SEEKING OPTIONS TO CONVENTIONAL ANAEROBIC DIGESTION

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ABSTRACT
There is widespread interest in the US in upgrading the performance of conventional digestion processes. Some have called it the renaissance of digestion, in particular, for anaerobic digestion. Research and experimentation with advanced digestion processes have involved numerous agencies and project locations, so keeping up to date is a challenge. Information from these various sources must be gathered and synthesized to gain a balanced perspective. This paper provides an overview of the current development status of several advanced digestion processes, and the authors’ observations about what we know and don’t know about them.

KEY WORDS
Class A pathogen reduction, digestion, thermophilic, two-phase, temperature phased, pre-pasteurization

INTRODUCTION
There is widespread interest in the USA in upgrading the treatment performance of both aerobic and anaerobic digestion, particularly through process variations of conventional mesophilic anaerobic. The level of interest is reflected in the number of pilot and demonstration studies underway, projects under design or construction, and new facilities in the early years of operation (Shimp et al., 2000). Keeping up with the growing information base and assessing how the advanced digestion process options stack up against each other is difficult. The focus of these projects is often quite narrow, and conclusions and findings must be synthesized from many different sources to obtain a complete and balanced perspective. Key information is also often lacking on factors related to feed solids characteristics such as the primary sludge (PS) to waste activated sludge (WAS) ratio, PS and WAS volatile solids content, and upstream liquid stream treatment process employed and operating parameters.

Most of these projects are aimed at meeting the requirements for Class A pathogen reduction as defined under 40 CFR 503 (USEPA, 1993)--as there is a growing school of thought that production of Class A biosolids will be, in effect, a pre-requisite for land-based management schemes. “Enhanced treatment” is also of keen interest in the United Kingdom (UK) and European Union (EU), where more stringent regulations for the use of biosolids in agriculture are being adopted (Evans 2001).

This paper provides a review of the US, UK, and EU experience with advanced digestion processes, and shares observations on implications for facility design, operation and maintenance.

STATUS OF PROCESS DEVELOPMENT, APPLICATION

Autothermal thermophilic aerobic digestion (ATAD)

ATAD has found greater acceptance in Europe than in the US, particularly in Germany. Early emphasis there was placed on pathogen reduction and the majority of treatment facilities are small and historically have land applied biosolids in liquid form. Only about 30 systems have installed in the US, all since 1990 (Alleman 2001), establishing for ATAD a reputation for odor and solids dewatering problems. Although presumed effective in reducing pathogens, a number of ATAD systems have had to rely on volatile solids reduction (VSR) in downstream aerated storage/cooling tanks to meet design performance expectations. Purdue University is currently involved in developing a design basis for a “second generation” ATAD systems that may solve the VSR and odor problems.

Full-scale experience indicates that thermophilic aerobic digestion results in polymer demand for dewatering up to several times greater than for mesophilic digestion. The poor dewatering characteristics will hinder wider use of
ATAD unless economical mitigation measures can be found. Pioneering research has been conducted at Virginia Tech and the University of British Columbia to address this problem. Virginia Tech researchers have suggested dual conditioning—using ferric chloride or alum in conjunction with polymer—as a mitigation measure (Murthy 2000; Novak 2001). Researchers at the University of British Columbia have attributed the deterioration in dewatering characteristics mostly to WAS. Thermophilic digestion was found to have little effect on primary solids dewaterability (Zhou 2001). Based on operating experience with thermophilic anaerobic digestion at Vancouver (Peddie 2000), post-process cooling may also be a key factor in improving the dewatering characteristics of ATAD solids. Like other advanced digestion processes, feed solids characteristics need to be considered when establishing process performance expectations relative to VSR.

ATAD may be the key to future of aerobic digestion, as we don’t have a confident basis for designing an aerobic digestion system to meet Class B pathogen reduction and vector attraction reduction requirements at ambient temperatures.

**Thermophilic anaerobic digestion**

A four-stage thermophilic anaerobic digestion system has been in operations since 1997 at the Vancouver (British Columbia) Annasis Island plant, becoming a valuable source of operating information on pathogen reduction and heat recovery in high-temperature digestion systems. A three-stage system at OWASA, Chappel Hill, North Carolina came on line in August 2000.

However, the current interest in thermophilic digestion is primarily in Southern California, where the majority of biosolids from the Los Angeles Basin is being land applied in nearby Kern County. Kern County has enacted an ordinance requiring Class A pathogen reduction as a pre-requisite for land application effective January 1, 2003. With little time to comply, the City of Los Angeles (Hyperion and Terminal Island plants) and County Sanitation Districts of Los Angeles County have been experimenting with conversion of mesophilic digesters to thermophilic digestion.

