufficient to protect the public.

Issues also include the desire to lower greenhouse gas production, reduce dioxins/furans and PCBs. Others include inability to finance treatment works and the desire of public organizations to divest themselves of the responsibilities for treatment works. In Europe and Japan, recycling of nutrients and fractioning out the waste stream components for more efficient treatment are now a consideration in many process design approaches. Product cost and recovery costs are market dependent. Markets fluctuate. Availability of land and acceptability of present practices are changing. The public now more closely watches the focus of biosolids management. They are involved in the selection. A biosolids management program must be able to respond to these changes. Since change is not manageable or predictable, the program must be flexible. A biosolids program should contain several different opportunities to meet new constraints and differing objectives.

If biosolids management is to be responsive to the trends and rising issues that face the waste treatment industry, new processes must be encouraged, evolve and improve. Time, temperature and pressure provide a framework to illustrate the various identified processes. This framework may prove a useful tool for process assessment and selection.

BACKGROUND

Systems that comprise the various emerging processes are largely either reduction or digestion technologies. These also include supporting processes such as pre-pasteurization and hydrolysis. To function, systems will also require ancillary processes such as thickening, drying, conditioning, dewatering and miscellaneous other treatment steps.

Figure 1 illustrates a typical suite of treatment processes that are available or under development as proprietary and other, for differing pressures and temperatures. In Figure 1, the main processes may be shown in two categories as illustrated in Table 1.

DIGESTION

Biological digestion processes share several steps in common. First, the microorganisms must break down complex organic that includes proteins, carbohydrates and fats. The microorganisms secrete extracellular enzymes to hydrolyze the complex organic into smaller molecules and allow them into the cell. Hydrolysis can be a rate-limiting step especially in aerobic treatment. Second, the hydrolyzed organic and fermentation product is acidified to 2, 3 and 6 carbon compounds through acidogenisis and acetogenisis. Third, principal intermediates are formed, and last, the products of digestion are produced. Where processes include anaerobic digestion, the rate-limiting step may be the latter in the formation of methane. Innovators have attempted to

