

WEFTEC 2003 WORKSHOP W104  
THERMOPHILIC DIGESTION: HOT UPDATE!  
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LOS ANGELES CONVENTION CENTER  
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AUTOTHERMAL THERMOPHILIC AEROBIC DIGESTION  
RESEARCH, APPLICATION AND OPERATIONAL EXPERIENCE

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## INTRODUCTION

Research, application and experience, through operations comprise a learning loop that expands and improves systems. Application often precedes research, but subsequent operation defines the need for research to support reinvestment in new and advanced systems. The autothermal thermophilic aerobic digestion (ATAD) process is an example of a treatment system that has followed this development and has attracted the imagination of scientists, engineers and operators in the development of an exciting and often enigmatic process. From the start in the late 60's, these adventurers produced thermophilic digestion in controlled laboratory reactors; in to the early 70's they used open uncovered vessels, and in the 80's and 90's they constructed the reactors in insulated facilities and provided automated operation. The thermophilic process now reaches higher temperature and digestion rates than their forebearers (the conventional mesophilic treatment facilities) for the treatment of moderately concentrated animal and human wastes. The treatment process provides Class A biosolids in low footprint digestion vessels. The small footprint, and lower construction and operating cost were the original reason for the selection of the process. The ability to produce a Class A biosolid, which is pasteurized and stabilized product has largely replaced this early reason for considering an ATAD.

In British Columbia, ATAD application, operation and research was initiated in 1976 with research, in 1981-1982 with pilot scale facilities at Sidney, B.C., and in the late 1980's with the construction of three full scale demonstration facilities followed by more research at the University of British Columbia in the 1990's. Several ATAD reactor configurations and new designs ensued, and several are being expanded today. A review of the recent research, current application and case studies are presented. The case studies reflect an updated North American survey.

## APPLICATION

WERF(1998) now classifies the ATAD as an *established* process as compared to the limited operating experience of *innovative* or the still bench tested *embryonic* process. While there is agreement on the key operating criteria of the process, there is still considerable misunderstanding of the process, frequent claims of special knowledge and many instances of inappropriate design. What is generally observed is that:

- a) untreated domestic sludges are not alike and will respond to thermophilic treatment differently, but not so differently that ATAD digestion is not possible given appropriate controls and training,
- b) supplemental energy requirements are primarily related to the efficiency of mechanical energy conversion to heat, sensible heat losses to feed and surroundings, latent heat losses of evaporation, the concentration of the organics, the energy content of the organics and the energy released from the organic wastes,
- c) oxidation is practical using aeration systems that produce fine bubbles and when used, pure oxygen appears to have greater effectiveness when compared on an equivalent basis;

regardless, the key reactions are believed to include fermentation processes to produce lower molecular weight carbon substrates for the aerobic digestion to be effective,

- d) biological (culture) changes and resulting foaming occur as a result of a sudden or relatively sudden change in the operating condition of a digester whether through temperature fluctuation, loss of substrate, introduction of a water spray, thin feed or poor mixing,
- e) products of oxidation in each reactor vary as the nature of the waste, the operating temperature and the degree of oxidation obtained,
- f) odor is a product of oxidation, incomplete oxidation, the fluid temperature and the characteristics of the original feed source,
- g) water holding capacity of the digested biosolids product is a result of the large surface area and the production of extracellular polymeric substances and proteins in the liquid fraction; recent investigation has not substantiated the claim that divalent cations are responsible for difficulty in water extraction from the digested solids but pH change did assist water reduction.

Vesiland (1979) is probably right, “there are no typical sludges” and Oleszkiewicz and Mavinic (2001) expand by saying, “there are no universal ‘proper’ residuals treatment and management schemes”. The means of sludge treatment including ATAD remain very much an art and universal solutions are not yet available given the variety of different sludge types and the variability of the sludge character. Flexible plant design is important but can add more expense. The message is to provide as much flexibility in the final solutions as in the process selection and design.

## **PHYSICAL PLANT DESIGN**

The application information was drawn from Kelly et al. (1990, 1993, 1995, 1996 and 1997) and WEF (2003 in print). Table 1 provides a list of advantages and disadvantages for the process.

### Process Components and Sizing

The ATAD process must have a feed control mechanism, which ensures that the organic feed is above a minimum concentration for adequate heat production. The solids must also be below a maximum concentration to allow adequate mixing. For municipal sludges, a prethickener is normally needed. The concentration of total volatile solids (TVS) can be used as a surrogate measure for COD, and total solids (TS) can be used as a measure for ensuring mixing effectiveness for municipal sludge feeds. A minimum TVS of 3% to 4% (COD concentration of 40 to 60 g/L) and a TS of less than 7% are typical requirements. TVS values as low as 2% have been observed but operation requires excessive mechanical energy to be effective.

Because of the higher reaction rates, the ATAD reactor volume requirements are one-sixth to one-half less than conventional aerobic and anaerobic digestion. Holding or post aeration tanks

will reduce the difference in some cases. Prethickening is often an added requirement for ATAD, but is considered important for anaerobic digestion as well.

The number of reactors selected will depend on the fluctuation of the hydraulic loading, or the desire to use continuous treatment with plug flow to aid in pathogen destruction. Unless a pre-feed storage tank is used to offset hydraulic variations, peak week loadings should be used to set minimum volumes for the selected design hydraulic resistance time (HRT). Where large fluctuations occur, such as at resort areas, three or more reactors may be needed for flexibility. A normal design minimum HRT of 8 days (although some systems have operated as low as 5 days) and a maximum of 15 days total are in use. A heat exchanger, if used, will bring the undigested feed solids to thermotolerant temperatures (30-40°C). Water-water, sludge-water or sludge-sludge spiral, double pipe or shell and tube, counter flow heat exchangers are in use as described by Kelly (1996).

Once digestion is complete, a final storage tank may be needed. Size will depend on solids reuse plans or dewatering plant operation and may be as short as one day or as long as is necessary. The final reactor or storage tank is a practice heat source for use as a heat supply for the preheat tank or first reactor. A biosolids temperature of less than 40°C to 30°C may be beneficial for sludge dewatering processes. This is not a rule, however.

**TABLE 1**  
**ATAD (KELLY, 2003)**

<b>ADVANTAGES</b>	<b>DISADVANTAGES</b>
<ul style="list-style-type: none"> <li>• Meets Class A</li> <li>• Reactor vessels are fully enclosed to simplify odour control</li> <li>• Requires no pretreatment of biosolids feed</li> <li>• Biosolids may be totally contained until they are pasteurized and stabilized</li> <li>• No open tankage required</li> <li>• Mechanical systems are simple and process is easy to operate, start-up and shut-down</li> <li>• Energy needs are less than other aerobic treatment systems (&lt;0.7 kWh/kg (DS), vs. &gt; 1)</li> <li>• Product will readily dewater to 25%+ dry solids on belt filter press and 30%+ dry solids on a centrifuge</li> <li>• Process may reuse existing digesters to save capital cost</li> <li>• The process may be designed to specific plant needs and avoid proprietary system package systems</li> </ul>	<ul style="list-style-type: none"> <li>• Product is odorous and system requires complete emissions control and treatment</li> <li>• Biosolids must be thickened to 5% dry solids prior to feed</li> <li>• Product may need to be dewatered; polymer requirements are 2 to 3 times per tonne that which is needed for mesophilically digested biosolids</li> <li>• Product requires cooling to reduce odorous off gassing and reduce polymer needs for dewatering</li> <li>• Side-stream may require treatment</li> <li>• Foam control is necessary</li> <li>• Some processes are proprietary</li> <li>• Some system suppliers/designers are inexperienced and inadequate systems have been installed</li> <li>• Requires attention to corrosion control</li> </ul>

ADVANTAGES	DISADVANTAGES
<ul style="list-style-type: none"> <li>• The process has an excellent track record where proven equipment is used</li> <li>• No boiler or gas handling combustion steps needed</li> </ul>	

### Operation

Operations are simplest on continuous<sup>1</sup> or semi continuous<sup>2</sup> feed and become more complex with full<sup>3</sup> or semi batch<sup>4</sup> processes. Conversely, operator attention may be greater for continuous and semi batch feeding in contrast to a simple once in 8 day batch feeding. The latter system is likely reserved for very small plants where added sludge storage volumes do not present the same impacts on plant operations such as odour control and solids handling. Where pasteurization is an objective, when one tank only is used, a full batch process is used. Semi continuous or continuous treatment requires multiple reactors to approach a plug flow and achieve pasteurization (Schafer, 1994). With either full batch or partial batch processes, operation requires timed transfers, controlled feeding and greater operator attentiveness. Figures 1 and 2 illustrate two control systems for a partial batch operation. Figure 1 illustrates a semi batch process and the use of an aspirator mixer with time initiated control. Level sensors are used to confirm transfer sequences. Figure 2 illustrates the use of venturi-pump recirculation and level control to allow flexibility in continuous to semi-continuous discharge to the first reactor. A semi-batch process is subsequently available to the subsequent reactors. Figure 3 illustrates a true batch process using two alternating reactors. The three figures illustrate sequences for transfer and normal digestion operations.

The operation shown in Figure 1 requires a pre-established operating level. To allow the ½ hour, once per day partial reactor transfers, full day storage of feed sludge for the volume to be transferred must be provided and reactor displacement must be predetermined to ensure minimum HRT is met.

The advantage of the venturi-pump operation shown in Figure 2 for semi-continuous or batch operations, is that the feed can be continuous or semi-continuous to the first reactor and this avoids storage. The venturi-pump recirculation mixer-aerator system works with the variable operating level to allow this flexibility and has this advantage over a fixed level aspirator-mixer system, shown in Figure 1. The Turborator allows about 1 m of level variation. Other aspirator-mixers may not. A variable level also allows optimization of hydraulic residence times.

The equipment shown in Figure 3 allows moderately variable operating levels but has a maximum tank depth limitation (submergence limitations on the Turborator aspirator mixer restricts operating depth). The reactors are alternated in single batch modes and filled once every

<sup>1</sup> Continuous tank contents are continuously displaced by an inflow of feed.