The City plans to use a three-stage thermophilic digestion system, with the third stage operated in batch mode to satisfy the time-temperature requirements for Class A pathogen reduction—-at least on an interim basis (Haug 2001). In early tests with Hyperion’s large-capacity centrifuges, dewatering does not appear to be significantly impacted by the change to thermophilic digestion. However, because of enhanced primary treatment, the ratio of primary sludge-to-WAS is still greater than 3:1 despite going to full-secondary treatment. Early fecal coliform testing raises concern about the difficulty in consistently producing biosolids compliant with the 503 limit for Class A (i.e.1000 MPN/gr TS).

Los Angeles County is no longer pursuing thermophilic digestion as a result of plant-scale testing at its Joint Water Pollution Control Plant showing too much impact on odors and polymer conditioning for dewatering (Morton 2001). Most POTWs with an interest in advanced digestion are looking more seriously at coupled systems, with only one stage at thermophilic temperatures.

**Two-phase anaerobic digestion**

Mesophilic-mesophilic (meso-meso), two-phase digestion may be the best process option for those seeking increased volatile solids reduction (VSR) and digester gas production without the complications of temperature staging. In lab-scale testing a Madison, Wisconsin, temperature phased anaerobic digestion (TPAD) provided higher VSR than meso-meso, two-phase—64 and 59 percent, respectively (Reusser 2001). But, in general, too little attention is being given to feed solids characteristics when establishing performance expectations. A general consensus has emerged that one of the two phases will need to be operated at thermophilic temperatures if Class A pathogen reduction is an objective.

Suez Lyonnaise and Infilco Degremont adopted a sequencing batch, draw-and-fill mode of operation for their 2-PAD™ system (Huyard 1999), which has been granted site-specific process to further reduce pathogens (PFRP) Equivalency based on pilot studies at Indianapolis, Indiana. Issuance of a general PFRP has been requested, but not yet issued. The batch holding time ultimately selected from the Indianapolis pilot studies was only eight hours. A longer interval will be needed to satisfy the Part 503 time-temperature compliance option for Class A pathogen reduction (i.e.24 hours at 55 deg.C).

Since July 2000, the Inland Empire Utilities Agency in western San Bernardino County, California, has been operating existing digesters in a three-stage mode that combines two-phase digestion and TPAD--mesophilic acid phase, followed by thermophilic and mesophilic methane-phase reactors in series (Drury 2001). The three-stage system is treating the solids production from treatment of about 2,2 m³/s of sewage. Elmhust, Illinois recently began operating a
series of one-day batch acid reactors, followed by a mesophilic, methane-phase digester. The batch reactors were designed for filling over a 12-hour period and, initially, will be operated at thermophilic temperatures (Wilson 2001).

North West Water (now United Utilities, UK) recently completed lab-scale studies on use of an acid-phase reactor to enhance pathogen reduction from mesophilic digestion, and is planning installation of a plug flow reactor (2-day SRT at maximum loadings) to continue its evaluation at plant-scale (Le 2000). The study investigators concluded that the main mechanism for pathogen kill is enzymic hydrolysis (the activity by the enzymes responsible for both cell lysis and hydrolysis). Mesophilic digesters operating in series achieved a 0.5 log increase in \textit{E Coli} kill compared to a control digester operating at 16 days SRT. Pre-treatment in a three-day SRT acid-phase reactor resulted in a 1.8 log increase in \textit{E Coli} reduction. Northwest Water has applied for a worldwide patent for its “enzymic hydrolysis” process.

Meso-meso, two-phase digestion may be a good choice for those seeking to provide a greater margin of Class B compliance from existing digesters. The need to maintain acid-phase SRT at 1.5 to 2 days under variable solids production is viewed by some as a problem. However, Baltimore is charting a future course with two-phase digestion at its Back River wastewater treatment plant, in anticipation of higher levels of VSR. Since Class A pathogen reduction is not needed in the near-term, both phases will be operated at mesophilic temperatures. WASA is still at the conceptual design stage for a new egg-shaped digester complex at the Blue Plains treatment plant, but anticipates initially operating in a meso-meso, two-phase digestion mode. Despite keen interest in producing Class A biosolids, WASA concluded that the cost and complexity associated with thermophilic-stage heating and heat recovery at large-scale may be too much for now (Sadick 2001).