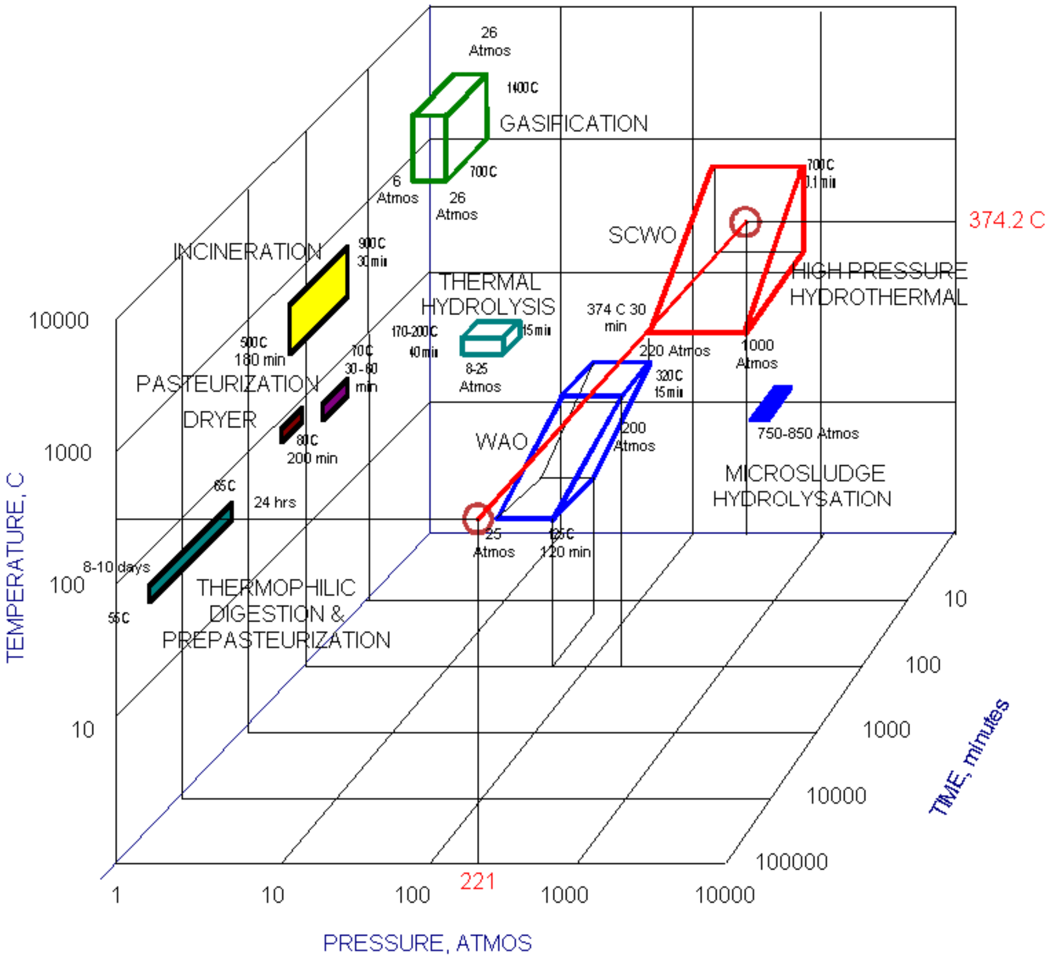

Figure 1, Treatment Technologies Temperature, Pressure and Time

Table 1 Digestion and Reduction Processes

	Main Process Component	Temp ^{0}C	Press Atmos	Time Min.
1.	**Digestion**			
a.	Hydrolytic processes that include pasteurization and are followed or preceded by digestion	170-200	8-25 [1]	15-40
b.	Pressure and chemical such as Microsludge treatment that are followed by digestion	30-40	750	?
c.	Disintegration processes that are followed by digestion	?	1	?
d.	Pasteurization processes such as submerged combustion contained in or followed by digestion	55-75	1	1440 & 60-30
e.	Biological processes that include various thermophilic treatment steps (anaerobic and aerobic)	65-55	1	1440-21,600+
2.	**Reduction**			
a.	Incineration processes (not including drying)			
	Multiple Hearth	500-950	1	30-180 Gas 8-10 sec
	Fluidized Bed	650-760	1	30? Gas 15 sec
b.	Entrained flow gasification, using pure oxygen	700-1400	6 – 26	N/A[2]
c.	Pyrolysis	400-800	1	N/A
d.	Fuel from sludge technology (using catalyst for oil specification)	400-450	1	N/A
e.	Wet air oxidation (WAO) or sub-critical water oxidation	120 – 350	10-200	120 – 15
f.	Supercritical water oxidation (SCWO) and high pressure hydrothermal treatment with oxidant (oxygen or peroxide)	374-650	217-1000	30 – 0.1

1. Norwegian KREPRO process uses 3.5 atmos, 30-40 minutes at pH of 1-2. (Ødegaard et al., 2002)
2. N/A Not available

improve the digestion process through use of supplementary hydrolyzation techniques and segregated digestion steps. In the latter to meet the heat treatment criteria, pre-treatment or post-treatment at elevated temperatures is undertaken in batch or plug flow.

Hydrolytic innovations include chemical treatment as described by Knezevic (1995) and physical hydrolytic processes as described by Muller (2000). A high-pressure is under experimental investigation by Stephenson (2000) and is intended to similarly improve digestion. Thermal hydrolytic processes as described by Weisz, (1999) are offered as pre-pasteurization steps as well as conditioning steps to improve the digestion process. Hydrolytic processes are offered as either all found solutions as in the case of thermal-chemical system or as pre-treatment to digestion. They include pressure, temperature or pH control, and require subsequent digestion steps.

Hydrolysis

Muller (2000) describes several methods of disintegration of sludge mass for hydrolytic improvements by as pressure techniques of mechanical (shear), direct pressure (500 atmospheres), sound pressures (20-40 Hz), and electro-hydraulic (10 kV) pressures. The analyzed techniques include use of a stirred ball mill, a high pressure homogenizer, an ultrasound homogenizer and high performance pulse device. These methods are both *innovative* and *embryonic* .King County (1998) also provides a test account of an application of the *innovative* electro-hydraulic method that uses a high performance pulse device. Camacho (2002) identifies investigation done using a high-pressure homogenizer that achieves pressures of over 700 atmospheres. This work did not demonstrate sizable reduction in sludge production and although COD was released solubilisation was poor. Stephenson (2000) is investigating the use of a homogenizer on mixed sludges. The process includes acid and caustic treatment to break down cell wall lipoprotein structures. The process requires prescreening to meet stringent size constraints. It is being tested at bench scale only and is considered *embryonic*. Deleris (2002) and Ahn (2002) reported research that supports the use of ozone in sludge thickening to reduce sludge mass as a pretreatments step that benefits the liquid treatment train. The ozone cost competed favorably with incineration. Use of ozone in this capacity is considered *embryonic* technology.