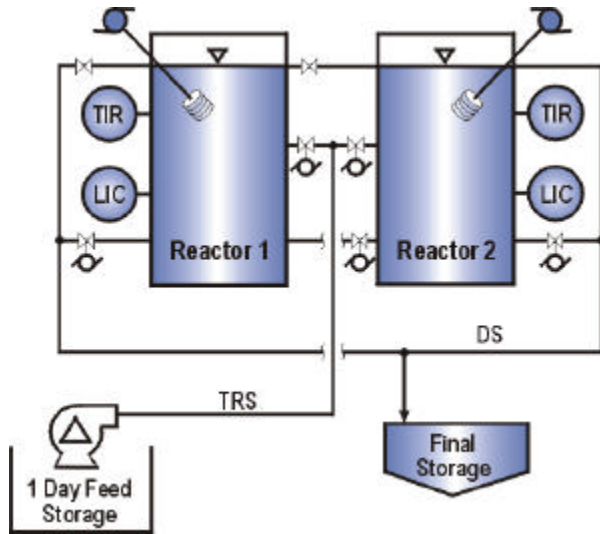
<sup>2</sup> Semi continuous tanks are partially displaced or drained and filled intermittently (hourly) throughout the day.

<sup>3</sup> Batch-tanks are completely filled and drained over one period of hydraulic retention time (HRT).

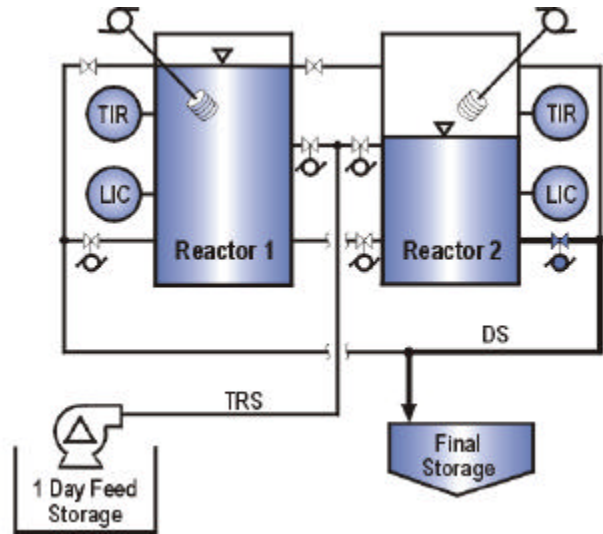
<sup>4</sup> Semi-batch tanks are partially drained and filled on a daily basis with a volume equal to a reactor volume divided by the HRT.

4 to 5 days. For a two tank system, a 4 to 5 day feed sludge storage is needed. It is likely appropriate for small plants only, but is the simplest to operate.

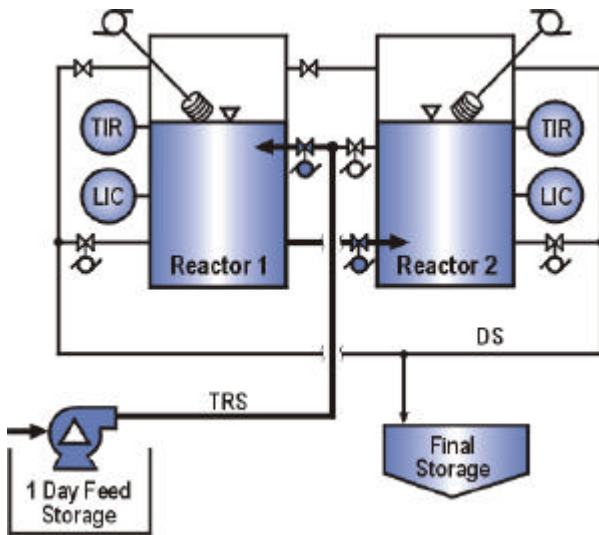
The Figure 2 semi-continuous or continuous operation was developed for large facilities where more control is needed on hydraulic residence time and where storage of feed sludge is not desirable.



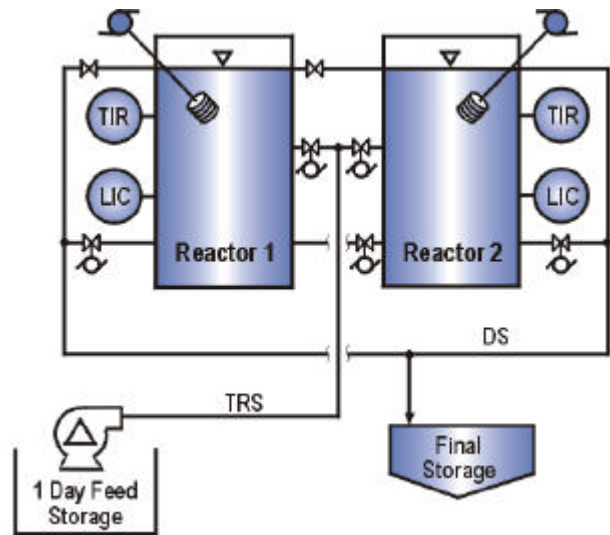
**1. Normal ON**  
0:00 to 23:00 Hrs.



**2. Initiate Transfer to Storage**  
23:00 to 23:30 Hrs.



**3. Equalize Vessel Levels and Fill Vessels Through First Reactor, 23:30 - 24:00 Hrs.**

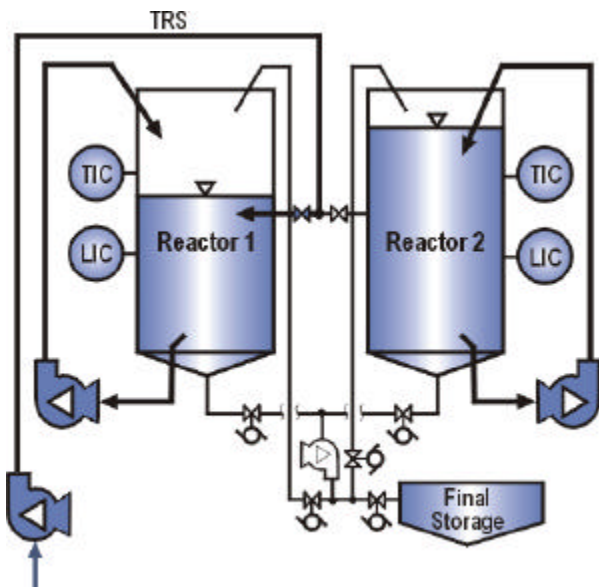


**4. When Reactors are Full, Aerators Mixers are Returned to Service, 24:00 Hrs.**

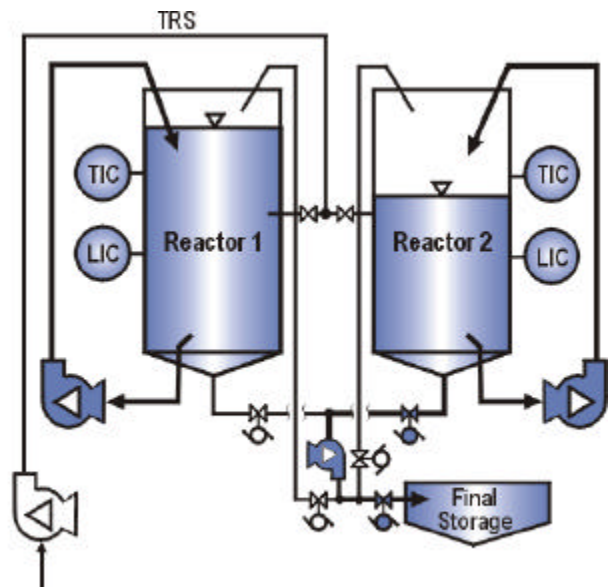
LEGEND			
DS	Digested Sludge		Pump On
TIR	Temperature Indicator Recorder		Pump Off
LIC	Level Indicator Control		Valve Open
TRS	Thickened Raw Sludge		Valve Closed

## Series Reactor Daily Batch Operation (Taken from FUCHS Gas und Wassertechnik GmbH)

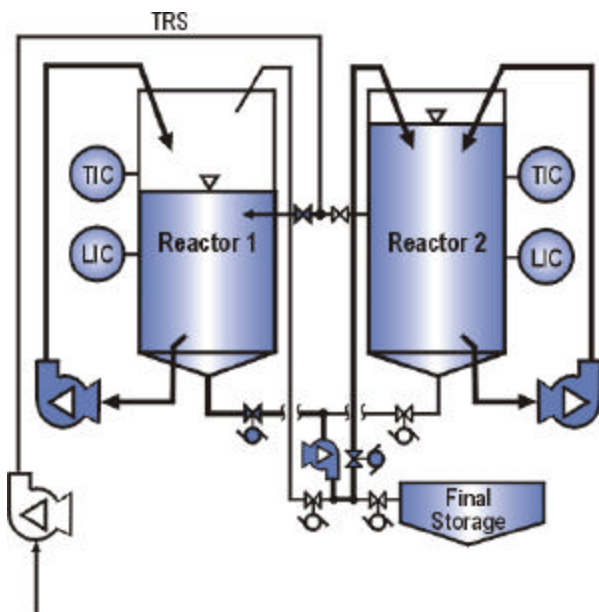
**Figure 1**



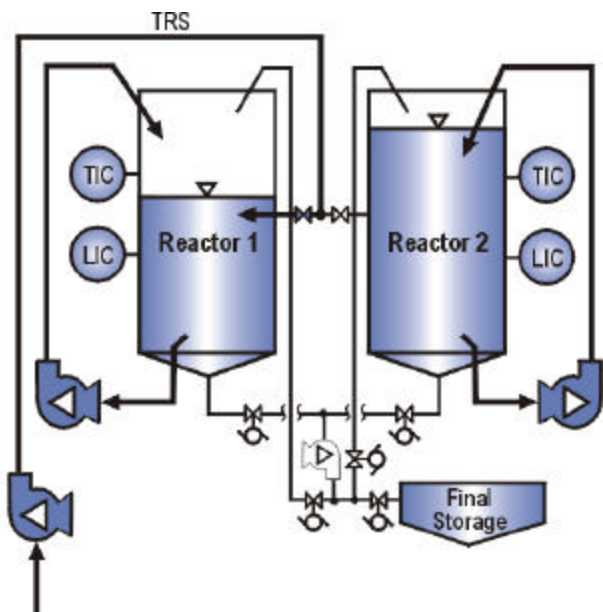
1. Normal: Reactor 1 Filling  
Continuous or Semi- Continuous



