

# DESIGN CONSIDERATIONS FOR AUTOTHERMAL THERMOPHILIC AEROBIC DIGESTION

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## ABSTRACT

ATAD design recommendations are developed from University research, demonstration pilot studies, and several years of plant operation and assessment. These investigations have provided a design approach for those who may be considering the ATAD process for biosolids treatment. Pilot work and operating systems have provided information for recommendation on design. Limited full-scale investigations were initiated at the Golden Heart WWTP in 2002. From this, we have determined that selection and design for the ATAD should consider the following:

1. Process selection and appropriateness; e.g., what are the design criteria for the ATAD process and what are the special considerations for equipment selection.
2. Physical plant design; e.g. what are the process constraints, complexity and minimum systems and how do they compare with alternative systems.
3. Process design; e.g. can one use conventional design criteria from anaerobic or aerobic digesters and what are the paramount considerations that must be included in any design.

Selection and design are discussed under the above three headings. Important reminders in design of ATAD are that penalties will be paid for over-design and that criteria used for aerobic or anaerobic digester design are not necessarily appropriate for ATAD.

## INTRODUCTION

In 2002, thermophilic digestion trials at the Fairbanks, Golden Heart WWTP were undertaken. These trials demonstrated that the process could be useful in achieving the biosolids treatment objectives for the Golden Heart Utility Services of Alaska in terms of solids reduction and as a component in the composting operation to achieve the Class A EPA 503 regulations for pasteurization and stabilization. Biosolids handling is markedly improved through reduction in mass, which subsequently aids the down stream composting operation. The trial ATAD operation was perceived to be a problem in the liquid train process due to the ammonia production and the presence of fines solids in the side stream return flows. These items were suspected

to inhibit the biological treatment in the pure oxygen plant. To identify solutions and explanations for these concerns, the Utility has undertaken a review to investigate the autothermal thermophilic aerobic digestion, ATAD operation at the facility. (ATAD is used in spite of the use of pure oxygen and not air. Other acronyms used by others include TOD, thermophilic oxidative digestion, and ATS, autothermal thermophilic stabilization), (Kelly and Mavinic, 2003).

## **THE ATAD PROCESS**

The name ATAD is a North American abbreviation for autothermal thermophilic aerobic digestion, and was likely derived from work by Jewell (1978). Although the acronym gives an indication of the process function, it is not accurate.

Firstly, the process is not completely autothermal and requires a heat component from mechanical mixing energy. This is not unique since all chemical and biochemical processes require some form of mixing energy to assist reactions. The mixing energy supplies less than 30 percent of the heat.

Secondly, although the process operates at thermophilic temperatures (above 55°C), the first of one or more reactors may not. The first allows the temperature to come up to where a second reactor, in series, can operate consistently above 55°C.

Thirdly, the process is not entirely aerobic; it is a combination of anaerobic, fermentative and aerobic biological activities. The addition of oxygen from air or pure oxygen sources provides the electron acceptor for the main biological heat production, which culminates in the formation of carbon dioxide and water products, but the accompanying anaerobic and fermentative processes provide the biodegradable substrate needed for rapid oxidation. This is contrasted to an anaerobic digester, which combusts a methane gas product to provide the principal heat source.

Finally, the process provides an indirect destruction of total volatile solids (TVS<sub>d</sub>). The substrate is normally a waste biological sludge (WBS) or a mixture of WBS and primary solids. In either case, the viable feed organism must undergo death and replacement by thermophilic bacteria; foaming at 40 to 50°C is an observed response to this occurrence. The digestion process includes a solubilization and reassembly of volatile suspended solids with eventual endogenous destruction of the newly formed thermophilic biomass. To support this theory of biomass restructuring, for short digestion times, Messenger (1993) has demonstrated that volatile suspended solids concentrations increase in the reactors.