To achieve degrees of disintegration of above 75% (the break point in economy of effort), about 30,000 kJ/kg of suspended solids is reported necessary by Muller (2000). Muller concludes that a well functioning plant will not benefit greatly by this technology. King County (1998) showed that the electro-hydraulic pulse device did not prove an aid in subsequent digestion. Neis (2000) identified the use of ultrasonic disintegration at 20 kHz to 10 MHz will enhance hydrolysis and shorten digestion time. Winter (2002) posits that operational savings can be shown if disintegration devices are used. These processes are *embryonic* and *innovative.*

The Cambi process as described by Weisz (1999) and Kepp (2000) is *innovative* to *established* and is shown to provide both pasteurization and hydrolyzation. It is used in several UK and European cities. Ødegaard (2002) describes an *innovative* Norwegian process that similarly digests sludge at low pH and with the addition of hydroxide and iron salts to recover phosphorus.

Table 2 gives claimed advantages and disadvantages of hydrolysis.

Table 2 Hydrolysis

ADVANTAGES	**DISADVANTAGES**
• Improves digestion process by reducing hydraulic digestion time, HRT or increasing digestion	• Not necessarily a benefit to well operated plants
• Increases gas production by increasing digestion	• Adds higher energy cost to plant operation
• May include pasteurization step	• Requires pilot work to determine benefits
• Low cost solution to digester upgrade	

Digestion

Several digestion processes and auxiliary treatment technologies are given in Table 3. These are identified further in following Tables 4 through 10 for probable advantages and disadvantages of each of the processes.

Except for the non-calorific gas producing systems, the digestion processes benefit from gas collection systems and the use of the gas for heating or combustion in engines and co-generation systems. All digestion processes benefit from the use of thickeners either prior to discharge to the reactors or during the digestion process. Also, good mixing is fundamental. US EPA has not yet approved continuous flow anaerobic digestion systems as Class A facilities unless they include a batch pasteurization step.

Table 3 Digestion Processes

Process	Primary functions	Class A	Use	Proprietary
Temperature Phased Anaerobic Digestion (TPAnD); *Innovative* Thermophilic (TAnD) *Innovative*	Thermophilic (>55^0C) followed by mesophilic (35^0C) anaerobic digestion or staged Thermophilic to achieve batch	Approved for Degramont,	TPAnD uses HRT duration as a function of temperature, otherwise is the same as the TAnD-MAnD combination. TAnD has longer history of use; Many non-proprietary in use or in intermittent use.	Not known, TPAnD on trial Diluth, Minnesota; TAnD tried at various cities but extensive experience is in Vancouver, B.C. for thermophilic digestion; thermophilic digesters designed from first principles.
Dual Digestion *Established*	High temperature pasteurization (55^0C- 70^0C) (aerobic) followed by MAnD (35^0 C)	Yes	Emerging but >15yrs in Europe and with pure oxygen in USA; <10 years with air in USA	UTB Aerotherm, Swiss CBI,Walker,ATP, USA FUCHS, German Linde, Roedinger, Envirex, USA Other non-proprietary
Two Stage Digestion *Innovative*	Hydrolysis and acid production followed by MAnD(35^0C)	Not yet approved	Iowa, US Scandinavia Experimental for acid production alone	Not known Univ BC, Vancouver
Torpey Process to enhance MAnD. *Established*	Recirculation of MAnD product to thicken and increase sludge retention time	No	Old technology but seeing a resurgence of interest	Not proprietary, Hunts Point and Tallman Island POTW's in New York City
Anoxic gas flotation (AGF) to enhance MAnD *Innovative*	Anaerobic digester gas is used to thicken the product which is returned to increase sludge retention time	No, unless pasteur-ization unit added	New modification of Torpey process with claimed advantage of improved gas quality, reduces ammonia, struvite and dewatering	Renton, King County, WA pilot tested the process and is evaluating full scale implementation Proprietary
Submerged Combustion with Anaerobic Digestion *Innovative*	High temperature pasteurization (70^0C) followed by MAnD (35^0 C)	Yes	1 in Monticello Minnesota, 1998; not yet working, 1 in North Yorkshire, UK 1980;>10 years	Improheat Industries, Vancouver, Canada, Proprietary (equipment?) WRc, & North Yorkshire Water, UK
Autothermal Thermophilic Aerobic Digestion (ATAD) *Established*	Fermentation, anaerobic and aerobic digestion (45^0 -65^0 C)	Yes	>20 years, < 15 years in North America	FUCHS Jet Aeration Other non-proprietary