2. Reactor 1 Full: Transfer Reactor 2  
to Storage



3. Transfer Reactor 1 to Reactor 2



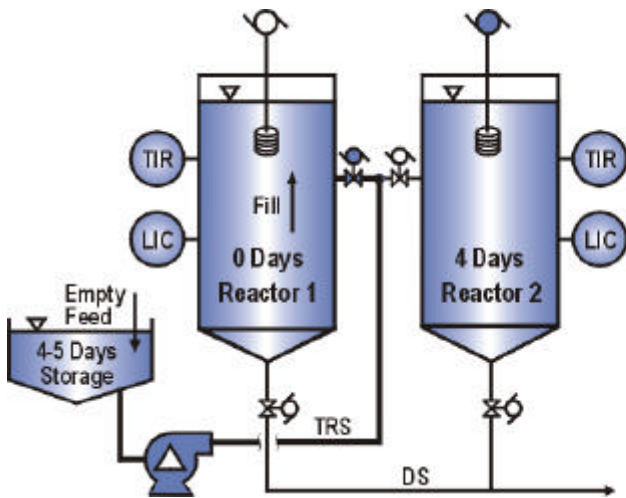
4. Normal: Reactor 1 Filling  
Continuous for Semi-Continuous

**LEGEND**

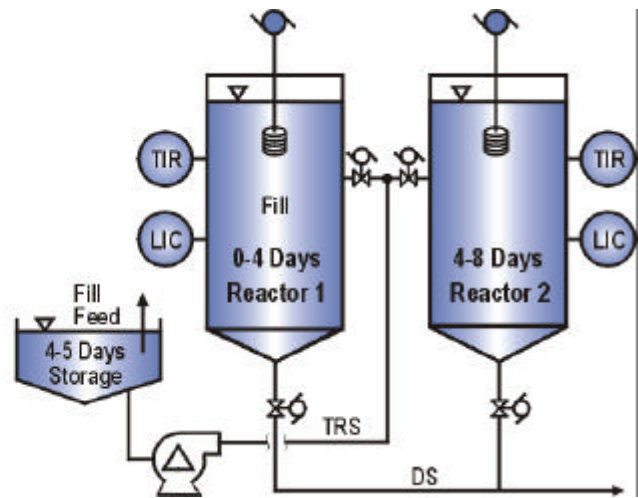
DS	Digested Sludge		Pump On
TIC	Temperature Indicator (Pump) Controller		Pump Off
LIC	Level Indicator (Transfer) Controller		Valve Open
TRS	Thickened Raw Sludge		Valve Closed

**Batch or Semi-Continuous  
Operation**

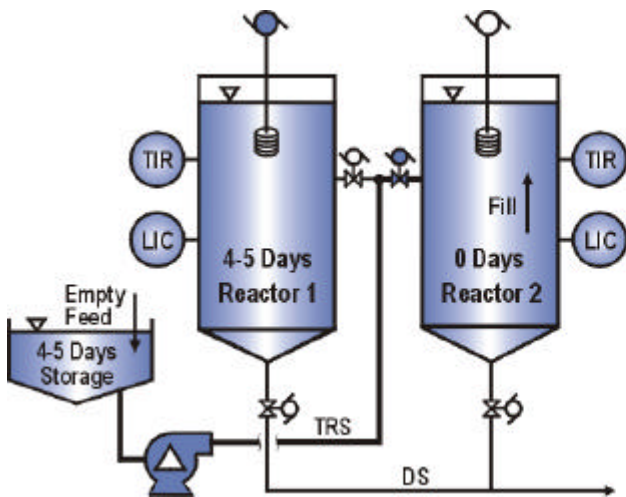
Figure 2



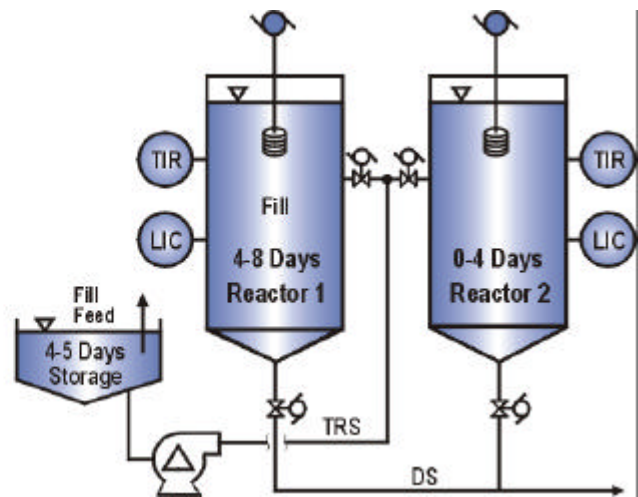
1. Reactor 1 Contents Emptied and Reactor 1 Filling; Reactor 2 Operating; Day 1; Feed Storage Depleted



2. Reactor 1 and Reactor 2 Operating; 4-8 Days; Feed Accumulates in Storage



3. Reactor 2 Contents Emptied and Reactor 2 Filling; Reactor 1 Operating; Day 4 or 5; Feed Storage Depleted



4. Reactor 1 and Reactor 2 Operating; 4-8 Days; Feed Accumulates in Storage

LEGEND			
DS	Digested Sludge		Pump On
TIC	Temperature Indicator Recorder		Pump Off
LIC	Level Indicator Control		Valve Open
TRS	Thickened Raw Sludge		Valve Closed

## Alternating Reactors Complete Batch Operation

Figure 3

## Equipment Selection

Equipment, not including ancillary pre-thickening and dewatering plant, includes mixers (including recirculation pumps), air aspiration devices, foam breakers (spray or mechanical), off gas exhausters, odour control, temperature and level monitors and automatic valves (hand control for very small systems only). Controls may include programmable logic controllers (PLC) or combinations of man machine interface (MMI) or a personal computer (PC) software and PLC.

Table 2 illustrates ATAD equipment and reactor options that are currently in use or marketed in North America.

**TABLE 2  
ATAD EQUIPMENT AND REACTOR OPTIONS**

<b>Type of Air Mix Supply</b>	<b>Aspirator-Mixer</b>		<b>Pump Recirculation Venturi Aeration<sup>(2)</sup></b>	<b>Turbine Diffused Air<sup>(3)</sup></b>
Equipment	FUCHS <sup>(1)</sup> - Spiral aerator - Circulation aerator	Turborator	Generic, pump and venturi, can include diffused air	Patented (Coulthard process)
Tank Material	Steel (or concrete at special request)	Steel or concrete	Steel or concrete	Fibreglass, steel or concrete
Retrofit Possible	No	Yes	Yes <sup>(2)</sup>	Not known
Limitation	Batch preferred: - constant tank level - new construction only - equipment in reactor	Depth tested to 4.3 m (14 ft.) SWD maximum	Pipe work for recirculation system. Erosion corrosion requires resistant metal	Two pieces of equipment, blowers and turbine. Possibly limited to small systems. High specific power needs.
Foam Control	Required – separate mechanical foam breaker, horizontal	Required – mechanical foam breaker, vertical (included on shaft)	Required; spray from recirculation or separate surface mounted mechanical foam breaker	Required
Equipment Enclosure	Generally open to atmosphere	General open to atmosphere	Can be either open or closed to atmosphere but process facilitates a covered operation at grade	Blower building must be in covered structure. Turbine is generally open to atmosphere.
Reactor	Fully enclosed cylindrical, insulated flat bottom typical coned in some installations	Fully enclosed box or cylindrical, insulated flat or sloped bottom	Full enclosed, box or cylindrical, insulated, flat sloped or cone bottom.	Fully enclosed cylindrical insulated, flat bottom
Insulation	Outside wool or foam	Inside or outside foam	Inside or outside foam	Wafer tank insulated

Type of Air Mix Supply	Aspirator-Mixer		Pump Recirculation Venturi Aeration <sup>(2)</sup>	Turbine Diffused Air <sup>(3)</sup>
Operation	Semi batch, daily	Batch, semi-batch, semi continuous, continuous	Semi-batch, semi continuous, continuous	Batch, semi-batch
Automation	Provides volumetric transfer for setpoint HRT and known operating reactors	Can use temperature controller to maintain setpoint temperature by varying mixer speed and airflow.	Can use temperature controller to maintain setpoint temperature by varying pump speed and airflow.	None known.
Flexibility of mixing energy and air flow	Limited range of speed variation of 80 to 100% full speed for airflow control. Is reported to cavitate if speed is increased above operating range.	Speed variation 65-100% full speed for airflow control; lower for mixing.	Speed variation 50 to 100% full speed for airflow; lower for mixing.	Diffused air system is independent of turbine mixer.
Response to Change in Flow	Add or delete tanks; store, ore change solids feed concentration	Add or delete tanks; store, or change solids feed concentration.	Change operating level in tanks; add or delete tanks; store, or change solids feed concentration	Not known
Simplicity of Operation	Moderate, complicated if not automated	Simple in continuous or semi continuous and for complete batch	Moderate, best when automated.	Simple as a small complete batch
Energy Efficiency	15-20 kW/hr/m <sup>3</sup> treated	20 kw-hr/m <sup>3</sup> treated	15-20 kW-hr/m <sup>3</sup> treated	>20 kW-hr/m <sup>3</sup>
Heat Recovery	Shell in shell; sludge-sludge	Shell in shell/tube in tube/spirals, sludge-water or sludge-sludge	Same as Turborator	Not known.
Compatibility with existing facilities	Best as new process but can use existing thickener and dewatering if reliable	Good for retrofit or can be used in new process. Can use existing thickener and dewatering if reliable.	Adaptable for existing plant as new or retrofit. Can use existing thickener and dewatering if reliable.	Not known.