**Temperature phased anaerobic digestion (TPAD)**

Treatment agencies in Duluth, Minnesota and Waterloo, Iowa have new TPAD facilities under construction. TPAD should be a good match for the feed solids characteristics at these plants—all high-purity oxygen WAS at Duluth, and predominately WAS at Waterloo. Several of the midwestern treatment plants that previously converted their existing conventional digesters to operate in the TPAD mode are now in the process of adding the capability of cooling down the second stage (mesophilic) digester. This capability is thought to be important to minimize impacts on dewatering and residual odors (Hobson 2001).

Sequential batch operation is one of the promising avenues for satisfying requirements for Class A biosolids, and may be more easily incorporated in TPAD than a two-phase system. In August 2000, Jefferson County completed an expansion of existing digesters at Birmingham, Alabama to enable operation in a sequencing batch, TPAD mode (Holbrook 2001). However, like the Suez Lyonnaise concept design for 2-PAD™, the Birmingham installation is designed for a batch holding time of only 6 to 8 hours—considerably less than the 24 hours needed to satisfy the 503 time-temperature requirements at 55 deg C. System operators will seek to satisfy the time-temperature requirements by operating at higher temperatures approaching 60 C.

Madison (Wisconsin) MSD has been investigating various advanced digestion schemes since February 2000 at lab-scale, and will soon begin the design of modifications to existing digesters at its 1.75 m³/s Nine Springs treatment plant to enable operation in TPAD mode (Reusser 2001). Likewise, King County (Seattle) is beginning design for conversion of the 4-tank digester complex at its South (formerly Renton) treatment plant to TPAD. In both cases, the decision to convert to TPAD was based on the desire to accommodate higher future solids loadings within the existing digester infrastructure. King County recently completed an extended pilot plant investigation of TPAD for its West Point treatment plant, where there is neighborhood pressure to reduce the number of digesters (Bucher 2001).

In summer/fall 2001, Black & Veatch will be sponsoring lab-scale studies at Iowa State University to investigate the stability and performance of a sequential batch TPAD scheme aimed at satisfying the Class A time-temperature requirements. Iowa State was the birthplace for TPAD in North America in the early to mid 1990s, but has been focusing its TPAD research on the treatment of animal wastes in recent years because of the lack of funding for municipal waste treatment research.

**Pre-pasteurization**

Pre-pasteurization schemes have not yet generated much attention in North America, but interest is growing along with recognition of the uncertainties of satisfying Class A requirements with continuous-flow two-phase digestion and TPAD. In most cases, pre-pasteurization is thought of as an “add-on” to conventional anaerobic digestion, although it is also potentially applicable with aerobic digestion. Pre-pasteurization provides a more certain route to achieving pathogen reduction and, accordingly, has been drawing greater interest for meeting newly enacted “enhanced
treatment” requirements in the UK and EU. Monsal and BHR Group have collaborated on some pioneering work in exploring the relationships between sludge rheology, mixing and heat transfer as applied to pasteurization of highly thickened biosolids in the UK (Brade 2001).

DC WASA has concluded that, if achieving Class A pathogen reduction was adopted as a high-priority objective for its planned digester improvements project at the Blue Plains plant, pre-pasteurization would be the most practical option (Sadick 2001). Alexandria, Virginia has opted to add pre-pasteurization facilities for this same reason. There are a number of proprietary packages for pre-pasteurization, based on a batch-operating concept. Recently, the Eastern Municipal Water District (California) and Ashbrook Corporation., Inc. have teamed to offer a pre-pasteurization package known as Eco-Therm™, based on a continuous, plug flow concept.

Cambi is a proprietary, thermal hydrolysis pre-treatment process, to be used in conjunction with conventional anaerobic digestion. Pasteurization is an incidental side benefit of using the Cambi process for downstream dewatering and other reported benefits. Employing Cambi solely for Class A pathogen reduction would probably be overkill. San Francisco is considering the Cambi process for its Southeast plant, where solids handling facilities are being relocated within the plant, and reducing the required volume of new egg-shaped digesters is a major consideration. Two mid to large-size Cambi installations are to come on line in UK over the next few years at Aberdeen, Scotland (mid 2001) and Dublin, Ireland (late 2002). But Cambi may be too complex for many POTWs.

OBSERVATIONS ON RESEARCH FINDINGS, OPERATING RESULTS

The wastewater industry is waiting for a consensus to emerge as to which one of the advanced digestion process options is best. But selection of the optimum alternative is likely to be site-specific, depending on a plant’s priorities, existing digester assets, and other factors. One common thread that emerges from the experimentation—anaerobic digestion appears remarkably resilient, contrary to its reputation of 25 to 30 years ago. At least at lab and pilot-scale, stable operation has been reported at low SRTs heretofore thought not possible.