Two-stage anaerobic digestion requires two reactors that separate the primary anaerobic respiration processes into first, the acid stage and second, the gas stage. The acid stage contains the hydrolysis reactions, acidification and acetification in the first small reactor. Some methanogenic activity may produce gas but the gas production is primarily carried out in the second larger reactor. Ghosh (1999) has undertaken considerable research into this treatment but the process is not yet used significantly despite the operating successes. The first stage may be operated at thermophilic temperatures and cooled prior to entry to the second reactor. In this way the reactor hydraulic detention time is reduced and it operates at a TPAnD process. The process is considered *innovative*.

The acid stage is being used alone for the production of carboxylic acids to supply nutrient for enhanced biological nutrient treatment processes. This process is described by Chu (1996) as a micro-aerophilic process fermenter. Table 4 provides supplementary assessment of the two-stage process.

Table 4 Two Stage Anaerobic Digestion

ADVANTAGES	**DISADVANTAGES**
• Shortens reaction time to <5 days (TPAnD) or <10 days for acid formers and < 20 days for gas formers	• Despite arguments of the users it is not considered to meet Class A by US EPA since it is a continuous flow process.
• Improved methane content >75%	• Requires pre-thickening to 5%+
• Stable alkalinity	• General reluctance for adoption of process

Dual digestion is a pre-pasteurization or post pasteurization process that achieves Class A by introducing a batch or plug flow heat treatment step into a first stage thermophilic aerobic digestion process. The process consists of two options. Either the pasteurization step is undertaken for 24 hours at $>55^0$ C or 1 to 2 hours at 70^0 C. In either case, air or oxygen is added to the first reactor and a heat exchanger is used to recover gas-fired boiler heat to preheat the pasteurization unit. Pre-pasteurized product is cooled in a heat exchanger to recover heat and cool the product to the second stage mesophilic digester temperature.

Table 5 Thermophilic Aerobic Pretreatment and Anaerobic Digestion
Dual Digestion

ADVANTAGES	**DISADVANTAGES**
• Achieves Class A	• High temperatures are corrosive and material selection for the pre-pasteurization reactor must be carefully chosen
• Hydrolyzes waste prior to MAnD treatment and reportedly improves overall digestion	• May reduce net gas production but evidence is conflicting
	• Proprietary systems are expensive but elegant
	• Requires pre-thickening to 5% dry solids

Temperature phased anaerobic digestion (TPAnD) applies thermophilic digestion to the first stage and mesophilic to the second stage. This process is the natural extension of thermophilic digestion as is described by Peddy (2000). Schaefer (2000) and Vandenburgh (2000) describe the TPAnD process. The latter authors include TPAnD with two staged digestion. Table 6 gives advantages and disadvantages. The TPAnD is considered an *innovative* technology.

The Torpey process was introduced in 1967 in New York City as a solution to enhancing digester performance through thickening of the product and recycle. The process is well documented and works well. Burke (1999) has improved the process by recycling and thickening with the digester gas and adding heat treatment steps. The process is called anoxic gas flotation (AGF). The AGF process also includes a pasteurization step between the two digesters to heat the biosolids by steam injection to 70^0 C before reaching the second digester. Claims of 70 to 80 percent digestion are made. King County (1998) and Nolasco (2000) claim that considerable capital savings can be obtained with these processes. Figure 2 illustrates the AGF process if it were added to a temperature phased anaerobic digestion process. Table 7 provides some advantages and disadvantages.

