VERTAD™ – AUTO-THERMOPHILIC AEROBIC DIGESTION USING A SUB-SURFACE VERTICAL TREATMENT PROCESS
DEMONSTRATION-SCALE TEST RESULTS

ABSTRACT

VERTAD™ is an auto-thermophilic aerobic digestion process, employing an in-ground vertical reactor to aerobically digest mixed primary and secondary wastewater treatment solids. The process occupies a minimal footprint, 20-30% that of a conventional ATAD process, and is suitable for retrofits or sites where visual and odour impacts are of concern.

High oxygen transfer efficiencies result in reduced energy costs, increased rates of volatile solids destruction in shorter periods of time and less off-gas to be treated in a biofilter.

This paper describes a demonstration plant constructed at the South Treatment Plant in Seattle. The reactor depth was 107m with a diameter of 0.5m and treated sludge from a population equivalent of 5,000.

Class A Biosolids were produced with a 4-day detention time at 60°C, the reactor achieved greater than 40% volatile solids destruction. Treated biosolids were float thickened to 8-12% solids and dewatered to 30% with relatively low polymer doses.

KEY WORDS

ATAD, Class A Biosolids, Deep Shaft, Sludge, Vertical Treatment.

by

Jeff Guild, NORAM Engineering and Constructors Ltd.*
Paul O'Callaghan, Atkins**.
Mike Boyle, King County Wastewater Treatment Division
Larry Sasser, E&A Environmental Consultants, Inc.
Dave Pollock, NORAM Engineering and Constructors Ltd.

* NORAM Engineering and Constructors Ltd.
Suite 400 – 200 Granville Street
Vancouver, BC, Canada, V6C 1S4
Phone: +1 604-681-2030, Fax: 604-683-9164
Email: jguild@noram-eng.com

** *Atkins, Villa Franca, Douglas Rd. Cork, Ireland.*
Phone : + 353 21 4290300
E-mail: paul.ocallaghan@atkinsglobal.com

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INTRODUCTION

Noram Engineering currently holds a number of patents for two vertical treatment processes, VERTREAT™, a wastewater treatment process and VERTAD™, an auto-thermophilic sludge digestion process. Both of these technologies are based on the deep shaft process developed in the early 1970's by ICI. This paper discusses a VERTAD™ demonstration plant constructed at the King County WWTP in Renton, Washington, USA.

PROCESS OVERVIEW

Deep shaft or vertical treatment processes employ in-ground vertical reactors in place of the large above ground tankage used in conventional treatment processes. A VERTAD™ process flow diagram is shown in Figure 1. The in-ground reactor reduces the visual impact, provides savings in land costs and makes odour control and containment easier. The cross-sectional area of a reactor is generally less than $7m^2$ and can be economically enclosed with the off-gas treated in a biofilter.

Reactors are typically 100m in depth and as large as 3 m in diameter. Conventional drilling techniques are used to drill a shaft, into which the reactor, which consists of a ¾" steel tube, is lowered in sections and grouted into place.

High oxygen transfer efficiencies are achievable in vertical treatment systems for two reasons:

1) Air is introduced at depth under pressure. The solubility of gases increases with increasing pressure so at the base of the reactor the theoretical solubility of oxygen is approximately 90mg/l.
2) Bubbles travel 100m upwards in the reactor before they reach the surface. The residence time of bubbles in the reactor is therefore 15-20 times what it would be in a conventional system.

The high oxygen transfer efficiency has a number of process advantages. Firstly it reduces energy costs and secondly it reduces the total volume of off-gas generated.

Air is introduced at the base of the reactor and serves three functions:

1) Meets the oxygen demand;
2) Circulates the contents of the reactor and creates a high energy mixing environment;
3) Float separates and thickens solids.

Liquor extracted from the base of the reactor is transferred to a float-thickening tank, here gases which were dissolved under pressure come out of solution, separating and float thickening the treated solids.

There are currently over 200 vertical treatment plants in operation world wide treating wastewater. The majority of these are in Japan where high land and energy costs were strong driving forces towards vertical treatment systems. Improvements in process design over the last 10 years have led to the use of shallower reactors which has resulted in reductions in drilling and installation costs. Vertical treatment systems are now competitive on Net Present Value analysis with alternative technologies, even in the absence of specific drivers such as limited land availability.

Typical reactor depths are 100m with a diameter of 1 to 3m.

DEMONSTRATION PLANT

The demonstration plant discussed in this paper was constructed at the South Treatment Plant in Seattle, Washington and is 107m deep with a diameter of 0.5m. A process flow diagram for the demonstration facility is shown in Figure 2. The reactor depth was 107m with a diameter of 0.5m and treated sludge from a population equivalent of 5,000. A summary of the design parameters for the demonstration facility is provided in Table 1.

Figure 3 is a photograph of the demonstration facility, as can be seen, the below ground nature of the system results in minimal infrastructure above ground.

METHODOLOGY

The testing program was designed to meet the goals of the King County research program to evaluate the viability of the technology with respect to reactor hydraulics, energy requirements, product quality and the ability to meet the vector attraction reduction and pathogen destruction requirements for Class A Biosolids. An additional goal was to develop the design criteria necessary for full-scale design and cost evaluation. Detailed methodology is not included in this paper due to limitations on space but is available on request.

RESULTS

VOLATILE SOLIDS DESTRUCTION

A summary of the digestion performance is presented in Table 2. The effect of solids residence time on VS reduction was demonstrated by the testing. Greater than 40% VS reduction was demonstrated at a 4-day SRT. This efficiency appears to decrease approximately linearly as the residence time is reduced. In testing at a 2-day SRT and 67°C, a 21% VS reduction was demonstrated.

The requirements for Class A Biosolids were met at an average detention time of 4-days at 60°C. As shown in Table 2, the system readily achieved greater than 40% volatile solids destruction at varied detention times and temperatures. In order to satisfy the volatile solids destruction criteria of 38% (U.S. EPA, 1990) in conventional ATADs, Kelly et al. (1993) suggested a 400°C-day product was necessary. The VERTAD™ results indicate that a 240°C-day product exceed the EPA requirements, with greater than 40% volatile solids destruction.