Type of Air Mix Supply	Aspirator-Mixer		Pump Recirculation Venturi Aeration <sup>(2)</sup>	Turbine Diffused Air <sup>(3)</sup>
Reliability and Components	Daily shaft cleaning, shaft rebuild annual or every second year and replacement after 2 rebuilds. Foam breaker maintenance annually. Motor and shaft are proprietary – not locally replaceable.	Impeller is knockoff, and replacement annually or every second year. Foam breaker will need replacement if submerged. Motor is generic; shaft is non-clogging, reversible and can be cleaned by stopping. Impeller and shaft are proprietary.	Weekly airline clearing. Correct metallurgy is required. Pump servicing and normal parts replacement of seals, bearings required. Pump and motor are generic and normally locally replaceable.	Not known. Fine bubble diffusers are known to clog in high solids concentrations.

SWD – side water depth.

<sup>(1)</sup> FUCHS Gas-und Wassertechnik GmbH

<sup>(2)</sup> CBI Walker Inc., ATP and Jet Tech, Jet Aerator are proposed as alternative proprietary processes, but are not known to include retrofit options. Data was not available for in full scale systems when this comparison was made.

<sup>(3)</sup> Degremont-Lyonnaise des Eaux market a diffused air proprietary process as well, although none are known to be operating in North America.

<sup>(4)</sup> JetTech report use of an oxidation reduction potential controller to vary air flow and recirculate the used air (1996).



Figure 3 - Foam Flooding on Small ATAD Reactor without Foam Protection Systems

### Mixing Energy

Mixing energy is needed to provide maximum interaction between substrate and the thermophilic, to reduce particle size for increased surface area, and to provide supplemental heat through mixing energy dissipation. An optimum reactor shape (liquid depth equal one-half to three quarters diameter) requires a shear gradient  $G$ , of  $450 \text{ sec}^{-1}$ . For temperatures of  $50\text{-}60^\circ\text{C}$ , this is about  $100 \text{ W/m}^3$ . Power densities of lesser and greater value are in use.

### Air Supply

Aspirator mixers or venturi mixers that produce fine elongated bubbles for improved oxygen transfer and redirect energy to assist in the breakup of larger particles through implosions (cavitation) appear to give advantage over other less violent forms of mixing equipment. Oxygen transfer for high power densities above  $150 \text{ W/m}^3$  is assumed high (better than 70 percent) when calculating the oxygen air requirements at a residual oxygen concentration of  $0 \text{ mg/L}$ .

### Off Gas Quality

Off gas quality is a result of the balance of fermentative and oxidative processes concerning in the digesters. The off gas differs from digester to digester; the first may contain higher concentration of nitrogen compounds that are produced from deaminization of proteins. This is observed in a high ammonia alkalinity and pH over background feed (Kelly, 1993). Oxidation of organic sulphur compounds, particularly the odorous alkaline soluble mercaptans, increase off gas concentrations of less odorous dimethyl sulfide (DMS) and dimethyl disulphide (DMDS). Further oxidation produces soluble thiosulphonate salts. Hydrogen sulphide ( $\text{H}_2\text{S}$ ) is expected to be less as oxidative digestion proceeds but is being formed by reducing reactions as well and has been found to increase in concentration. High concentration of carboxylic acids, particularly acetic, propionic and butyric appear to add a strong penetrating sour odour to the off gas and dewatered biosolids. Also alcohols, turpenes, ketones, indoles and a variety of organic compounds are observed to be present in gas chromatography results.

Multi stage scrubbers using acid and caustic solutions in conjunction with sodium hypochlorite are in use as well as soil biofilters. Bowker and Trueblood (2002) provide an excellent assessment of ATAD off gas characteristics for two Vail Valley, CO plants. Caution in design is needed and observance to site meteorological conditions is essential to avoid public complaints. College Station, TX has assed a 22 day aerated holding tank, which is claimed by Serovic (2003) to have reduced the final product odor and reduced the conditioning requirements of the biosolids to improve dewatering.

### Pathogen Survival and Recontamination

Numerous studies (Fuchs, 1980; Stauch, 1985; Kelly, 1993) have shown the suitability of heat treatment in the ATAD process to adequately destroy pathogens. Regulations and guidelines throughout the world name the ATAD process as a process meeting pasteurizing requirements for unrestricted end use, providing other limitations such as metals concentrations are below safe

limits. The US EPA 503 Regulations name the ATAD process as a Process to Further Reduce Pathogens (PFRP) to meet the Class A requirements for unrestricted use biosolids.

However, assurance of continued PFRP quality requires attention to housekeeping and elimination of possible cross contamination in design and operation.

### Foam Control

Foaming is believed to be a response to a population shift of competitive bacteria. As less temperature tolerant strains lyse and make way for temperature tolerant strains, the released intracellular materials from the ruptured cells are believed to contribute to the foaming by lowering the liquid surface tension. This can occur from one reactor to another especially if a sudden change in environment occurs. Foaming is illustrated in the photo of the Grand Chute-Menasha West, WI, 1994 ATAD operation shown in Figure 3.

Foaming can be controlled by reducing air supply, densifying the foam through mechanical breakers, providing a large freeboard allowance (not likely economical), adding sprays and adding defoamants. Operating at thermophilic temperatures also suppresses foaming and an operating system that uses feed sludge preheating, can achieve a rapid rise in digester temperature or uses a continuous feed can reduce the likelihood of foaming.

### Dewaterability

ATAD biosolids can obtain high cake solids concentrations when dewatered with mechanical processes such as centrifuges, belt presses, inter alia, relative to biosolids from conventional digestion processes. Generally high polymer additions are needed however, and the dewaterability of thermophilic biosolids product can be quite variable. Experience has found that cooling and the use of a flocculant in conjunction with a cationic polymer will reduce dewatering cost. Murthy et al. (1999) at College Station, TX, and Kelly et al. (2000) at Salmon Arm, B.C. have shown this improved costs significantly.

## **CASE STUDIES**

Appendix 1 includes a list of 12 North American ATAD facilities and gives a description of the key features of the systems and operational issues. In addition, eight facilities are provided to highlight different design conditions and level of operation. The main attributes and concerns are also given.

### Salmon Arm WPC, District of Salmon Arm, B.C., Canada

The ATAD was added in 1988 with an expansion to the plant and served as part of a demonstration process that initially used diffused air and submerged mixing, and ultimately used novel surface mounted aspirator mixers known as Turborators. The plant was expanded in 1997 from three to four reactor vessels. Two of the initial reactor vessels are about one-half the size of the larger reactor vessels. The plant is full automated for transfers and temperature control. The continuous feed - batch process is used to meet PFRP requirements. Centrifuges are used to

dewater the treated biosolids to about 35% dry cake. The solids are trucked to farmland for agricultural use.

The ATAD experienced cyclic loading conditions during trickling filter sloughing events during periods of biological stress. This caused excessive loading to the reactors and necessitated the addition of a Turborator. Once added, the mixing energy was sufficient to meet the excessive loading conditions. Foam conditions were an occasional problem in the early operating years but experience with operation and loading conditions as well as the installation of foam detector controls and foam breaker blades on the Turborators has contained foam problems. Odor treatment had used the trickling filter as a scrubber and with the most recent expansion (2004) a dedicated odor treatment plant is to be installed for the ATAD process. Dewatering chemical use is balanced between addition of inexpensive iron salts (pickle liquor) and polymer. The chemicals were optimized reducing cost from over \$280/dt to \$145/dt, and the results published by Kelly et al. (2000). Caustic soda is used to treat the centrate to control odor and restore pH.

Figures 4 and 5 illustrate the upper deck of the ATAD reactor in Salmon Arm and show the Turborator aerator-mixers. Table 3 identifies some of the key features of the District of Salmon Arm Water Pollution Control Center (WPCC).

**TABLE 3**  
**DISTRICT OF SALMON ARM WATER POLLUTION CONTROL CENTER**

<b>Loading</b>	
Population	11,500
Flow	4500 m <sup>3</sup> /d
BOD <sub>5</sub>	850 kg/d
TSS	765 kg/d
<b>Major Unit Processes in Plant, 2003</b>	
Primary settling	2
Anaerobic, Anoxic, Oxic tanks in combination with Trickling Filter (Activated Biofilter) for enhanced biological nutrient removal	
Secondary clarifiers, disk filtration and UV disinfection	2 each
Waste biological sludge drum thickener	1
Centrifuge dewatering and chemical centrate treatment	1; (2 future)
Odour treatment: nitrifying tower, ozone and wet chemical scrubber	2500 sm <sup>3</sup> /hr
<b>Feed Conditions</b>	
Source	Primary and Waste Biological
Feed Strategy	Semi-Continuous
Normal Feed Rate	20.5 m <sup>3</sup> /d
Feed Per Cent	4-6
Mass Loading	1221 kg/d
<b>ATAD Reactors</b>	
Number	4
Material construction	Concrete
Insulation	100mm Dow SM
Dimensions (all four reactors are different sizes, the past two are for storage)	Rectangular
Active volume total	160m <sup>3</sup>
<b>Equipment</b>	
Aspirator mixers (Turborators, surface mounted) total	6@ 5.6 kW
Foam cutters (Lightnin surface mounted)	2 @ 0.5 kW
Connected power total	34.6 kW
<b>Performance Factor</b>	
Total detention time	9 days avg.
Batch isolation time	< 10 minutes
Volumetric loading total	0.13 m <sup>3</sup> /m <sup>3</sup> -d
Mass loading total	7.6 kg/m <sup>3</sup> -d
Power density	216 W/m <sup>3</sup>
Specific energy use	0.68 kW-hr/kg
Reactor vessel temperatures	60-70 <sup>0</sup> C
Volatile solid reduction	40-50%
<b>Conditioning</b>	
Ferric chloride salts as flocculants	40-50kg/dt
Cationic Polymer	15-18 kg/dt
Centrifuge dewatering	1 at 35-38% cake



Figure 4 - District of Salmon Arm, B.C., WPCP ATAD



Figure 5 - District of Salmon Arm, B.C., WPCP ATAD Turborator Aerator Mixers

#### North West Langley WWTP, Langley, B.C., Canada

The North West Langley WWTP was expanded in 1999 by converting a RBC into a TF/SC and adding an activated sludge tank for treating a high industrial waste load and residential load. The two pre-existing convention aeration digesters were left unchanged since the Greater Vancouver Sewerage and Drainage District was at the time not certain as to the final use of the facility. An evaluation of the digesters was undertaken to determine if modifications should be made to upgrade their service to ATAD or other. The recommendations were postponed to collect additional data. In May 2003, the aeration in one tank only was changed from two surface aerators to three Flygt Flo-get submersible aerators and the tanks were operated at side water depths of 4 to 4.5 m. In June 2003, the liquid surface was lowered to a side water depth of about

1.6 m and the temperature increased from 20° to 48°C, and in the summer of 2003 averaged as 44°C.