The ATAD process was initially selected in North America for its potential cost and space savings over other conventional processes such as anaerobic or conventional aerobic digestion. This is found to be especially true when existing facilities can be reused for expansion (Kelly, 1989 and Kelly et al, 1993). In later years the process has been promoted for its ability to produce a pasteurized biosolid meeting EPA 503

regulations for Processes to Further Reduce Pathogens (PFRP). As such, the ATAD product has unrestricted reuse and thus wider marketing opportunities than unpasteurized biosolids.

## FEED AND OXYGEN PARAMETERS

Total volatile solids (TVS) concentration in the feed undigested sludge is a surrogate measure of the feed quality and indicator of oxygen requirements (COD). The TVS/COD ratio to COD is an important parameter for predicting oxygen demand and TVS/TS ratio is important for determining the minimum percent solids that should be fed to the digester. Example 1 illustrates a typical air flow calculation for a specific feed character.

### EXAMPLE 1:

For primary and WBS sludge, a typical ratio of COD/TS may be about 1.3 and a ratio of VS/TS might be about 0.7 making the COD/VS ratio about 1.86/1. If 1 kg of oxygen is needed for 1 kg COD removed the oxygen needed for an 8 day HRT ATAD process with a 43% COD reduction and a COD loading of  $8.1 \text{ kg/m}^3\text{-d}$  (5% TS) would be  $3.48 \text{ kg/m}^3\text{-d}$ . At standard conditions, for 70 percent oxygen transfer, this is about  $0.68 \text{ m}^3 \text{ air/m}^3\text{-hr}$  of reactor volume ( $\text{O}_2$  is 23.2% by weight in air, and when air is  $1.3 \text{ kg/m}^3$ ). These values have been confirmed to be satisfactory for design and operation. If pure oxygen is used, however, the oxygen transfer rate is higher, and the required specific rate is less by a factor of 4, which is about  $0.17 \text{ m}^3 \text{ pure O}_2/\text{m}^3\text{-hr}$  of reactor volume.

Air supply can be evaluated from a thermodynamic approach as well, (Kelly and Warren, 1995, and 1997).

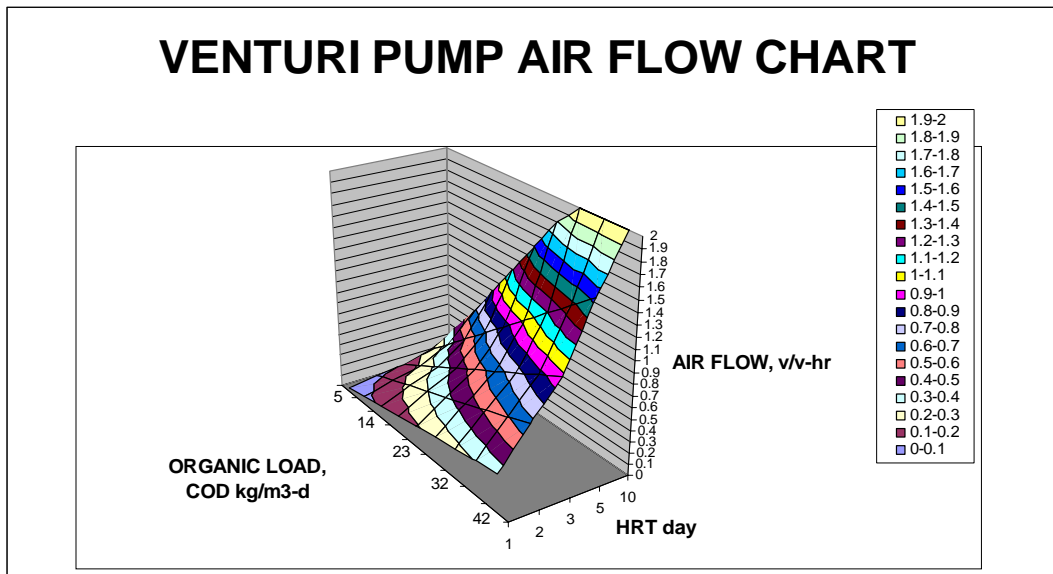
Figures 1 and 2 compare the use of pure oxygen to air. At a 98% pure oxygen supply, the amount of gas flow is reduced by a factor of 4. This impacts sensible heat loss, evaporative cooling loss, the amount of off gas treatment required, and the mixing energy needed to secure a temperature balance.