PATHOGEN DESTRUCTION

Pathogen destruction was excellent with a 7-log reduction in fecal coliform and both fecal coliform and salmonella below detection limits in the Class A Biosolids product. Fecal coliform and salmonella were measured in the feed solids and digested VERTAD™ product weekly during the first operating period and intermittently during the third operating period. Fecal coliform in the feed solids averaged 5.39E+07 MPN/g dry solids and salmonella averaged 5.87 MPN/4 g dry solids. Densities in the VERTAD™ product were consistently below the detection limit (fecal coliform: 5 MPN/g, salmonella: 1.6 MPN/4g).

REACTOR MIXING

Salt tracer studies were carried out to determine the reactors compliance with the US EPA time-temperature requirements for attaining Class A pathogen control (40 CFR 503). A pulse of saline was pumped into the reactor quickly with enough salt for a 10-fold increase in reactor conductivity. Samples were taken at regular intervals from four points in the system: the head tank (surface), 213 feet below grade surface (bgs), 268.5 feet bgs, and the deep extraction line.

The results of this tracer study are presented in Figure 4.

The mixing test clearly indicates that the salt tracer did not reach the deep extraction point until approximately 4 hours had elapsed. The theoretical time for breakthrough (based on the 2 gpm extraction rate and the soak zone volume for plug flow) is 4 hours 20 minutes. The study therefore demonstrates that short-circuiting is not occurring in the reactor soak zone and that the process meets the time temperature requirements for solids less than 7%. To our knowledge, this is the first continuous feed, single reactor design that complies with the EPA time-temperature regulations.

These studies verify the plug flow nature of the soak zone and eliminate concerns about short-circuiting in the system.

FLOTATION THICKENING

Tests on the treated biosolids extracted from the soak zone indicated that it was possible to float thicken the 3.5% total solids (ts) product. Tests were carried out to determine the effect of lowering the pH on floatation thickening. The effluent was acidified with sulphuric acid to approximately pH 5, at this pH dissolved carbon dioxide is released as small bubbles which attach to biosolids particles and float them to a compact blanket. With acidification to pH 5 it was possible to float thicken to between 8% and 12% total solids with a capture efficiency of approximately 95%. Similar results were obtained using alum to acidify the biosolid.

PRODUCT DEWATERABILITY

De-watering tests were carried out on-site using a press method and off-site by Andrtiz and Ciba using benchscale centrifuges. Three different types of sludge were tested for product dewaterability: 1) Sludge from the on-site Mesophillic Anaerobic Digester, 2) Biosolids extracted directly from the VERTAD™ and 3) Biosolids from the VERTAD™ which had been acid float-thickened.

The results are presented in Table 3 and Figure 5. Using the on-site press it was possible to de-water the anaerobically digested sludge to 20% ds, while the VERTAD™ and Acid Float Thickened VERTAD™ de-watered to 30% ds. The filtrate quality in the acid float thickened VERTAD™ product was far superior to the filtrate quality in the VERTAD™ product extracted directly from the bioreactor.

In the bench-scale centrifuge tests the anaerobically digested product was de-watered to 12-14% dry solids, while both the VERTAD™ and Acid Float-Thickened VERTAD™ was dewatered to 30% ds (Figure 5). The polymer dose required for the Acid Float Thickened VERTAD™ biosolids was almost a third of the polymer dose required to de-water the straight VERTAD™ product. The solids capture efficiency was 95-96% for the anaerobically digested biosolids and VERTAD™ biosolids and 99.5% for the Acid Float-Thickened VERTAD™ biosolids.

It is generally accepted that thermophilically digested aerobic biosolids can be dewatered to higher cake solids than anaerobically digested biosolids, however this has historically come with the expense of greater polymer demand (Murthy et al., 2000). Murthy et al. performed an examination of an autothermal process to isolate the cause of high polymer demand and high recycle chemical oxygen demand (COD). They found that the presence of monovalent ions in solution such as sodium, potassium, and ammonium ions can interfere with charge-bridging mechanisms occurring in the floc. This is a problem in conventional ATAD systems because the release of ammonium ions is the result of the absence of nitrification in the thermophilic process (Burnett, C.H., 1994). This free ammonia release appears to be less pronounced in the VERTAD™ process, possibly due to the pressure in the reactor which results in the combination of free ammonia with dissolved CO_2, forming ammonium bicarbonate.

Murthy et al (2000) also found that the amount of biopolymer (proteins and polysaccharides) in solution was heavily correlated to increased polymer demand. They concluded that the concentration of biopolymers in solution was minimized by limiting the solids retention time (SRT) of thermophilic digestion, and by minimizing the concentration of monovalent ions (specifically ammonia) in solution. These factors favour the VERTAD™ process because a relatively short SRT of 240°C-day is enabled by the high oxygen transfer achieved in the system, and ammonium bicarbonate is formed in the reactor, minimizing free ammonia.

ORGANIC NITROGEN & FOG DESTRUCTION

A summary of the digestion performance results for VS, FOG, and organic nitrogen is presented in Table 4. The values reported are averages over one detention time after the process was stable for three detention times. A complete mass balance was achieved for each of these tests from which the reported efficiency values were calculated.

The reduction of organic nitrogen and fats, oils and grease were relatively high considering the short solids retention times that the VERTAD™ process was tested at. The results were similar to the reduction efficiencies attained in the STP anaerobic digesters at a 28 day SRT.

These results are significant since undigested Org-N and FOG are generally responsible for the objectionable character of biosolids. These results also have significance when considering a dual digestion flowsheet with VERTAD™ pre-treatment ahead of anaerobic digestion. The technologies appear to be complementary in that the VERTAD™ technology readily degrades fats and proteins, compounds known to cause scum build-up and mixing problems in anaerobic digesters, and the anaerobic digestion process is capable of destroying the cellulose material still present in the VERTAD™ product.

ODOUR & OFF-GAS CONTROL

In the VERTAD™ system, the self-contained nature of the head works allows easy control over off-gas emissions. Off-gas can be easily routed to biofilters to remove the trace ammonia and dimethyl sulfide (DMS) compounds common with aerobic digestion technologies.