Considerable foam was generated as seen in the Figures 6 and 7. The digesters are open and uninsulated. Had an insulated roof slab and insulation been applied to the reactors, the temperatures would have operated at thermophilic temperatures. Many facilities have observed similar phenomena and some owners were encouraged to complete a design to control a thermophilic digestion process. The key difficulty in operating these high temperature mesophilic digesters is foam control. The Langley operations staff has the benefit of a large digestion surface and an under loaded process that allows a large freeboard to contain the foam. Foam is dissipated by a pump discharge set on a timer.

The aeration supplied by the two operating Flygt submerged aspirator mixers is air flow of about  $0.83\text{m}^3/\text{m}^3(\text{tank})\text{-hr}$ . Biosolids stability as measured by SOUR is about 0.25 - 0.32  $\text{mgO}_2/\text{hr}$ . Odour is unmistakably ATAD but insignificant. The digestion period of 30 days oxidizes the sludge sufficiently to allow measurement of dissolved oxygen of above 2mg/L for periods each day. Table 4 provides the current operating data.

**TABLE 4**  
**NORTH WEST LANGLEY WWTP AEROBIC DIGESTERS**

Loading, 2003	
Population (design 50,000)	30,000 +/-
Flow	9,000 m <sup>3</sup> /d
BOD <sub>5</sub>	2,590 kg/d
TSS	2,340 kg/d
Major Unit Processes in Plant, 2003	
Primary settling	Fine screening
Trickling Filter and Solids Contact/Activated Sludge	2 + 1
Secondary clarifiers	2 rectangular, folded flow
Waste biological sludge drum thickener	1 + 1
Dewatering and chemical centrate treatment	Lagoon
Odour treatment: nitrifying tower, ozone and wet chemical scrubber	None
Feed Conditions	
Source	Primary and TF Waste Biological
Feed Strategy	Continuous
Normal Feed Rate	16 – 30 m <sup>3</sup> /d
Feed Per Cent	4
Mass Loading	800 kg/d
ATAD Reactors	
Number	1
Material construction	Concrete
Insulation	Open
Dimensions	Rectangular
Active volume (373m <sup>3</sup> /m depth)	600 m <sup>3</sup>
Equipment	
Aspirator mixers (Flygt Flo-get submersible aerator mixers)	2+1 @ 26kW ea
Foam cutters	Pump on timer
Connected power per reactor	78 kW (3)
Performance Factor	
Total detention time	30+/- days
Volumetric loading	0.03 m <sup>3</sup> /m <sup>3</sup> -d
Mass loading	1.3 kg/m <sup>3</sup> -d
Power density	87 W/m <sup>3</sup> used
Specific energy use (2 aerators)	1.56 kW-hr/ kg
Reactor vessel temperatures (1)	44 <sup>0</sup> +/- C
Digestion VS reduction	45-47%



Figure 6 - NW Langley, B.C. WWTP Aerobic Digestion



Figure 7 - NW Langley, B.C. WWTP Pump Foam Reduction on Timer

### Sawgrass WWTP, City of Sunrise, FL

The ATAD reactor has two trains of three vessels each designed for 130,000 people. The first train was started in March 1999 and was operational within the first month of operation. While both trains reportedly operate successfully, it is reported that the recycle pumps have had several failures in bearings and seals, which have caused operational difficulties.

At startup a fluid transient problem in the recirculation piping caused a resonant vibration in the piping system. Adding stiffener supports to the piping has reported to have reduced the

vibration. The motorized valve actuators that are used for automatic tank transfers were however, damaged due to the vibration, and have not been replaced. This has suspended the automatic control that was provided for the ATAD liquid transfers and transfer is now done by hand. The operators reportedly feel they are able to get closer to the control of the system by this hands-on routine. To avoid the vibration failure problem, future design should consider mounting the actuators away from potential vibrating systems. Temperature set points are used to control the digester operation through speed control pot on the variable speed drives of the pumps. The operations staff often turns a recirculation pump off once temperature set points are met.

Struvite formation downstream of the final heat exchanger became a problem but was reduced with the addition of a tri-phosphate compound. The compound is reportedly able to reduce the existing struvite marginally, but is most effective in slowing the formation rate down.

The plant was designed with an open belt filter press and while the product is cooled to the recommended temperature in the third vessel, the foul air from the ATAD product is far too odorous to accommodate in an open dewatering plant area. For this reason the product is taken by tanker truck directly and land spread. Prior to removal the digested product is cooled by recirculation of plant effluent in the third reactor vessel and through a plant effluent to digested biosolids heat spiral exchanger. The heat exchangers must be back flushed daily due to a natural build up in rope like material common to most aeration plants.

Table 5 provides a partial description of the facility. No formal data are available. Figures 7, 8, 9 and 10 are from 1999 records.

The owner reportedly has concerns that the facility cannot be operated to the anticipated design loading with the current method of operation. As of August 2003, no outside audit or inspection has been undertaken to assess the ATAD loading or operation, although the Owner has reportedly undertaken stress testing.

**TABLE 5  
CITY OF SUNRISE FL, SAWGRASS WWTP ATAD**

<b>Loading (2000)</b>	
Population estimated (FL Department of Environmental Protection)	117,000
Flow (FL Department of Environmental Protection)	45,410
BOD <sub>5</sub> (calculated for 114 mg/L BOD <sub>5</sub> )	5200 kg/d
TSS (calculated for 172 mg/L TSS)	7800 kg/d
<b>Major Unit Processes in Plant,</b>	
Primary settling	None
Activated Sludge	8
Secondary clarifiers	8 circular
Dissolved air flotation	2
Belt filter press dewatering (not used)	1; (2 future)
Odour treatment: two stage wet chemical scrubber for ATAD, belt filter press and digested biosolids storage tanks.	20,000sm <sup>3</sup> /hr
<b>Feed Conditions</b>	
Source	Waste Biological
Feed Strategy	Semi -Continuous
Normal Feed Rate two trains (2003 reported)	115 -150 m <sup>3</sup> /d
Feed Per Cent (2003 reported)	6
Mass Loading (calculated)	7000-9000 kg/d
<b>ATAD Reactors</b>	
Number	2 + 1 per train
Material construction	Concrete
Insulation	50mm Dow SM
Dimensions	Rectangular
Active volume, each	430 m <sup>3</sup>
<b>Equipment</b>	
Aspirator mixers (pump-venturi aeration and mixing) Trains A and B, reactors 1, 2 and 3	2 ea@ 37.3 kW (1 & 2), 2ea @ 22.3 kW (3)
Foam cutters (spray and speed control from each pump)	-None used
Connected power per reactor Trains A and B	74.6 kW (1&2), 44.6 kW (3)
<b>Performance Factor</b>	
Total detention time, three reactors per train, assuming reactors 1 and 3 operated half full and reactor 2 is operated full	10-15 days
Batch isolation time	5 – 10 minutes
Volumetric loading total volume	0.06 – 0.08 m <sup>3</sup> /m <sup>3</sup> -d
Mass loading total volume	4 - 5 kg/m <sup>3</sup> -d
Power density	50-200 W/m <sup>3</sup>
Specific energy use	< 1 kW-hr/kg
Reactor vessel temperatures (1, 2 and post-ATAD 3)	48 <sup>0</sup> , 60 <sup>0</sup> , <40 <sup>0</sup> C



Figure 8 - City of Sunrise, Florida, Sawgrass WWTP ATAD



Figure 9 - City of Sunrise, Florida, Sawgrass WWTP ATAD Pump Gallery



Figure 10 - City of Sunrise, Florida, Sawgrass WWTP ATAD Heat Exchanger



Figure 11 - City of Sunrise, Florida, Sawgrass WWTP ATAD Venturi Aerator Nozzles

Avon WWTP and Edwards WWTP, Eagle River Water and Sanitation District, Vail CO

The Avon WWTP and Edwards WWTP ATAD facilities have been useful processes in achieving the biosolids treatment objectives for the Eagle River Water and Sanitation District in terms of the EPA 503 regulations for pasteurization and stabilization. Figure 11 illustrates the ATAD flow diagram for either plant. Figures 12 and 13 show the venturi design at Edwards and the pump gallery at Avon.

Biosolids handling is markedly improved and reuse options have greatly expanded since the ATAD systems were commissioned first in Avon in 1996 and last in Edwards in 2000. Prior to the ATAD process the District hauled aerobically digested sludge at 1000 trucks per year. Once ATAD was commissioned, the truck numbers decreased to less than 200 per year. Composting also improved as seen in Figures 15 and 16. In 1995, the facility process 25,000 yd<sup>3</sup>. In 2003, the annual production is 2000 yd<sup>3</sup>, which is less than 1/10 the volume during a period of high population growth.