Table 6 Temperature Phased Anaerobic Digestion

ADVANTAGES	DISADVANTAGES
• Shortens HRT and reactor size for first reactor by operating at thermophilic temperatures.	• Despite claims of pathogen reduction performance the process is continuous flow and does not meet EPA acceptability for Class A
• Can be designed with traditional design knowledge	• Requires attention to corrosion protection with high temperature operation
	• Requires pre-thickening to >5% dry solids
	• High concentrations of ammonia

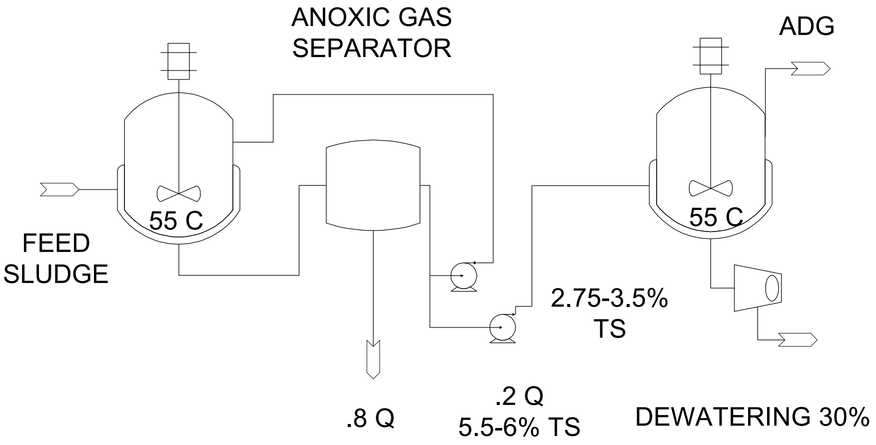

Figure 2, Anoxic Gas Flotation in Thermophilic Anaerobic Digestion

Table 7 Torpey and AGF Process

ADVANTAGES	DISADVANTAGES
• Increases capacity 3 to 5 times	• Odors from thickeners
• Reduces dewatering time 3 to 5 times	• Attention is required for corrosion protection
• AGF improves gas quality and production	• Recycle of ammonia load to the treatment plant impacts treatment process.
• AGF claims reduction in ammonia 25%	• No Class A rating unless pasteurization step is provided.
• AGF claims carbonate formation through CO_2 flotation and subsequent reduction in struvite	

Hudson et al., (1988) gives an early description of submerged combustion for Colburn, Yorkshire, UK. Cochrane, (1999) and Whitaker (1999) describe two concepts that use submerged combustion. Whitaker uses a submerged flame in the digester directly while Whitaker constructs a pre-pasteurization reactor following similar principles of dual digestion. The digester gas is ignited in the liquid resulting in 100% heat transfer efficiencies. This may require special training and accreditation for operation. Table 8 gives advantages and disadvantages.

Table 8 Submerged Combustion

ADVANTAGES	**DISADVANTAGES**
• Achieves Class A if used for pre-pasteurization	• Requires special training for operations staff
• Inexpensive retrofit if used as a pre-stage add-on	• Corrosion and safety concerns
• Higher efficiency in digester heating	• Not yet operational

Kelly (1999) provided a comparison between Class A processes for heat drying, thermal-chemical and autothermal thermophilic aerobic digestion (ATAD). The ATAD process is a combination of anaerobic, fermentative and aerobic biological processes. Sufficient air is added to oxidize the wastes and avoid methane formation. Several proprietary as well as non-proprietary processes are marketed. The process is *established* but not well understood. Odour is a trademark of all thermophilic processes and the ATAD process is no exception. If the collection and treatment of off gases are planned to manage odour, the product is accepted. Planning may require curing, windrow aeration, subsurface injection or composting.

Table 9 ATAD

ADVANTAGES	**DISADVANTAGES**
• Meets Class A • Reactor vessels are fully enclosed to simplify odour control • Requires no pretreatment of biosolids feed • Biosolids may be totally contained until they are pasteurized and stabilized • No open tankage required • Mechanical systems are simple and process is easy to operate, start-up and shut-down • Energy needs are less than other aerobic treatment systems (<0.7 kWh/kg (DS), vs. > 1) • Product will readily dewater to 25%+ dry solids on belt filter press and 30%+ dry solids on a centrifuge • Process may reuse existing digesters to save capital cost • The process may be designed to specific plant needs and avoid proprietary system package systems • The process has an excellent track record where proven equipment is used • No boiler or gas handling combustion steps needed	• Product is odorous and system requires complete emissions control and treatment • Biosolids must be thickened to 5% dry solids prior to feed • Product may need to be dewatered; polymer requirements are 2 to 3 times per tonne that which is needed for mesophilically digested biosolids • Product requires cooling to reduce odorous off gassing and reduce polymer needs for dewatering • Side-stream may require treatment • Foam control is necessary • Some processes are proprietary • Some system suppliers/designers are inexperienced and inadequate systems have been installed • Requires attention to corrosion control

Figure 3 provides an illustration of one of the ATAD process variants.