Volumes of gaseous emissions from the VERTAD™ system are a fraction of those produced in conventional aeration processes due to the high oxygen transfer efficiency. Ammonia is converted to ammonium bicarbonate in the reactor, helping to eliminate ammonia emissions. In order to minimize the ammonia release from the system, reactors are operated at a maximum temperature of 60°C, preventing the dissociation of the ammonium bicarbonate.

The odor panel analysis was conducted by Odor Science & Engineering, Inc (OS&E). These tests measured the odors generated by the VERTAD™ process and the effectiveness of the biofilter for odor treatment. Odor was quantified by dilution-to-threshold (D/T) ratio and panelists described the odor character. The results of the odor panel work are provided in Figure 6.

These results show that the biofilter reduced 99.5% of the odor loading present in the Feed Tank off-gas. The Feed Tank contains the untreated feed sludge. The off-gas from the VERTAD™ reactor itself had relatively low odor levels and was characterized using terms such as 'compost, earthy, vegetation'. These results have highlighted the need to treat off-gas in a biofilter.

OXYGEN TRANSFER EFFICIENCY

Oxygen transfer studies were performed to test the oxygen transfer rate (OTR) first into water and determine the theoretical maximum efficiency of the system, and second into sludge to determine the oxygen transfer efficiency attainable in the digestion process.

The oxygen transfer efficiency was approximately 66% into water at 54°C (129°F). This OTE represents a significant advancement in aeration technology over conventional aeration systems using air, which typically attain 10-20% OTE into water at 20°C, a lower temperature which facilitates oxygen transfer through increased solubility.

Sludge viscosity was found to have a pronounced effect on the oxygen transfer efficiency (OTE). As shown in Figure 7, an OTE of 50% was attained easily at a reactor concentration less than 4.5% TS. At greater than 4.5%

TS, the transfer efficiency started to decrease and was as low as 35% at reactor concentrations of 6.2% TS. The practical operating cutoff before the sludge viscosity seriously affects the OTE was found to be 4.5% TS. A conventional ATAD system that was tested achieved an average OTE of approximately 24% across a three-stage system.

Doubling fluid viscosity changes oxygen diffusivity in the sludge in inverse proportion (i.e. it is halved). Metcalf and Eddy (1991) suggest that viscosity may decrease by a factor of 2 or more over the range of 3 to 6% ds for undigested sludge, with viscosity declining rapidly as sludge is digested. This is supported by the VERTAD™ OTE data which suggests that the OTE is nearly halved with a doubling in reactor solids.

Kelly et al. (1993) have suggested that a 400°C-day product is necessary in ATADs to attain a volatile solids destruction of 38%. The VERTAD™ results indicate that a 240°C-day product exceed the EPA requirements, with greater than 40% volatile solids destruction. The increased oxygen transfer in the VERTAD™ system is thought to be the primary factor in decreasing the solids retention time to meet EPA vector attraction requirements and enhancing digestion. The high oxygen transfer rates achievable in VERTAD™ are associated with the pressure and depth at which compressed air is introduced to the bioreactor.

VERTAD™ FOLLOWED BY ANAEROBIC DIGESTION (DUAL DIGESTION)

The process of dual digestion involves the use of an autothermal aerobic digestion process as a pre-treatment step before mesophilic anaerobic digestion. Dual digestion is a well-established Class A and sludge reduction process.

The effect of VERTAD™ pre-treatment on subsequent mesophilic anaerobic digestion was tested using bench-scale reactors in studies performed at the University of Washington by Jenny Yoo (supervised by Dr. David Stensel). The results of the dual digestion study are presented in Table 5.

The results indicate that following VERTAD™ with mesophilic anaerobic digestion provides additional reduction of volatile solids without significant reductions in the volumes of gas produced. Anaerobic digestion of the VERTAD™ product resulted in 67% total volatile destruction with a 4-day SRT in VERTAD™ followed by an 11-day mesophilic anaerobic SRT. A 70% total volatile destruction was achieved with a 4-day SRT in VERTAD™ followed by a 15-day mesophilic anaerobic SRT. Comparatively, a control anaerobic digester obtained 52% VS destruction with an 11-day SRT. While the control digester showed greater VS reduction in the anaerobic stage than the VERTAD™ fed anaerobic digesters (presumably due to the lower VS content in the feed from VERTAD™), the total reduction efficiencies of the dual digestion systems were much higher than that of the anaerobic control.

The technologies appear to have a synergy from a performance and operability perspective. For example, the VERTAD™ technology readily degrades fats and proteins, whereas anaerobic digestion is capable of cellulose destruction. Observations during the bench scale testing were that the control digester experienced considerable foaming and had mixing problems. The dual digestion systems had no foaming problems and were readily mixed, indicating lower viscosity. This may be attributed to the efficient Org-N and FOG destruction in the VERTAD™ process.

The ability to float thicken the VERTAD™ product is another benefit for the combined system. Thickened product could be fed to anaerobic digestion, allowing operation at higher solids concentrations. The lower volumetric flow associated with the thicker feed would allow for either reduced digester volume requirement or increased solids retention time.

FULL-SCALE DESIGN AND ECONOMICS

The results of the demonstration project provided the basis for full-scale design parameters and cost estimates for the VERTAD™ process. Planning level designs were developed for three alternatives for solids treatment facilities at a planned 36 MGD treatment plant in King County. The alternative flowsheets presented in Figure 9 were developed in detail for the County.

The present worth of capital costs for a system with VERTAD™ pre-treatment prior to anaerobic digestion was similar to that of mesophilic anaerobic digestion alone.

The present worth of operating costs for a system with VERTAD™ pre-treatment prior to anaerobic digestion was significantly less than conventional anaerobic digestion alone, primarily due to savings in dewatering and haul cost in the VERTAD™ system.

CAPITAL COSTS

For larger facilities the capital cost of a VERTAD™ system is lower than that in conventional plants of similar size. Below a certain minimum population equivalent the costs of drilling form a greater portion of capital costs, the cut-off point at which VERTAD™ becomes less competitive when compared with alternatives is dependent on local site costs and will vary from location to location.