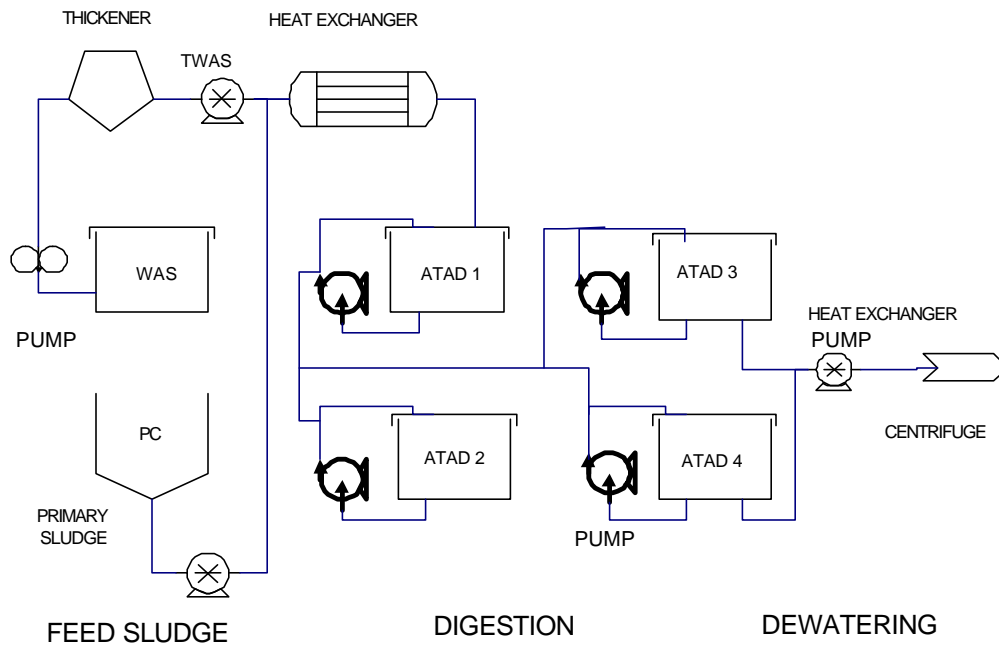


Figure 12 - ATAD System Flow Diagram for Avon and Edwards

The District began to have problems with the ATAD in 2000 to 2002. Investigation into the operation showed that the facilities were not concentrating the primary sludge sufficiently and the reactor vessels were not being used to the allowable volumes. This created low residence times. Foul air was problematic as well. The District has added odour treatment systems to the ATAD systems as well as the other plant facilities and changed out all handling systems to completely cover or enclose the ATAD products. Figure 14 shows the Edward odor treatment system. This has resolved odour issues both inplant and outside of the fence line. The District corrected the thin primary sludge problem by adding magnesium hydroxide. Improved control of the sludge inventory handling has resulted. Process control was concluded as the key to good operation, not a lack of air or tank capacity. This District has the capability of wasting excess sludge from Avon to Edwards. Avon treats both Vail and Avon (Beaver Creek) sludge flows.

**TABLE 6**  
**EAGLE RIVER WATER AND SANITATION DISTRICT, AVON-VAIL AND**  
**EDWARDS WWTPS ATADS**

	AVON-VAIL	EDWARDS
<b>Loading 2001 Audit</b>		
Population (calculated assuming 350 Lcpd)	26,000	10,000
Flow	9100 m <sup>3</sup> /d	3500 m <sup>3</sup> /d
BOD <sub>5</sub>	2080 kg/d	800 kg/d
TSS	2080 kg/d	800 kg/d
<b>Major Unit Processes in Plant, 2003</b>		
Primary settling	2	2
Activated Sludge		
Secondary clarifiers	2	
Waste biological thickener	1+ 1 gravity belt	1+ 1 sludge drum
WAS storage tanks	2 (219 m <sup>3</sup> ea)	1
Centrifuge dewatering and chemical centrate treatment	1 + 1	1 + 1
Odour treatment: nitrifying tower, ozone and wet chemical scrubber	2200 sm <sup>3</sup> /hr	1400 sm <sup>3</sup> /hr
<b>Feed Conditions</b>		
Source	Primary and Waste Biological	Primary and Waste Biological
Feed Strategy	Semi-Continuous	Semi-Continuous
Normal Feed Rate Peak Week calculated	144	67
Feed Per Cent proposed	5	5
Mass Loading Peak Week	7200 kg/d	3330 kg/d
<b>ATAD Reactors</b>		
Number	3 + 1	3 + 1
Material construction	Concrete	Concrete
Insulation	100mm Dow SM	100mm Dow SM
Dimensions	Rectangular	Rectangular
Active volume	304 m <sup>3</sup> ea	138 m <sup>3</sup> ea
<b>Equipment</b>		
Aspirator mixers (pump-venturi aeration and mixing), Pre-ATAD, ATAD and Post ATAD reactors.	2ea@56kW (1&2), 2ea @ 30 kW (3&4)	2ea @ 30kW (1,2,3&4)
Foam cutters (spray and speed control from each pump)	-	-
Connected power per reactor	112kW (1&2) 60kW (3&4)	60 kW (1,2,3&4)
<b>Performance Factor</b>		
Total detention time Peak Week (three reactors)	6.3 days	6 days
Batch isolation time transfer	5-10 minutes	5-10 minutes
Volumetric loading Peak Week (three reactors)	0.16 m <sup>3</sup> /m <sup>3</sup> -d	0.16 m <sup>3</sup> /m <sup>3</sup> -d
Mass loading (three reactors)	7.9 kg/m <sup>3</sup> -d	8.0 kg/m <sup>3</sup> -d
Power density	100-360 W/m <sup>3</sup>	100-400W/m <sup>3</sup>
Specific energy use	0.5-1 kW-hr/kg	0.5-1.5 kW-hr/kg
Reactor vessel temperatures (1, 2, 3, 4)	45, 60, 60, 55 <sup>0</sup> C	Average 50 <sup>0</sup> C all vessels, Maximum 55-60 <sup>0</sup> C
<b>Product conditioning</b>		
Recommended flocculant and polymer combination	15kg/dt polymer	Not available
Product	>30% ds cake	>30% ds cake



Figure 13 – Edwards, CO, WWTP ATAD Venturi Aerator Nozzle Mixer



Figure 14 – Avon, CO, WWTP ATAD Pump Gallery



Figure 15 – Edwards, CO, Odor Control, NTF, Ozone Wet Chemical Scrubber



Figure 16 - ERWSD Vail, CO, Compost Operation, October 1994



Figure 17 - ERWSD Vail, CO, Compost Operation, May 2003

Whistler WWTP, Resort Municipality of Whistler, B.C., Canada

Whistler WWTP ATAD was built in 1989-90 following a separate investigation of three demonstration facilities as reported by Kelly (1990) and Kelly et al. (1993). The venturi-pump option was selected over aspirator air aeration and mixing technology primarily due to the winter conditions and need to keep operating equipment in an enclosed area. The Whistler ATAD was designed for peak week winter resort loads, which in 1999 surpassed the facility design loading capacity. While pasteurization is secured, the volatile solids reduction is not always achieved in peak week conditions and has varied from 30 to 50%. Recent investigation has shown that incipient concrete corrosion is taking place in the first reactor. This is probably the result of high sulfide concentration. Protective coatings should likely have been applied to the concrete at the time of construction.

Table 7 provides an illustration of the peak week loading at the time of the 2000 audit for 1999 flows and loads. Figure 17 shows a winter photograph of the facility with the primary and secondary digesters shown in the foreground.

**TABLE 7**  
**RESORT MUNICIPALITY OF WHISTLER, B.C., CANADA WWTP ATAD**

Loading 1999	
Population average day load	45,000
Flow average annual	11,000m <sup>3</sup> /d
BOD <sub>5</sub> average day	2150 kg/d
TSS average day	2000 kg/d
Major Unit Processes in Plant, 2003	
Primary settling	3 used +1
Trickling Filter – Solids Contact and iron salts for phosphorus removal	1 TF, 2 SC
Secondary clarifiers	2 small + 1 large
Rotating drum thickener	Future
Belt filter press dewatering	1; (2 future)
Odour treatment: biological wet scrubber	2000 sm <sup>3</sup> /hr
Feed Conditions	
Source	Primary and Waste Biological
Feed Strategy	Semi-Continuous
Normal Feed Rate Peak Week	80 m <sup>3</sup> /d
Feed Per Cent	5
Mass Loading Peak Week	4435 kg/d
ATAD Reactors	
Number	2 + 2
Material construction	Concrete
Insulation	100mm Dow SM
Dimensions	Cylindrical, 7m diameter
Active volume	115 m <sup>3</sup> ea
Equipment	
Aspirator mixers (pump-venturi aeration and mixing) per reactor vessel	2 ea@ 22kW
Foam cutters (spray and speed control from each pump)	-
Connected power per reactor	44kW
Performance Factor	
Total detention time (Assumes 3 reactor vessels fully operating)	4.3-5 days
Batch isolation time	15 minutes
Volumetric loading peak week (three reactor vessels)	0.23 m <sup>3</sup> /m <sup>3</sup> -d
Mass loading peak week (three reactor vessels)	12.8kg/m <sup>3</sup> -d
Power density	150-389 W/m <sup>3</sup>
Specific energy use	0.7 -0.95 kW-hr/kg
Reactor vessel temperatures (1, 2, 3, 4)	50, >60,>60 45 <sup>0</sup> C
Product conditioning	
Proprietary as flocculant	7 - 10kg/dt
Cationic Polymer	2 - 6 kg/dt
Belt Filter press dewatering	25-29% cake



Figure 18 - Resort Municipality of Whistler WWTP ATAD Venturi-Pump

Douglas County, Wenatchee, WA

The reactor is a three-vessel FUCHS ATAD design that additionally incorporates pre-existing anaerobic digesters as pre and post storage tanks. The foul air is collected from the three ATAD reactors and storage tanks, and is then treated in a parallel wet scrubber and soil-bark filter combination. The ATAD reactors operate at pasteurizing temperatures and currently handle flows of 19 to 30.4 m<sup>3</sup>/d (5000 to 8000 gallons per day) of 4% dry solids feed. Volatile reduction is better than 50 - 60%. At the present time, two reactors are needed only. The HRT is 14 to 22 days and the degree-day product is over 1000.

The FUCHS design requires a daily transfer of biosolids from the reactors to the post holding tank, then liquid level balancing and finally a transfer of fresh biosolids from the pre- holding tank (blend tank) to the first reactor. The transfer requires about 1 hour per day.

Once the biosolids are digested, they are dewatered in a Andritz centrifuge to 23 - 30% dry cake. The cake is deposited in an open truck and spread on farmland.

The ATAD plant had an initial odour problem but since replacing the soil biofilter with a mixture of wood chips and compost media, the problem has not resurfaced.

Table 8 provides a summary of the plant operation. Figures 18 and 19 illustrate the reactors and odor treatment soil biofilter.