## MIXING ENERGY

Mixing energy is needed to provide maximum energy to promote interaction between substrate and the thermophilic organisms, to reduce particle size for increased surface area, and to provide supplemental heat through mixing energy dissipation. For air aeration, 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 50-60°C, this is about  $100 \text{ W/m}^3$ , (Kelly, 1996). Power densities are less for pure oxygen since the heat release from the digestion process is much more efficient.

## OXYGEN SUPPLY

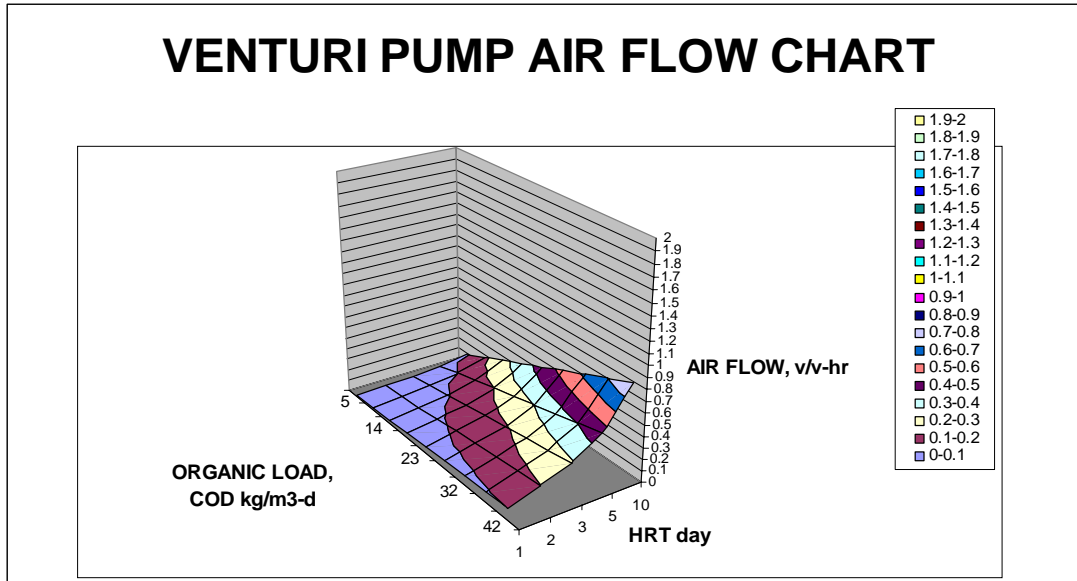
Turbine mixers with sparger rings, aspirator mixers or venturi mixers that produce fine elongated bubbles for improved oxygen transfer and redirect energy to assist in the breakup of larger particles through implosions (cavitation), appear to have advantages over other less violent forms of mixing equipment. Oxygen transfer from air bubbles is shown to be high (better than 70 percent) when calculating the oxygen air requirements at a residual oxygen concentration of 0 mg/L.



**Figure 1 - Air Flow Requirements for ATAD Reactor for Load and Hydraulic Retention**

With air at standard temperature, the oxygen saturation is about 10 mg/L. With pure oxygen, the oxygen saturation is about 40 mg/L or 4 times, which results in a higher driving force for solubilization of oxygen.

Figures 1 and 2 illustrate air flow requirements over pure oxygen gas flow requirements relative to differing organic loading rates and hydraulic retention time (HRT).



### GOLDEN HEART WWTP OBJECTIVES

The objectives for the sludge handling and treatment using the ATAD process include:

1. Treat the side stream ammonia and solids load resulting from the thermophilic process.
2. Produce a Class A Biosolids Product for reuse and utilize composting as a value added solution for increasing product value.
3. Reduce the mass of material for ultimate reuse and to reduce the size of the composting operation.
4. Provide an expandable facility for future growth.
5. Allow relative ease in operation.