A number of factors contribute to the lower capital costs:

1) *Decreased land requirements*
VERTAD™ requires 10-20% of the total land required for conventional anaerobic plants of equivalent capacity. Less surface tankage and concrete is required with 80% of the bioreactor volume is below grade.

2) *Smaller Reactor Volume Required compared to ATAD*
Due to the high oxygen transfer efficiency in a VERTAD™ system, the residence time required in the bioreactor is decreased relative to conventional technologies – making the required reactor volume smaller.

3) *Reduced Requirement for Downstream Dewatering Facilities*
The solids can be acid float-thickened to 8-12% TS out of the VERTAD™ bioreactor. Float thickening in this manner significantly reduces the size of the downstream dewatering facility.

OPERATING COSTS

The most significant savings realized in the VERTAD™ process relate to the aeration system. The basis of the VERTAD™ process is that the oxygen transfer efficiency is significantly higher than that in a conventional aerobic digestion system due to the pressure at the depth where air is introduced to the bioreactor, 50% OTE versus 24% OTE respectively. In a recent comparison study of the energy requirements between VERTAD™ and ATAD processes, it was found that VERTAD™ out-performed a conventional ATAD process, operating with 31 to 45% less energy per kilogram of VS destroyed in the system. These results are summarized in Table 6.

CONCLUSIONS

The following conclusions were made based on the results of this demonstration project:

1. Class A Biosolids were achieved with a 4-day solids retention time (EPA 40 CFR 503, Alternative 1).

2. Oxygen transfer efficiency was greater than 50% when the reactor total solids concentration was at or below 4.5%.

3. The present worth capital costs for a system with VERTAD™ pre-treatment prior to anaerobic digestion are similar to that for mesophilic anaerobic digestion alone. Above a certain minimum population equivalent, the capital cost of a VERTAD™ system is lower than conventional ATAD plants of similar size.

4. The present worth of operating costs for a system with VERTAD™ pre-treatment prior to anaerobic digestion are significantly less than conventional anaerobic digestion alone due to savings in dewatering and haul costs.

5. VERTAD™ has lower operating costs than ATAD due to low energy requirements, low polymer requirements and low trucking/disposal costs.

6. The VERTAD™ lower zone is hydraulically separate, providing strict adherence to the Class A pathogen requirements of EPA 40 CFR 503.

7. VERTAD™ product can be float thickened to 8-12% TS by pH-shift CO_2 release. Float thickened product dewaters to greater than 30% cake solids with low polymer demand (6.4kg /ton).

8. Organic nitrogen and fats, oils and greases were preferentially degraded over organic solids comprised primarily of cellulose.

9. Mesophilic anaerobic digestion of VERTAD™ product provided overall volatile solids destruction of 67%. Incorporation of a post-VERTAD™ mesophilic anaerobic digestion step shows considerable promise as there are synergies between the two technologies.

10. The VERTAD™ process has a minimal footprint requirement making it an ideal retrofit for facilities that require additional capacity, or current Class B biosolids generators that wish to produce Class A Biosolids.

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TABLES

TABLE 1 – DESIGN PARAMETERS FOR VERTAD™ DEMONSTRATION FACILITY

VERTAD™ DEMONSTRATION PROJECT FACILITY DESIGN SUMMARY

Influent Characteristics		**Value**
Influent		Thickened Municipal Biosolids (THS)
Loading		500 to 1,500 lbs solids/day (2,500-7,500 pop. equivalent)
Solids Concentration		6.5%
VSS		78 – 80%
Primary Sludge		60%
WAS		40%
Temperature		20 – 21°C
Biofilter treatment – building exhaust		800 cfm
Biofilter loading rate		5 cfm/sf
Feed Rate	@ 3 day HRT	1,770 gallons/day
	@ 6 day HRT	889 gallons/day
Equipment Inventory		
VERTAD™ BIOREACTOR		
Casing		1 @ 20 inch diameter by 350 feet deep
Draft tube		1 @ 10 inch diameter by 143 feet deep
Extraction		1 @ 3 inch diameter by 347.5 feet deep
Reactor Volume	Total	740 cubic feet (cf)
	Liquid	710 cf
VESSELS		
Feed Tank		1 @ 60 inch diameter by 72 inch high
Digester Head Tank		1 @ 60 inch diameter by 72 inch high
Purge Water Tank		1 @ 38 inch diameter by 48 inch high
MECHANICAL		
Aeration Compressor		87 scfm, 150 psi, 25 HP
Feed Pump		1-10 gpm, 50 psi, 3 HP
Purge Water Pump		20 gpm, 26 foot TDH, 5 HP

TABLE 2 – VOLATILE SOLIDS REDUCTION AT VARIED TEMPERATURE AND RESIDENCE TIMES

Test	HRT (days)	Temperature (ºC)	Aeration Rate (scfm)	VS Reduction (%)
Dec'98	4	56	56	40.9
Sept'99	4	65	80	42.2
Nov'99	3.4	56	36	42.3
Dec'99	5.5	61	30	43.5*

TABLE 3 – ONSITE PRESS TESTING OF VERTAD™ PRODUCT DEWATERABILITY

Characteristics	Anaerobic	VERTAD™	Acid Float Thickened VERTAD™
Cake Solids (%)	20	32	31
Polymer Dose (lbs/ton)	17	17	17
Filtrate Quality	Clear	Very Turbid	Very Clear

TABLE 4 – DUAL DIGESTION USING VERTAD™ AND MESOPHILIC ANAEROBIC DIGESTION

COMPARISON OF ANAEROBIC CONTROL WITH COMBINED SYSTEM PERFORMANCE

	11 day SRT Anaerobic Control	15 day Anaerobic with VERTAD™	11 day Anaerobic with VERTAD™
Solids Retention Time (days)			
VERTAD™	0	4	4
Anaerobic	11	15	11
Total	11	19	15
Volatile Solids Reduction (%)			
VERTAD™	0	40	40
Anaerobic	52	49	45
Total	52	70	67
Anaerobic Gas Production			
Liters Methane / day	2.8	2.0	2.5
Liters Methane / gram COD removed	0.51	0.39	0.36