**TABLE 8  
DOUGLAS COUNTY WWTP, ATAD**

<b>Loading</b>	
Population	14,000
Flow	5700m <sup>3</sup> /d
BOD <sub>5</sub>	1000 kg/d
TSS	1000 kg/d
<b>Major Unit Processes in Plant, 2001</b>	
Primary settling	1 + 1
Activated Sludge	2 + 1
Secondary clarifiers and UV disinfection	2
Blend tank	1
Disgested biosolids holding tank	1
Andritz centrifuges for thickening and dewatering	1 + 1
ATAD Odour treatment: two each single stage wet scrubbers and soil biofilters (blend of wood chips and compost)	3700sm <sup>3</sup> /hr
<b>Feed Conditions</b>	
Source	Primary and Waste Biological
Feed Strategy	Series, batch
Normal Feed Rate	19 - 30.4 m <sup>3</sup> /d
Feed Per Cent	4 %
Mass Loading	760-1220 kg/d
<b>ATAD Reactors</b>	
Number	3 (2 used)
Material construction	Steel
Insulation	Yes
Dimensions	Cylindrical 8.7 m dia x 3.7m SWD
Active volume	217 m <sup>3</sup> ea
<b>Equipment</b>	
Aspirator mixers ( Fuchs Spiral aerators side mounted, central Circulation aerator)	3 ea @9kW + 1@5.5kW
Foam cutters (Fuchs surface mounted)	8 ea @2.2kW
Connected power per reactor	50.4kW
<b>Performance Factor</b>	
Total detention time (2 vessels)	14 – 22 days
Batch isolation time	23 hours
Volumetric loading (2 vessels)	0.05 m <sup>3</sup> /m <sup>3</sup> -d
Mass loading (2 vessels)	2.3 kg/m <sup>3</sup> -d
Power density, each	232 W/m <sup>3</sup>
Specific energy use (kW-hr/kg dry solids processed)	1.21
Reactor vessel temperatures (1, 2)	57 <sup>0</sup> , 64 <sup>0</sup> C
<b>Product conditioning</b>	
Cooling in 7.6 m diameter by 6 m high storage tank	7days
Centrifuge dewatering Andritz	23-30%ccake
Cationic polymer	4kg/dt
Flocculant (proprietary)	8 kg/dt



Figure 19 - Douglas County WWTP, ATAD Digesters in left background, pre and post holding tanks in center-right background.



Figure 20 - Douglas County WWTP Odor Collection and Treatment using water scrubber and soil-bark filter bed.

## RESEARCH

The Canadian Government (NSERC) and Dayton & Knight, Ltd., Vancouver have sponsored most of this research. Don Mavinic (UBC) and Harlan Kelly (Dayton & Knight, Ltd. and Adjunct Professor, UBC) have directed supervision. Most of this research and development has taken place at the UBC BNR-ATAD Research Pilot Plant Facility with the exception of the work by Ms. Cross, which was undertaken at the Department of Bio-Resource Engineering under Dr. Anthony Lau. Dr. Lionel Coulthard who first introduced the process in 1976 with Dr. Philip Townsley of the Bio-Resource Engineering Department, Vancouver, B.C. and with the Capital Regional District, Victoria B.C. in a 1981–1982 pilot test in Sidney, B.C. had participated in several early patents on a thermophilic aerobic process (Coulthard, 1976).

The UBC research accept for Zhou has been largely focused on use of ATAD for production of short chain volatile fatty acids for biological nutrient removal. Zhou's work is focused on improving dewaterability of the thermophilic digested product.

### Key Findings From UBC's ATAD Research

#### **Chu (1995)**

1. A degree-day product of about 300° C-day produced a minimum 30% TSS reduction, in a 6 day HRT (SRT), 2 stage ATAD digester.
2. Microaerophilic (oxygen-deprived) conditions for airflow of only 0.126 v/v/h produced the highest VFA concentration, at about 950 mg/L; increasing the airflow rate to 0.28 v/v/h produced only about 80 mg/L of VFA; and a truly aerobic airflow of 0.6 v/v/h produced negligible VFA. Under all aerobic conditions, acetate constituted about 80% of the VFA produced.
3. VFA production was directly proportional to the degree of aeration (airflow rate), and could be manipulated accordingly, depending on the desired concentration of VFA for subsequent use in an anaerobic digester or EBPR process.
4. A successful "biochemical model" was developed to explain the mechanism of VFA metabolism in an ATAD process.
5. ATAD digestion of only primary sludge clearly showed that carbohydrates and proteins were the major macromolecular substrates responsible for VFA accumulation in the digester. Lipid levels were insignificant.

#### **Cross (1995)**

1. The digestion system was found to be excellent for solids and COD destruction. The transformations of phosphorus in the system are very complicated.

2. "Bio-P" sludge (containing phosphorus accumulating organisms), high in phosphorus above 5% dry weight, reacted differently to high aeration rate and low aeration rate digestion.
3. High aeration rate conditions accumulated phosphorus in the mass in the first digester and released phosphorus to the liquid bulk in the second digester but maintained a lower overall soluble concentration compared to the low aeration rate digester.
4. Low aeration rate conditions caused an overall release of about 10% of the phosphorus from the solid portion to the liquid portion of the sludge.
5. Total nitrogen decreased in the system generally and the liquid phase nitrogen content increased. The largest overall decrease occurred in a 48-hour experiment at high aeration rate. The largest liquid phase increase occurred in a 24-hour experiment at the low aeration rate.
6. To minimize release of phosphorus from the solid to the liquid phase, the dissolved oxygen concentration should be about 1.5-2.0 mg/L.

#### **Boulanger (1995)**

1. Co-digestion of P-rich BNR sludge and primary sludge resulted in 46-79% P release back to the supernatant, depending on the extent of aerobic vs. anoxic time frame during feeding.
2. Under oxygen-deprived (microaerophilic conditions), ATAD supernatant total N was the highest; some NO<sub>x</sub> formation occurred under oxygen excess conditions.
3. There was no difference in TVSS destruction between oxygen-deprived and oxygen-excess operation. The same result was achieved with COD reduction.
4. Oxygen-deprived operation produced higher levels of dissolved volatile solids, dissolved COD and VFA in the supernatant, than oxygen-excess conditions; this was attributed to an increase in solubilization under ATAD operating conditions.
5. ORP on-line monitoring proved to be a reliable indicator of the aeration state of the ATAD digester.

#### **Fothergill (1996)**

1. Mixtures of primary and secondary sludge were successfully digested in a single-stage, 3 day HRT (SRT) ATAD digester. The addition of secondary sludge significantly enhanced VFA production, under all conditions. Secondary sludge alone produced the highest VFA concentrations, ranging from 600-900 mg/L.
2. Regardless of primary/secondary sludge ratios, acetate constituted greater than 85% of total VFAs, with no proportional feed speciation.

3. Considerable stored phosphorus and ammonia was re-released into the supernatant, under all operating conditions. Nitrification was fully inhibited at the elevated temperatures.
4. ATAD was suggested as a pre-treatment step to mesophilic anaerobic digestion, due to the high VFA production potential, specifically acetate.

### **Sharma (1999)**

1. Employing a single-stage ATAD digester; operating under microaerophilic (oxygen-deprived) conditions and a primary/secondary sludge ratio of 35: 65, resulted in a 20-24% TSS destruction efficiency and a maximum VFA concentration of about 500 mg/L, mostly acetate.
2. VFA production was calculated to range from 0.009-0.183 mg VFA generated/mg TSS destroyed, depending on airflow rates.
3. P release was calculated to be from 0.018 to 0.0312 mg P/mg TSS destroyed, with the maximum measured with little or no air supplied.
4. “Optimum” VFA/PO<sub>4</sub> was found to be about 8.2, at an air supply rate to the ATAD equal to 25 mL per min. (microaerophilic conditions).
5. VSS destruction efficiency was independent of airflow rates, in the range of 0 – 100 mL/min.

### **Li (2001)**

1. Both batch and continuous feeding of ATAD supernatant (from a microaerophilic operation) were provided to BNR anaerobic and anoxic zones, as carbon supplement for phosphorus and nitrogen removal. Results clearly showed that ATAD supernatant (with high VFAs) was capable of enhancing P release and denitrification both, similar to sodium acetate.
2. Carbon sources, other than VFAs, were also identified in ATAD supernatant; these were also utilized successfully in the BNR process train. It was found, however, that ATAD supernatant should be applied to the BNR process as soon as possible after generation (e.g. after sludge dewatering), to minimize the loss in VFAs due to storage.
3. Under all tested conditions, there was also an increase in total N and P in the ATAD supernatant; this suggested that an “optimization scheme” may be necessary for ATAD operation, to maximize the beneficial use of available carbon, but minimize the extra nutrient load on the follow-up BNR system.
4. A molecular weight cut-off (MWCO) procedure was successfully used to analyze the carbonaceous and nutrient distribution in the ATAD supernatant.
5. Real-time aeration control is necessary to control the microaeration (oxygen-deprived) operation and optimize VFA production. ORP monitoring did correlate well to the status of

microaerophilic aeration, but did not correlate well to the actual concentration of VFAs in the digester, just confirmation of their existence.

6. Approximately 30% VSS destruction was achieved at an HRT of 7 days, at 50-60° C. VFA concentration (as high as 2600 mg/L) was found to be proportional to the feed sludge solids concentration, ranging from 0.60-2.67%. An “over-aerated mode” of operation did not enhance solids destruction efficiency.
7. A “headspace CO<sub>2</sub> monitoring method” was developed in this work and tested successfully – it was used to estimate the overall available carbon source, or VFA equivalent in the ATAD supernatant for subsequent BNR application.