Ten constraints to achieving these goals were assessed to measure the success of the process or process components. Odor is one constraints. Others include treatment specifications, costs, operating ease, equipment suitability, safety, etc.

For the Golden Heart ATAD a pre-heated sludge feed of 5 to 6% TS (ds) is to be added to the first of four cells of each of the two digester trains in service. Off gas is re-circulated and exhausted from the reactor tanks for odor treatment. Foam control mechanisms are added to control foam-over and similar nuisances.

Adequate oxygen supply and mixing energy are fundamental requirements; these should be variable inputs to the process. This insures that temperature objectives are met. The ATAD temperature regime is stable and reasonably resilient to change, however environmental conditions will affect the biology and foaming occasionally

results. Oxygen supply and mixing are important factors in foam control. Excess air or oxygen supply can encourage excessive foaming, and where excessive aeration is used, can cool the process. On the other hand, oxygen supply is needed to allow the ultimate oxidation in the process. Addition of the oxygen must be well balanced. Recirculation of unused oxygen and positive foam control can assist by improving flexibility in oxygen supply. Suitable temperature controls, oxygen recirculation and positive foam control are not available.

In high temperature incomplete digestion processes, odor results from incomplete oxidation of organic compounds. These compounds are typically the building blocks of proteins and fats. The ATAD process like other biological processes is dependent on the symbiosis of fermenting bacteria and respiring bacteria. As such, purely aerobic conditions are not exclusively desirable but a balance of fermentative, aerobic and anaerobic conditions is. Oxidation-reduction measurements are useful in establishing the desired oxidation conditions. Complete oxidation of the odorous compounds is possible but requires high oxygen tension and long digestion periods. This impacts cost and may also reduce the ability to dewater the biosolids product. Use of higher temperatures in the reactors is a practical solution and improves dewaterability and possibly odor potential where sufficient protein and biopolymer destruction is obtained (Zhou, 2002).

## **CURRENT WWTP SLUDGE HANDLING**

Golden Heart operations staff has identified issues that are of concern including temperature control, insulation, and thickening of feed, cooling thermophilic product, dewatering and treatment of side-stream flows for return to the liquid treatment aeration basins.

The current mesophilic digester operation handles less than 150 m<sup>3</sup>/d of waste biological sludge (WBS) at about 0.8% TS. This is 35% of the 435 m<sup>3</sup>/d (115,000 gpd) sludge flow from the aeration plant. The digested sludge (biosolids) undergoes over 18 days of HRT and a higher solids retention time that (although unconfirmed) meets EPA 503 vector reduction criteria for biosolids stabilization. Volatile destruction is not recorded but was anticipated to be 25% by the original designers. The undigested sludge is dewatered and directly incorporated into the compost operation with the digested biosolids. Untreated sludge production is about 1.11 kg/sludge per kg BOD<sub>5</sub> (1.11 lb sludge per lb of BOD<sub>5</sub>) removed. Just less than 3630 kg (8000 lb) of sludge (dry weight) is produced daily. Wet sludge of 6820 tonnes (7,500 tons) per year is delivered to the compost operation (at about 18% solids). The plant 2002 average flow was about 20.4 ML/d (5.4 mgd). Plant capacity is reported to be limited to 22.7 ML/d (6 mgd) but was originally rated when built in 1976 at 30.2 ML/d (8 mgd).

A limited experiment by operations staff in 2002 identified that the ATAD process could be used as a means of improving sludge handling.

## **GOLDEN HEART WWTP ATAD IMPROVEMENTS**

The process is presently a conventional mesophilic aerobic digestion using pure oxygen. Digester improvements are possible by retrofit to an ATAD process that uses pure oxygen. The ATAD will increase treatment capacity, improve the product, and enhance operations. Installation of monitoring equipment and instrumentation would be added to maintain the systems. The improvements would provide an increase in operational flexibility to allow the operations staff to meet the treatment objectives more easily.