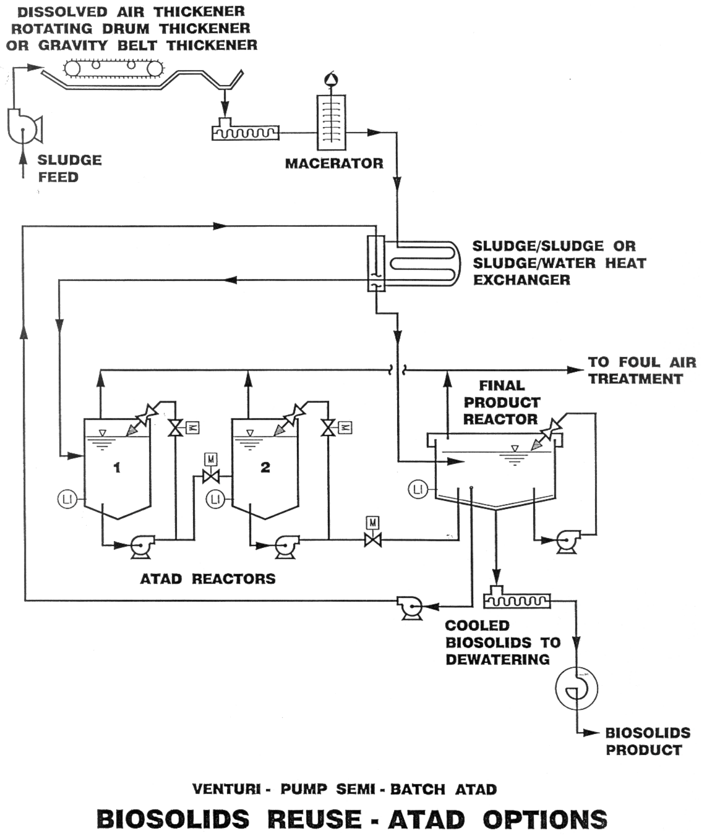

Figure 3, Autothermal Thermophilic Aerobic Digestion

REDUCTION

Incineration processes have improved significantly. Design preferences appear to have changed from multiple hearth to fluidized bed for improved energy efficiencies. Incineration is a “reduction” technology that according to Campbell (2000) is presently not popular with the public. Air quality and ash disposal are the cited concerns. Dangfran (2000) shows that fluidized bed incineration has succeeded multiple hearth processes since 1988 and over 43 are now operating in the USA. Excellent comparisons are given in this paper. Guibelin (2002) posits three cases in which if incineration can be shown to recover energy through CHP systems, it can be considered favorable over land spreading of biosolids. Otherwise it is not. Bacon (2001) introduced a plasma arc sludge oxidation (PASO) process that uses a plasma torch in a rotary oven to initiate catalytic reactions and improve economy of reduction. Incineration processes are not further discussed here.

SCWO and hydrothermal processes are also reduction processes but are more complete as will be shown. WAO is subcritical water oxidation and is an intermediate step to SCWO. Both have been primarily used for industry and munitions destruction but have application for municipal biosolids treatment. Pyrolysis as well as fuel from sludge operates at similar or slightly higher temperatures but at atmospheric pressure. Skrypsi-Mantele,(2000) states that the fuel from sludge temperature is specific to the reactions needed for desired oil viscocities. Gasification operates under pressure at much higher temperatures; Jaeger, (2000) reports that it offers high conversion to CO_2 in contrast to incineration processes, full destruction of dioxins and furans, high calorie gas for direct reuse, and construction products with non-leaching qualities for reuse.

Gasification and Pyrolysis

According to Whipps (1999), the term is used for a number of different processes that transfer energy from the solid to the gas phase. Gasification is a thermal conversion of hydrocarbons to gas by partial combustion of a waste in the presence of oxygen or air. In the absence of air the process is known as pyrolysis. The processes are considered *established* but undergoing much *innovative* change. Figure 4 illustrates gasification and pyrolysis for oil production.

Table 10 lists advantages and disadvantages.