A number of parameters and performance measures are of interest when considering a biological digestion process. Following are the authors’ observations on what we know and don’t know from the available experience with advanced digestion processes.

**Capability to achieve Class A pathogen Reduction**

There is a growing belief that public perception, negative news media coverage, and other factors will drive the need to treat biosolids to Class A standards. The enthusiasm over the potential of advanced digestion to fulfill this treatment need is being eroded by growing recognition of the difficulties in meeting US EPA’s high expectations for compliance with the Part 503 requirements for Class A. These requirements consist of two parts:

- **Performance** - reducing the densities of fecal coliforms to less than 1,000 MPN/gram TS, or salmonella to less than 3 MPN/4 grams TS
- **Operational** - ensuring that “every particle” has been exposed to conditions known to be effective in rendering the biosolids to be essentially “pathogen-free” (or at least below detection limits).

For the latter, there are essentially two routes for compliance with the operational provision for advanced digestions systems:

- Satisfying the time-temperature criteria specified in Part 503 through either batch or plug-flow operations (“Alternative 1”, Subpart D).
- Obtaining approval from the Pathogen Equivalency Committee for a PFRP-equivalent process, based on a comprehensive demonstration of the process’ capability to effectively reduce pathogen to non-detectable levels. (“Alternative 6”, Subpart D).
The latter route is daunting, as illustrated by the experience of Suez Lyonnaise at Indianapolis (Huyard 1998, 1999) and Metropolitan Water Reclamation District of Greater Chicago (Tata 2001). For most advanced digestion systems, the key to satisfying the requirements for Class A appears to be successfully incorporating sequential batch operation.

But even if a practical means is devised for adapting an advanced digestion system to meet the operational requirement for Class A, satisfying the performance requirement shouldn’t be taken for granted based on pilot testing at Los Angeles (Haug 2001) and lab-scale testing at Madison (Reusser 2001). Fecal coliform test results can be highly variable, and the same realization is emerging relative to *E Coli* testing in the UK (Le 2000). Testing for salmonella as an alternative pathogen-indicator may produce more consistent results, but at higher cost and less convenience.

**Volatile solids reduction (VSR), digester gas production**

Nearly all advanced digestion systems have reported either improved VSR reduction, or similar levels of VSR as single-stage, mesophilic digestion at significantly shorter SRTs (Schafer 2000). Madison investigators found that TPAD achieved similar VSR levels in about one-half the time as single-stage, mesophilic digestion (Reusser 2001). VSR from pilot-scale testing of TPAD at Seattle was comparable to that from the single-stage mesophilic digestion in the plant-scale digesters, even at significantly lower SRTs. Approximately 80 percent of the overall VSR occurred in the thermophilic stage, the remaining 20 percent in the mesophilic stage (Bucher 2001). These results were consistent with those from Madison, where most of the VSR was found to occur in the first-stage, thermophilic reactor.

Digestion of WAS fraction is more likely to be enhanced with advanced digestion than digestion of primary solids. Means of cell lysing other than advanced digestion are being investigated in the US and UK, and may be equally as effective in increasing VSR. The Orange County Sanitation Districts and six water companies in the UK, for example, are experimenting with a proprietary ultrasound technology that shows promise in this area (Morton 2001).

Overall system gas production (volume of gas produced per unit mass of VS destroyed) of advanced digestion processes does not appear to vary significantly from that expected from conventional, mesophilic digestion. Again, feed solids characteristics must be considered in setting performance objectives for VSR and gas production from advanced digestion processes.

**Recycle nutrient loads, nutrient content of processed biosolids**

With higher levels of VSR comes more complete conversion of particulate organic nitrogen to soluble ammonia and further lysing of cell mass leading to higher concentrations of soluble phosphorus. The resulting increased nutrient contents of recycled streams from sludge handling processes could become a challenge to treatment facilities required to control N and/or P from its discharge. These are unavoidable side-effects of advanced digestion; but, for most, are far outweighed by the benefits of enhanced pathogen reduction and VSR. Too little experience exists to know whether higher soluble phosphorus concentrations will lead to increased incidence or severity of struvite formation.