### **Zhou (2003)**

1. Bench-scale reactors, operating at 22°C and 60°C, and digesting primary, secondary and mixtures of both sludges, were operated for up to 30 days. Thermophilic aerobic digestion significantly improved the sludge cake dryness but markedly increased conditioning chemical requirements (as measured by specific capillary suction time, SCST) of the secondary sludge, and to lesser extent with the mixed sludge and lesser again with primary sludge. With continued digestion, mesophilic aerobic digestion showed a gradual, but continual, deterioration in the dewaterability as measured by SCST of all sludge combinations.
2. Sludge retention time had little or no influence on thermophilic digested sludge dewaterability, but did influence mesophilic aerobic digestion dewaterability.
3. Thermophilic digestion resulted in a rapid deterioration in dewaterability of the secondary sludge, resulting in a rapid increase in soluble protein, polysaccharides and phosphate.
4. Mesophilic digestion of the different sludges showed a strong correlation between poor dewaterability and soluble protein and polysaccharides only.
5. Thermophilic digestion continuously produced smaller and finer biofloc solids resulting in increased surface area, than mesophilic digestion, perhaps a key marker in increased demand for the conditioning polymer.
6. Secondary sludges were digested at 22°C, 40°C, 50°C, 60°C and 70°C for up to 12 days. It was found that, during the first few hours of digestion, the higher temperatures resulted in more rapid and more significant deterioration in dewaterability, than the lower temperatures but that as digestion continued the dewaterability became similar as measured by SCST such that continued digestion resulted in improved (60° and 70°C), unchanged (40° and 50°C) and gradually deteriorating dewaterability (22°C).
7. Substances affecting dewaterability were primarily located in the liquid phase of thermophilically digested solids, not the solid phase. Protease treatment of the thermophilic biosolids improved dewaterability by 13-19%, confirming the role of protein removal in

improving dewaterability. Boiling treatment produced no significant changes. A drop in pH of the digested sludge did improve dewaterability. Divalent cation concentration did not show an influence on dewaterability. Soluble protein and soluble polysaccharide increased in concentration in the liquid bulk as temperature increased to a maximum concentration at about 55° to 60°C and then dropped rapidly in concentration at 70°C. (More work needs to be undertaken at elevated temperatures above 70°C.)

8. Mechanical shear, applied to the digested sludge, had a significant effect on dewaterability as measured by SCST, on both types of aerobically digested sludge; in most cases, the effect was more pronounced than that of actual digestion temperature. Mechanical shear produced a decrease in floc charge and floc size, which contributed to deterioration in sludge dewaterability.

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## **APPENDIX 1**

<b>Plant:</b>			
Location:	<b>1. Surprise, Arizona</b>	<b>2. Princeton, Indiana</b>	<b>3. Gibsons, BC</b>
Contact:	Mr. Jim Swanson	Mr. Charles Woodruss	Mr. Greg Foss
Phone:	(623) 583-1000	(812) 385-3343	(604) 681-8035
Designer:	Kruger, Inc.	Kruger, Inc.	Dayton & Knight
<b>Liquid Treatment Process:</b>			
Daily Flow:	3.2 mad (12.000m <sup>3</sup> /d)	2 mad - 30% from Toyota plant (7.500m <sup>3</sup> /d)	1,200 m <sup>3</sup> /d
Service Population:	60,000	8,400	4,500
Treatment:	Oxidation ditches, clarifiers, tertiary filter	Oxidation ditches	Secondary treatment
<b>Pre-ATAD Process:</b>			
Length of Operation:	Since 1996	6th year	Since 1989
Digester Feed:	Secondary	Secondary	Primary & Secondary (Trickling filter)
Influent Solids:	TSS: 267	4%-5%	2% - 3%
Thickening:	Belt thicken with chemical process	Gravity belt	No
Heat exchange:	No	No	No
<b>ATAD Operation:</b>			
No. of Tanks:	2	2	2
Sizes:	100,000gal (375m <sup>3</sup> )	20,000gal (75m <sup>3</sup> )	25,000gal (95m <sup>3</sup> )
Operation:	Batch	2 Stage	Batch, thickening after, waste back to P.C.
Temperatures:	Avg. 50°C	50°C - 60°C	Avg. 70°C
Retention time:	1.5 Days	7 - 10 Days	7 days
Method of mixing:	Circulated with pumps	Spiroaerators	2-10hp mixers, 2-25hp pumps for circulation
Air application:	Air compressor at bottom	Air compressor at bottom	Air induced venturis
VS Reduction:	MLVS Avg: 2200	>38%	
<b>Post-ATAD Process:</b>			
Biosolids cooling:	No	2 cooling tanks	In the thickener tank
Dewatering:	Centrifuge	Sludge press	None
Applications:	Fertilizer plant, farmers for land applications	To farmer with permit. Mixed and land applied.	Liquid form hauled away for land dispersal

<b>Plant:</b>			
Location:	<b>4. Gig Harbour, Washington **</b>	<b>5. Titusville, Florida (Blue Heron Plant)</b>	<b>6. Paris, Texas</b>
Contact:	Mr. John Wilson	Mr. Matt Hixson	Mr. JP Hinkle
Phone:	(206) 284-0860	(321) 383-5642	(903) 785-6376
Designer:	Dayton & Knight	Kruger, Inc.	Kruger, Inc.
<b>Liquid Treatment Process:</b>			
Daily Flow:		Ann Avg. 1.9 mgd (7,200m <sup>3</sup> /d), Cap. 4 mgd (15,000m <sup>3</sup> /d)	4.28 mgd (16,000m <sup>3</sup> /d)
Service Population:		25,000	30,000 but Eq Pop. is 50,000
Treatment:		A2O, Secondary Anoxic, 5 stage process	Activated sludge
<b>Pre-ATAD Process:</b>			
Length of Operation:		Since 5/1996	5.5 years
Digester Feed:		Secondary	Secondary
Influent Solids:		5.50%	4-6%
Thickening:		Rotary drum	Sieve drum concentrator with Drum thickener
Heat exchange:		No	No
<b>ATAD Operation:</b>			
No. of Tanks:		2	3
Sizes:		62,000gal (240m <sup>3</sup> )	30,000gal (115m <sup>3</sup> )
Operation:		Series	Series
Temperatures:		Avg. 65°C	#1-30°C #2-45°C #3-55-60°C
Retention time:		22 Days	8 Days
Method of mixing:		Centriaerators in the middle, Spiroaerators on sides, Foam cutters on top	2 spiroaerators, 1 centriaerator
Air application:			
VS Reduction:		Unknown	38%
<b>Post-ATAD Process:</b>			
Biosolids cooling:		No	Yes. Holding/cooling tank
Dewatering:		No	No, though sometimes use drying beds when it can't be sprayed
Applications:		Haul it out liquid for land application	Overland sprayed

\*\* Not operating, off-line for over a year.

<b>Plant:</b>			
Location:	<b>7. Lakefield, Minnesota</b>	<b>8. Waseca, Minnesota</b>	<b>9. Ephrata, Pennsylvania (WWTF #2)</b>
Contact:	Mr. Harold Loaps	Mr. Gary Bennett	Mr. Jay Snyder
Phone:	(507) 662-5920	(507) 835-2833	(717) 738-9282
Designer:	Kruger, Inc.	Kruger, Inc.	Kruger, Inc.
<b>Liquid Treatment Process:</b>			
Daily Flow:	0.6 mgd (2,250m <sup>3</sup> /d)	1.2 mgd (4,500m <sup>3</sup> /d)	Design: Ann Avg: 2.3mgd (8,700m <sup>3</sup> /d) Peak Mon: 3.5mgd (13,250m <sup>3</sup> /d) Current: Ann Avg: 1.3mgd (5,000m <sup>3</sup> /d)
Service Population:	1,800	9,600	
Treatment:	Oxidation ditch, clarifier	Lift station, grit chamber, extended aeration	Prelim, oxidation ditch, activated sludge, clarifiers
<b>Pre-ATAD Process:</b>			
Length of Operation:	Since March 1997	Since 1996	Nov-97
Digester Feed:	Secondary	Secondary	Secondary
Influent Solids:	0.75%	2%	
Thickening:	Rotary Drum with polymer to 4%	Drum thickener with polymer	Rotary Drum to 3-5%
Heat exchange:	During winter add heat with hot water through coils on the ATAD system	Low pressure boiler in the ATAD	No
<b>ATAD Operation:</b>			
No. of Tanks:	2 - only 1 used as reactor other for storage	3. approx. 50°C. 60°C. 65-68°C	3
Sizes:		18ft wide, 12ft high (5.5m wide, 3.7m high)	42,000gal (160m <sup>3</sup> )
Operation:		Series	Batch
Temperatures:	55°C		+/-50°C using 503 time temp. for compliance
Retention time:	24 hours (once the tank temp reaches 55°C)		8 Days
Method of mixing:	Mixer in the tank and aerator	2 Spiroaerators, 1 centriaerator	Spiral aerators
Air application:			
VS Reduction:			+/-45%
<b>Post-ATAD Process:</b>			
Biosolids cooling:	No	No, just holding tank	No. Holding tank
Dewatering:	No	No	Belt Filter process, stored on an open pad
Applications:	Large underground storage tank, land applied twice a year	Applied on state approved and regulated land	Farm land applications

<b>Plant:</b>			
	<b>10. Franklin, Indiana **</b>	<b>11. College Station, Texas</b>	<b>12. Grande Prairie, Alberta</b>
Location:	10. Franklin, Indiana **	11. College Station, Texas	12. Grande Prairie, Alberta
Contact:	Mr. Rick Littleton, Superintendent	Mr. Fred Serovic	Mr. Lynne Coulter
Phone:	(317) 736-3640	(979) 764-3665	(780) 532-3996
Designer:	Kruger, Inc.	CDM, Inc.	
<b>Liquid Treatment Process:</b>			
Daily Flow:		15,600 m <sup>3</sup> /d (calculated)	15 ML/Day (15,000m <sup>3</sup> /d)
Service Population:		52,000	40,000+
Treatment:		Activated sludge, no primary	Prelim, 2 Primary Clarifiers, Activated Sludge
<b>Pre-ATAD Process:</b>			
Length of Operation:		+/- 5 yrs	Since 2000
Digester Feed:		Secondary	Scum + Secondary
Influent Solids:		4-5%	4-4.5%
Thickening:		Gravity and Drum	No
Heat exchange:		No	No
<b>ATAD Operation:</b>			
No. of Tanks:		3	3
Sizes:		190 m <sup>3</sup>	7m high, 10m diameter
Operation:		Fuchs, series - semi-batch	Series
Temperatures:		> 55°C	1-high 30°Cs. 2-50°C. 3-60°C
Retention time:		7-8 days total	1.5 Days
Method of mixing:		3 spiral aerators, 1 central circulation	US Filter Jet, Blowers and pumps outside tank,
Air application:			
VS Reduction:		> 50%	35-40%
<b>Post-ATAD Process:</b>			
Biosolids cooling:		No	No
Dewatering:		Centrifuge (1) - Sharples and Alum	Centrifuge
Applications:		Agricultural use, studying other solutions	Landfill used as cover, stopped using for land

\*\* ATAD currently bypassed. Treatment plant was upgraded. ATAD upgrade likely part of the next phase.