Table 10 Gasification and Pyrolysis

ADVANTAGES	**DISADVANTAGES**
• Destroys organic compounds	
• Synthesis gas (20-30% H_2, 1-20% CH_4, 50% C/CO_x, 0-25% N_2) can be used as chemical feedstock or after additional processing as a power source	• Use of air lowers energy content compared to ADG by 2 to 5 times. Use of oxygen improves calorific value. Pyrolysis gas is similar to ADG
• Provides heat that can be converted to steam and power.	• Some processes produce char that requires further disposal.
• Lower volumes of flue gas that incineration	• Risks for scale up
• Lower NOx emissions than incineration and low dioxins/furans	• Safety issues especially with pure oxygen
• Produces stable solid residues that allows further recycling, binds heavy metals into unleachable matrix	• Requires pre-treatment to meet <500um as dried feed from dryer
• COS, H_2S oxidized to elemental sulfur	• Complex
• Reduced CO_2 emission per kW-hr	• No current cost data
• Meets Class A	• Limited operating data
• >1200 ^{0}C destroys dioxins	•

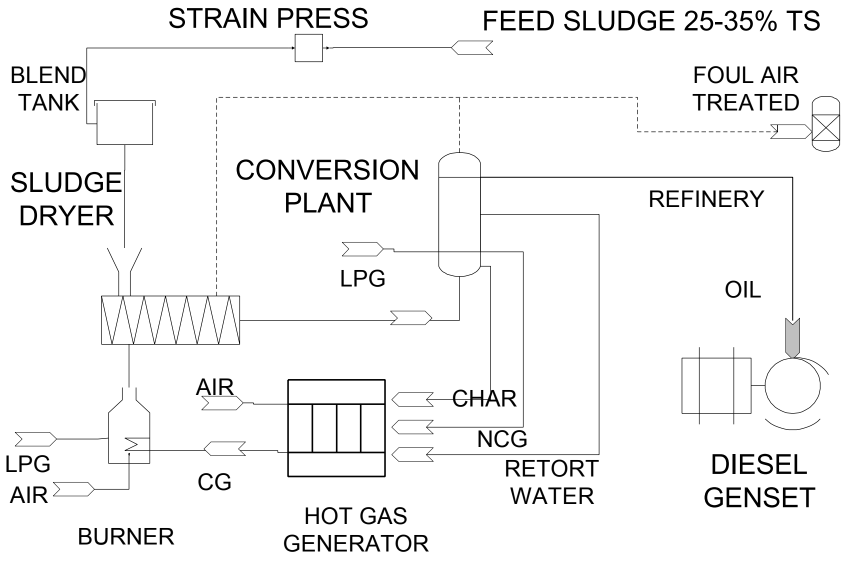

Figure 4, Gasification and Pyrolysis in Oil Production

Oil From Sludge (OFS)

The oil or fuel from sludge technology is an enhanced pyrolysis process that through specified pressures and catalysts is used to produce lightweight oils of desired viscosity. Several supporting processes are needed and an alternative process should be available should the process be down for maintenance or other reasons. Figure 3 provides an illustration. Table 11 gives probable advantages and disadvantages. After over 10 years of research, the OFS process has acquired *innovative* status.

Table 11 Oil From Sludge

ADVANTAGES	**DISADVANTAGES**
• Production of commercially saleable oil or cogeneration	• Requires back-up treatment to secure continuous operation when process is down
• Products include useable char, reaction water and non-condensed gases	• Requires as many as 6 pre-treatment steps including sludge cleaning, blending, dewatering to 25-35% and drying to 95% dry solids, conversion of dry pellets to oil, char and NCG, hot gas generator for dryer and co-generation plant when used
• Can be essentially self sustaining	• Requires unique design for each sludge, eg., phosphorus changes fusion temperature for ash; primary sludge to WAS ratios impact design
• Achieves greenhouse gas reduction	• Fouling of condensers off sludge dryer
• Other benefits as with pyrolysis	• Limited ability to obtain desired oil viscosity

WAO

Djafer (2000) and Gloyna (1998) describe wet air oxidation as a sub-critical water oxidation process that operates at temperatures of 150-350^0 C, pressures of 1-10 Mpa over periods of 15 to 120 minutes. Compared to incineration the process needs no fuel and produces superior products and low emissions. It can produce useful byproducts for enhancing treatment and use as construction materials. Table 12 illustrates some of the advantages and disadvantages. Maugans (2000) provided numerous examples of use with POTW's in North America. WAO is an *established* process.