TABLE 5 – VOLATILE SOLIDS, FOG, AND ORGANIC NITROGEN REDUCTION

Test	HRT (days)	Temperature (°C)	VS Reduction (%)	Org-N Reduction (%)	FOG Reduction (%)
Dec'98	4	56	40.9	57.9	91.7
Sept'99	4	65	42.2	49.8	80.8
Nov'99	3.4	56	42.3	44.1	--
Dec'99	5.5	61	43.5*	49.9	80.4

TABLE 6 – COMPARISON OF VERTAD™ AND CONVENTIONAL ATAD PROCESSES

Parameter	ATAD (Design)[1]	ATAD (Case Study)[2]	VERTAD™ (Design)[3]
Power Usage (kW•hr/ton TS fed)	442	520 – 641	315
Power Usage (kW•hr/kg VS destroyed)	1.52	1.85 – 2.32	1.27
Aeration (m^3/hr/m^3 active reactor volume)	4	Not Measured	1.7
Time for VS Destruction of 40-42% (days)	5 – 8	12 - 15	3.5 - 5
Average System OTE (%)	Not Reported	24%	50%

1 EPA Technology Transfer #EPA/625/10-90/007 – "Autothermal Thermophilic Aerobic Digestion of Municipal Wastewater Sludge"

2 Measurements at a full-scale, 4 ton TS/day ATAD facility.

3 VERTAD™ design numbers based on the King County findings.

FIGURES

FIGURE 1 – VERTAD™ PROCESS FLOW DIAGRAM