**Ability to handle “difficult-to-digest” solids/mitigate foaming**

A widely perceived benefit of both two-phase digestion and TPAD is the capability of these processes to effectively operate on all-WAS or pre-dominantly-WAS feed solids without significant foaming. Two-phase digestion was implemented at Du Page County to solve an historic foaming problem from conventional digesters operating on WAS. No problems with foaming have been encountered since the transition to two-phase (Buoy 2001). Additional documentation of these processes to successfully mitigate foaming tendencies is still limited--perhaps because foaming is often a periodic event and, even in conventional mesophilic digestion, is poorly understood despite being a recognized problem for decades.

**Digester loadings and volume requirements**

Both TPAD and two-phase digestion appear to provide opportunities of increasing the capacity of existing digestion facilities by taking advantage of their inherent higher biological reaction rates—if Class A pathogen reduction is not also a high priority. Designing for Class A may limit the extent to which higher loadings and shorter SRTs can be attained. King County (Seattle) is pursuing this attribute of TPAD for both its South (formerly Renton) and West Point treatment plants. At present, King County is assuming that a future “add-on” process will be needed to reach Class A.
Effect on downstream dewatering

Thermophilic digestion (including TPAD) of WAS has been shown to increase the polymer requirements for downstream dewatering in lab-scale tests (Murthy 2000, Novak 2000 and 2001). However, there is limited data to quantify these impacts at plant-scale, and the results to-date have been mixed. In early trials with centrifuge dewatering of thermophilically digested biosolids at its Hyperion treatment plant, the City of Los Angeles found dewatering impacts to be insignificant (Haug 2001). But the ratio of primary solids to WAS at Hyperion is still greater than 3:1 because of enhanced primary treatment. The Inland Empire Utilities Agency reports improved dewatering with its three-stage process, but primary solids represent about 65 percent of the total mixture to digestion (Drury 2001). Los Angeles County reported a 30 to 40 percent increase in polymer demand for centrifuge dewatering of solids from thermophilic digestion, compared to mesophilic digestion--despite not yet having a full-complement of WAS (Morton 2000). Post-process cooling and dual conditioning may be effective mitigation measures—as suggested for ATAD.

Residual odors

Los Angeles County has abandoned its interest in thermophilic digestion, in large part because of odors generated in plant-scale tests. The City of Los Angeles is proceeding with thermophilic digestion, at least for the near-term, with hopes that odors will be tolerable. Both the acid-phase of two-phase digestion and the thermophilic stage of TPAD are known to be odorous but, in both cases, the odors can be mitigated by downstream mesophilic digestion. A modest increase in odors attributable to ammonia release should be anticipated for both processes, but these odors are rapidly dispersed and may not be a significant impact.

ISSUES FOR FACILITY DESIGN

Adapting two-phase digestion and TPAD to satisfy the requirements for Class A pathogen reduction will require facility designers to “think outside the box”. There are a number of significant design issues to be mastered in shifting from general process concepts to detailed facilities design, three of which are noted here.

Operating protocol for digester system feeding, transfer between stages

The key to satisfying the time-temperature requirements for Class A pathogen reduction appears to be modifying semi-continuous flow process models such as two-phase digestion or TPAD to incorporate sequential-batch operation. Determining how this can best be accomplished without significantly compromising process stability and treatment performance will be the challenge of POTWs and their design engineers over the next 5 to 10 years.

System heating, heat recovery, cooling

Maintaining digester temperatures within target ranges and for the desired duration will be critical to fulfilling performance expectations. Heating to thermophilic temperatures requires about twice the heat input needed for mesophilic digestion. For example, Los Angeles County concluded that the steam required to maintain the thermophilic temperature of 55 deg C in its plant-scale digesters would be about 2.3 times that needed to run at 35 deg C (Morton 2000). So heat recovery and will be needed for economical operation and the importance of good mixing to distribute the heat input and ensure uniform operating temperatures should not be overlooked. Advanced digestion mixing systems will need to cope with varying liquid levels, as draw-and-fill becomes the operating norm. At present, the equipment needed for trouble-free heat recovery is far from perfected. Early designs have pressed conventional hot water-to-sludge heat exchangers into this new duty, but operations and maintenance experience is still too limited to gage the consequences.

System instrumentation and control (I&C)

More comprehensive I&C will be needed for future advanced digestions systems—both for internal and external purposes. Internally, I&C will be needed for process control and to ease the burden of sequential batching or similar schemes on plant operators. Externally, I&C will build credibility that advanced digestion processes are run consistently and in accordance with established protocols, and enable continuous monitoring of operating temperatures and perhaps other critical performance parameters. Like it or not, POTWs purporting to produce Class A biosolids will bear the burden of proof relative to in-plant QA/QC and end-product quality.
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