Table 12 Wet Air Oxidation

ADVANTAGES	**DISADVANTAGES**
• Improves dewaterability	• Operates at 10 to 100 atmospheres and high temperatures 150-350^{0}C
• Low energy requirements and no fuel requirements	• Capital cost is high, (10 gpm, \$2.7M, 125 gpm, \$4M)
• Low air pollution concerns; no NO_x, SO_2, HCl, dioxins, furans, flyash	• Maintenance cost is high
• Maximum biosolids reduction in small footprint	• If unusable, waste liquors contain high concentrations of carboxylic acids that require treatment
• Suited to problem sludges with high metal content or synthetic organics	• Use of deep shaft WAO systems are yet unproven
• Possible use of product acids for enhanced biological nutrient removal	• Does not reduce total solids significantly (7%)
• Immobilization of heavy metals in form of hydroxides, carbonates and insoluble phosphates	• Deep shaft systems have encountered solids buildup and plugging
• Reduction of greenhouse gas (CO_2) production	• Systems are prone to scaling, Calcium concentrations in the feed are limiting
• Residual solids are intrinsically resistant to leaching	• Let down valves may be problematic
• COD and VSS reduction of 70 and 90%	• High ammonia production may be a problem with downstream treatment
• High organic nitrogen removal to 70% through oxidation to elemental nitrogen with catalyst	• High corrosion problems have caused some operations to be suspended, many are currently at their end of life design and need replacement.
• Provides a Class A product	• Cleaned and thickened feed to 5%
• Over 100 plants in operation since 1985	

SCWO

Super critical water oxidation, also called hydrothermal oxidation, is explained by Gloyna (1998) and summarized for use with sludge by Shanableh (2000), Patterson (2001) and Svanström (2001). Water above 374.2^0 C and 22.1 MPa reaches a super critical instability that is similar to a condition of vapor and liquid in one amorphous mass. Reaction time may be a fraction of a minute to several minutes for difficult wastes. The characteristics of solutes in water and reaction kinetics completely change in the hydrothermal range, above the critical point. Specific gravity is reduced by 1/4th and the fluid becomes a dense gas, solubility of solutes are reversed (organics increase and inorganics decrease), heat capacity increases exponentially, viscosity decreases, free radical reactions increase and dielectric constant decreases. The addition of an oxidant to the plasma like fluid secures immediate and complete oxidation with the formation of high quality effluents, reduction of CO_2 through formation of carbonate salts, formation of inert ashes and release of air emissions. Table 13 provides a list of advantages and disadvantages. SCWO is an *innovative* process.

Table 13 Super Critical Water Oxidation

ADVANTAGES	DISADVANTAGES
• High reduction in VS and TS, 60-80%	• Corrosion problems (especially halogenated wastes)
• Complete oxidation of organics, COD>99.9% reduction	• Requires safety systems for handling pure O_2 or H_2O_2 as oxidants.
• High quality effluent	• There are few plants and are all designed for industrial or military use
• Low air emissions, (NO_x, SO_2 scrubber needs) No HCl, halogens, furans, dioxins, PCB's	• Requires sophisticated reaction chambers and pre-processing/thickening
• Residuals intrinsically resistant to leaching	• Problems with scaling, high calcium wastes
• Provides Class A product	• Settling of material in feed lines can produce explosions
• Immobilization of heavy metals in form of hydroxides, carbonates and insoluble phosphates	• Problems with let down valves from high pressures (safety)
• Provides complete reduction in greenhouse gas over WAO	• May need to further treat the gas for nitrogen and sulfur compounds
• Improves sludge settleability	• Produces ammonia that may impact the liquid treatment process
• Suited to treatment of hazardous waste	• High capital cost (5gpm, $2.2M)
• Provides heat recovery and is self sustaining	• High maintenance cost ($0.50/gal)
• Low fuel requirements	• Requires feed waste be cleaned and pre-thickened to 5-10%
	• Feed sludge is required to be homogeneous and free from grits (<300 um)
	• Requires ash disposal and side-stream effluent handling
	• Energy considerations are necessary to determine process viability
	• SCWO may require pretreatment of solids by pyrolysis or other
	• Selection of oxidant, reaction time, temperatures and pressures requires study or pilot work

Conclusion

There is a need to be acquainted with emerging treatment solutions. Promulgation of environmental laws is increasing, as is public awareness, and the likelihood of Class A being a single requirement for all land application solutions is becoming a real possibility. Innovation in digestion and reduction technologies can form part of the solution. These two broad technological categories have advantages and disadvantages, and selection depends on familiarity, need and suitability of use.

Flexibility remains a key component in biosolids management.

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