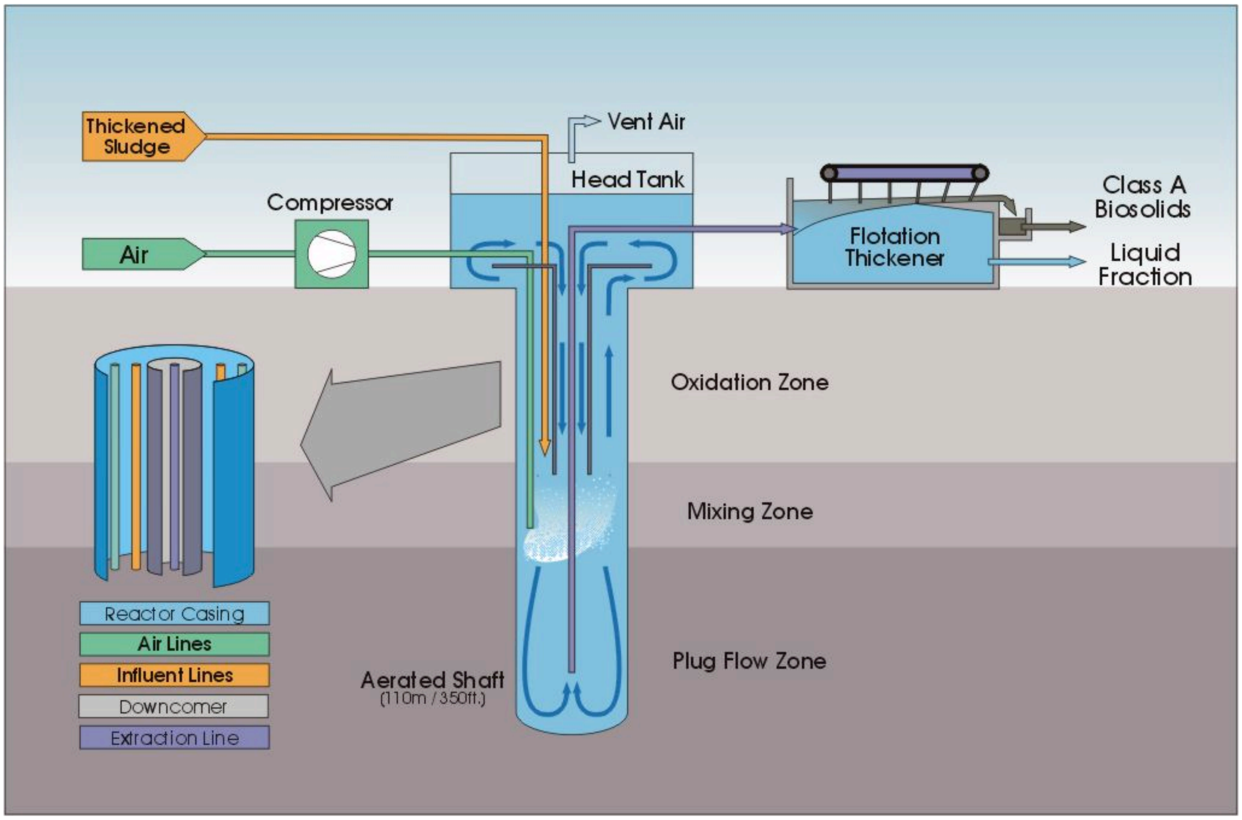


FIGURE 2 – VERTAD™ DEMONSTRATION FACILITY PROCESS FLOW DIAGRAM

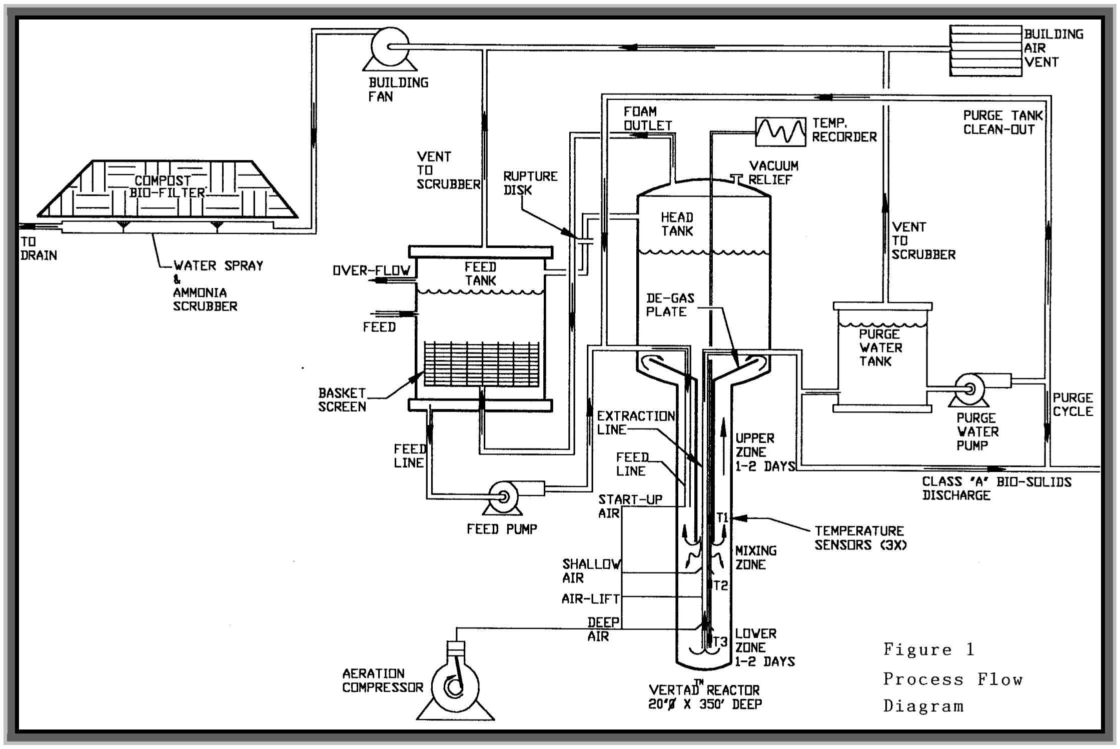


FIGURE 3 – VERTAD™ DEMONSTRATION FACILITY AT RENTON, WA

FIGURE 4 – VERTAD™ SALT TRACER STUDY CONFIRMING NO SHORT CIRCUITING

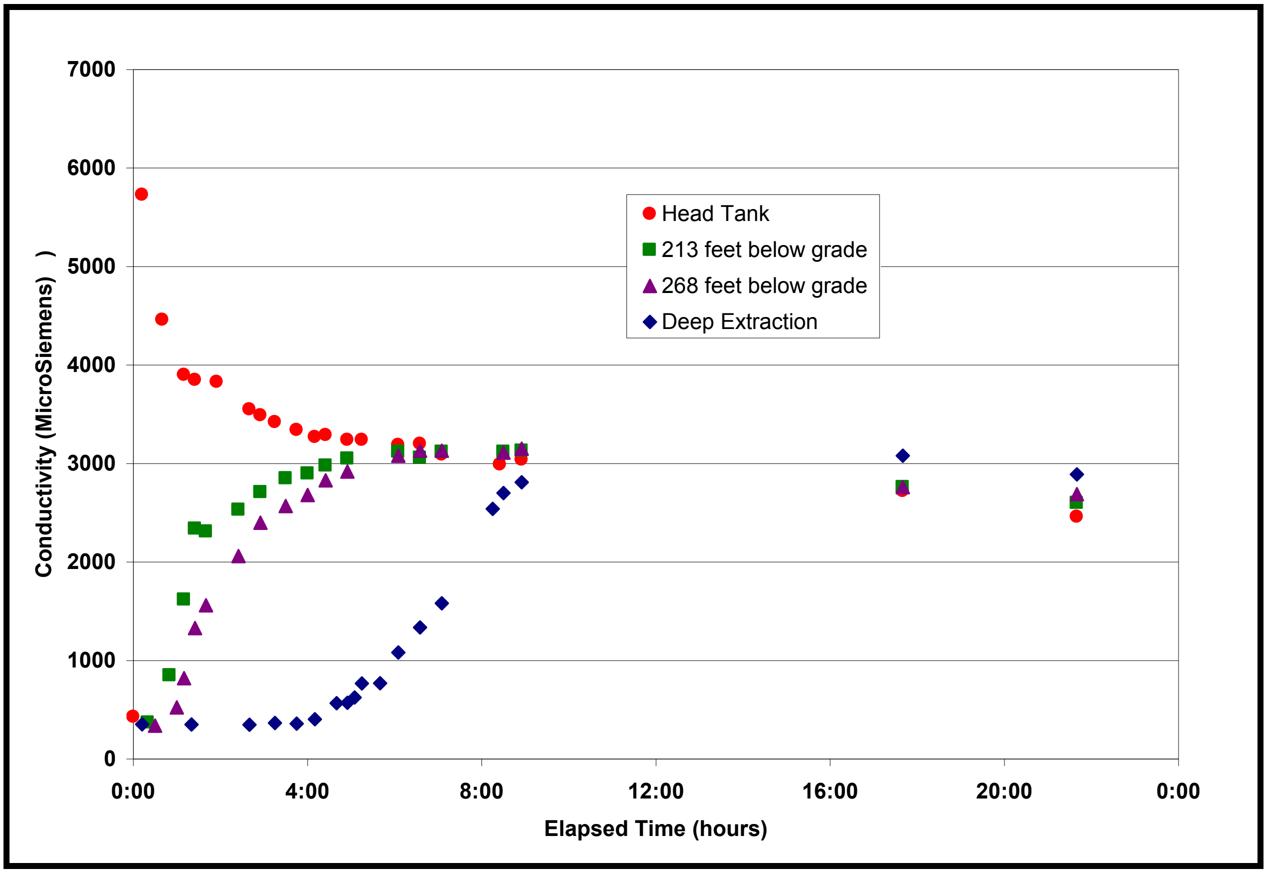


FIGURE 5 – ANDRITZ LAB CENTRIFUGE TESTING OF VERTAD™ PRODUCT DEWATERABILITY

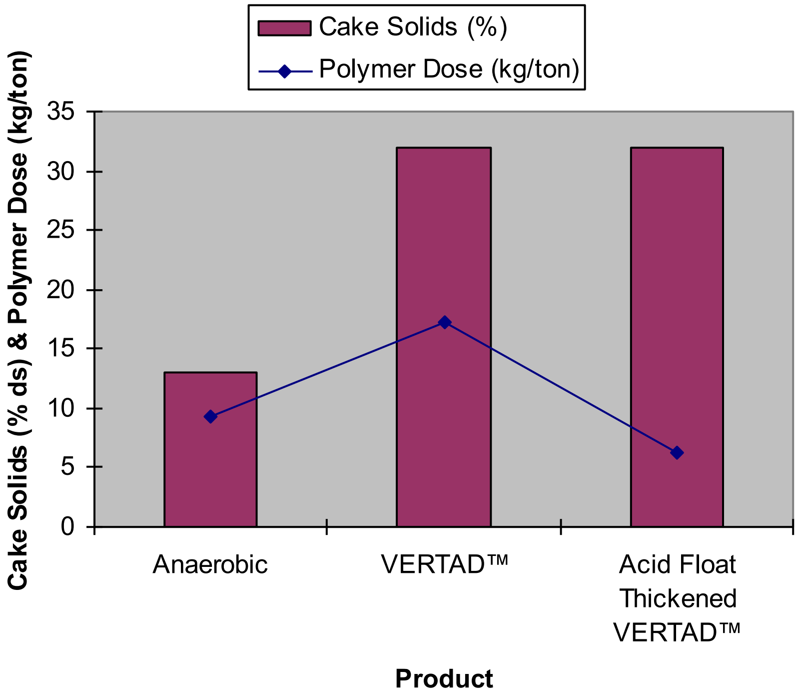
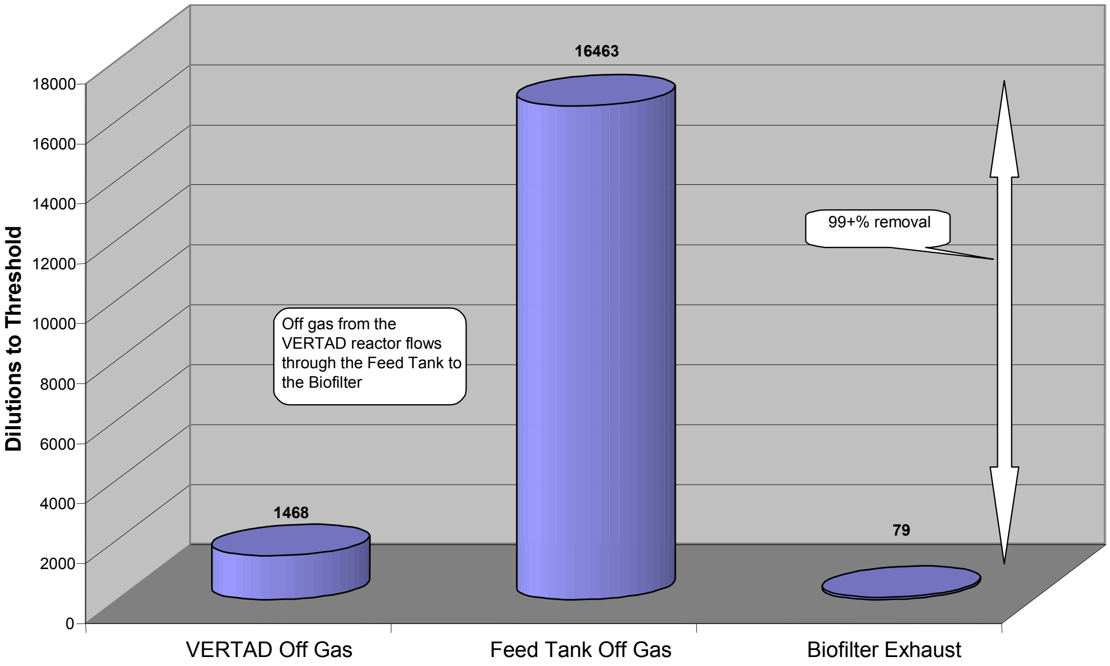