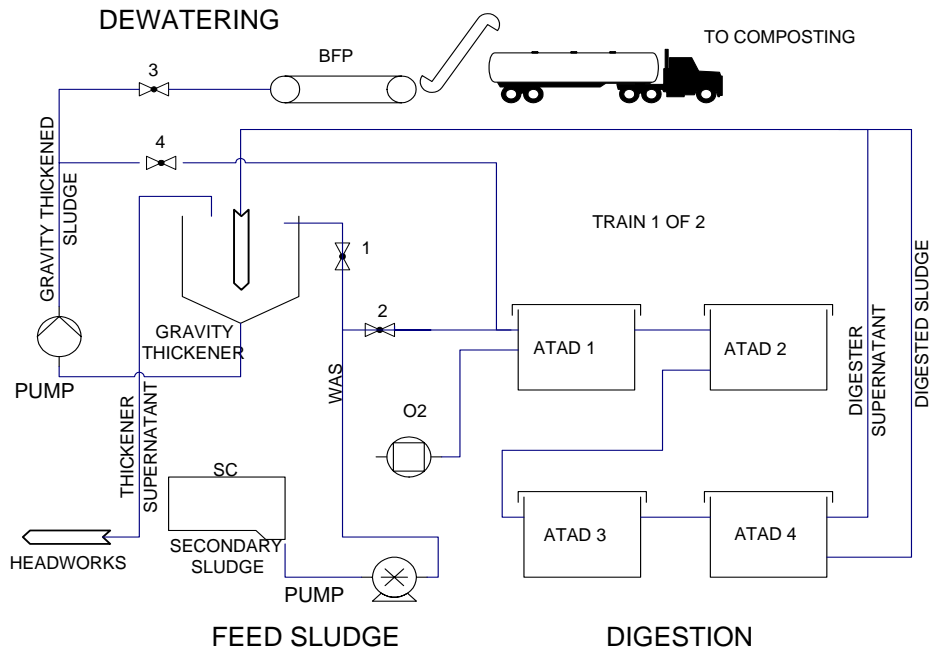
Improvements in capacity include increased operational temperature and control, improved insulation and mixing systems, foam control measures, changes in feed thickening, heat exchange and improved dewatering and odor control. For the short term, this has a high value in extending the existing treatment process life. For the medium to longer term, a review of enhancement of the ATAD process could include downstream anaerobic digestion with combined heat (recovery) and (co-generation) power (CHP) facilities. For the immediate case, improvements to capacity and process should consider the addition of positive foam control and recirculation of foul air. A rotating drum thickener, RDT (or dissolved air floatation, DAF) should be operated on a 24-hour or shift basis to allow the TWAS pumping rate to be reduced and to secure higher retention times, temperature and a greater reduction in VSS. Other issues include improvements to cool the hot biosolids before dewatering, secure adequate odor treatment and provide pressate or centrate treatment.

The six upgrade recommendations are as follows:

1. Pre-thickening of the feed sludge from less than 1% to above 5% TS to reduce feed flow rates to the digesters,
2. Improve the control for oxygen flow, improve diffusion, control foam and provide feed back temperature control,
3. Provide foul air collection and treatment of off gasses generated by the thermophilic process and subsequent dewatering and biosolids handling systems,
4. Construct a heat exchanger to undertake cooling of the product prior to dewatering to reduce vapor, odor and polymer demand,
5. Improve dewatering systems by providing improved preconditioning and potentially changing the main dewatering device,
6. Addition of a separate treatment step for the side stream pressate or centrate flows from the dewatering process.

The most practical solution is to operate the digesters in parallel. Alternatively, series operation could allow a phased development by using the first digester as the thermophilic digester and the second as a mesophilic digester. For full loads to the digesters however, modeling predicts that the thermophilic temperatures will carry through to the last digester cells and the likelihood of cooling and satisfying nitrification to avoid the construction of the sidestream treatment plant will not be obtained. This solution may however, be a means of undertaking the first phase of

the project to keep costs lower and to investigate the series operation. Figure 3 provides an illustration of a single train flow diagram proposed.



**Figure 3 - Golden Heart WWTP Digester System Flow Diagram**

For the full program, the least cost solution is to continue use of the belt filter presses and increase foul air treatment and sidestream treatment for the pressate. This cost compares to the cost for the full program of adding a centrifuge versus the belt filter press at a \$0.2 M premium.

The operations cost will increase despite the reduction in oxygen use, however a net saving of about \$100,000 annually is probable with the reduced solids production to the compost operation. Capitalized, this supports savings of the compost facility of about \$2.5M as reduction in the compost facility size. Other factors should be included that reflect the increased product value. By eliminating the odor treatment and the mixer and diffuser additions the cost could be reduced to about \$1.8M. If the Utility undertakes some limited trials at the plant, the reduced improvements could be confirmed and the program carried out.

Improvements in operations will need to include training programs, development of cross training programs, update of equipment lists and use of computer maintenance management systems for plant record keeping, consolidation of reporting techniques and extension of the data. A review of the present data collection and reporting is needed as well as confirmation of solids loading information. The monitoring systems, when installed should be checked and updated as needed.

## CONCLUSIONS

The Utility should complete limited ATAD trials and determine the risk of eliminating or delaying odor treatment, and in postponing or eliminating the mixer and diffuser improvements to reduce the cost of the ATAD retrofit. Also, the Utility should review their compost improvement plans and costs to determine the cost trigger that would allow the full or a partial program of the ATAD design to proceed. For example, the costs of adding the thickening equipment could be justified regardless of the full or partial ATAD program.

## REFERENCES

- Jewell (1978), W.J. and M. Kabrick, Autoheated Aerobic Thermophilic Digestion with Air Aeration, paper presented at 51<sup>st</sup> Annual Water Pollution Control Federation Conference, Anaheim, California, October 2.
- Kelly (1989), H.G., “Aerobic Thermophilic Digestion or Liquid Composting of Municipal Sludges”, Proceedings ASCE, Environmental Engineering Specialty Conference, Austin, Texas, pp. 650, 662.
- Kelly (1993), H.G., H. Melcer, D. Mavinic, “Autothermal Thermophilic Aerobic Digestion of Municipal Sludges: A One-Year, Full-Scaled Demonstration Product”, Water Environ. Res., 65, 849.
- Kelly (1995), H.G., and R. Warren, “What’s in a Name? – Flexibility”, Water Environment and Technology, WEF, 7, No. 7, July 1995, pp. 46-50.
- Kelly (1996), H.G., “Autothermal Thermophilic Aerobic Digestion – Heat Budgets”, Proceeding WEF, the annual Specialty Conference on Biosolids, Denver, CO, 1996 pp. 8-17, 8-24.
- Kelly (1997), H.G., and R. Warren, “Autothermal Thermophilic Aerobic Digestion”, Proceedings CSCE/ASCE, Environmental Engineering Specialty Conference, Edmonton, AB, Canada, 22-26 July, pp 217-225
- Kelly (2003), D. Mavinic, “Autothermal Thermophilic Aerobic Digestion Research, Application and Operational Experience”, WefTec 2003 Workshop W104, Thermophilic Digestion: hot Update, Los Angeles, CA, USA, October 11
- Messenger (1993), J.R. et.al., “Evaluation of the Dual Digestion Systems: Parts 1, 2, 3 and 4”, Water SA, No. 3, pp. 185-216.
- Zhou (200) Jianpeng, D.S. Mavinic, H.G. Kelly, W.R. Ramey, “Effects of Temperatures and Extracellular Proteins on Dewaterability of

Thermophilically Digested Biosolids”, Journal of Environmental Engineering and Science, 1, No. 6.