FIGURE 6 – ODOR PANEL RESULTS



Off gas from the VERTAD reactor flows through the Feed Tank to the Biofilter

FIGURE 7 – VISCOSITY EFFECTS ON PEAK OXYGEN TRANSFER

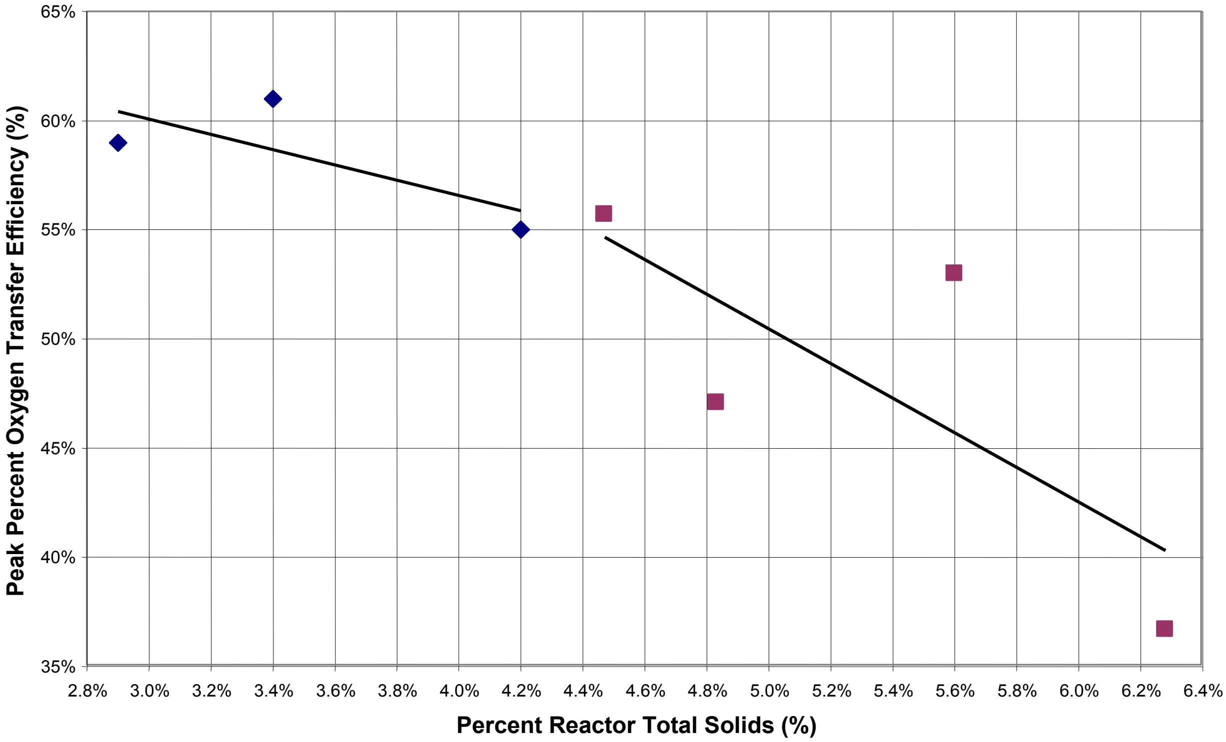


FIGURE 8 – DUAL DIGESTION USING VERTAD™ AND MESOPHILIC ANAEROBIC DIGESTION

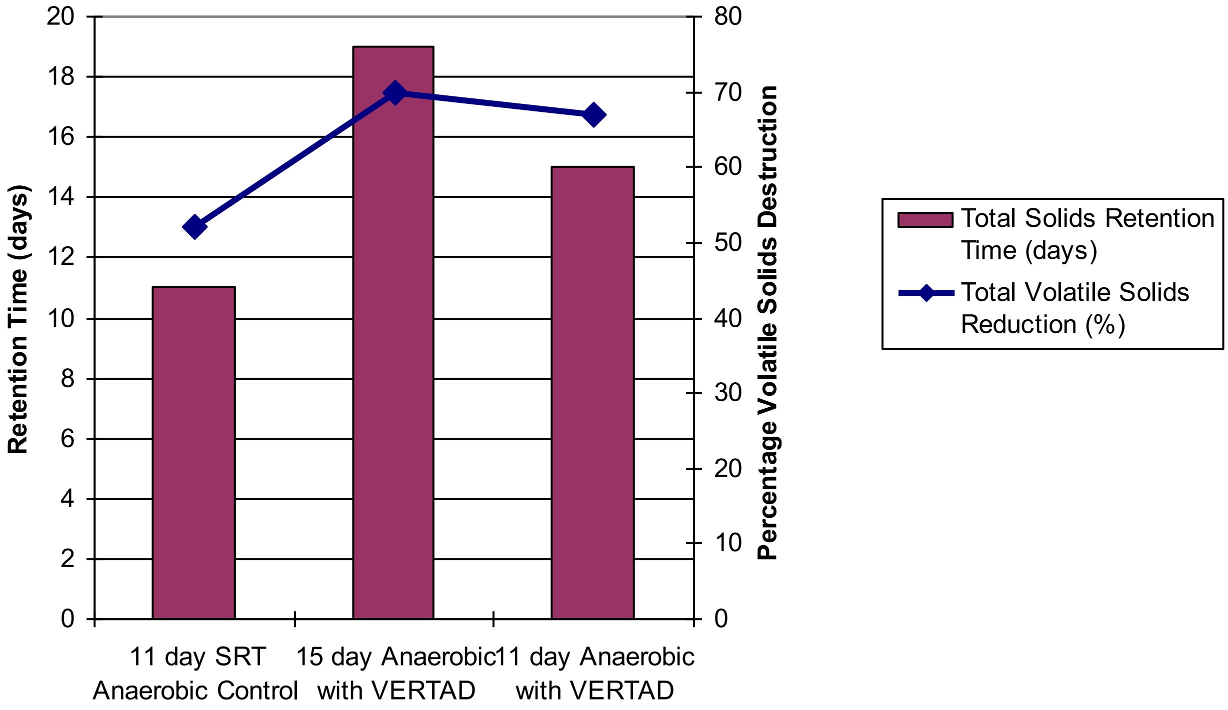
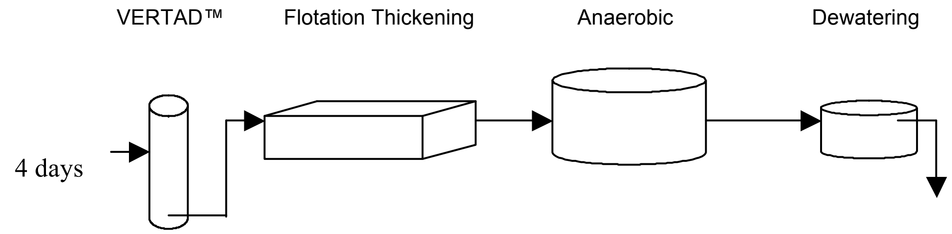
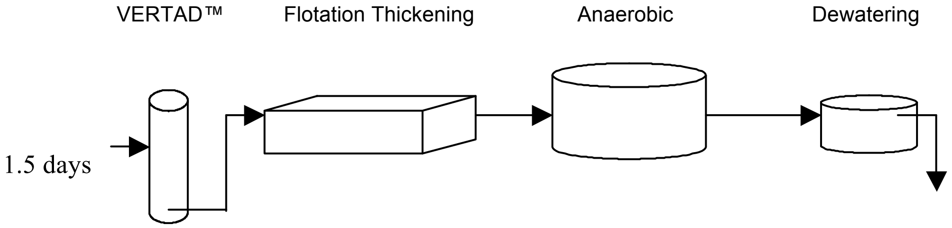


FIGURE 9 – VERTAD™ PROCESS FLOW DIAGRAMS

CONCEPT 1: CLASS A VERTAD™ DIGESTION FOLLOWED BY ANAEROBIC DIGESTION



CONCEPT 2: TIME-TEMPERATURE VERTAD™ FOLLOWED BY ANAEROBIC DIGESTION



CONCEPT 3: CLASS A VERTAD™ STAND ALONE DIGESTION PROCESS