

OBSTACLES IN THE IMPLEMENTATION OF ANAEROBIC TREATMENT TECHNOLOGY

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ABSTRACT

The anaerobic methane fermentation process is able to be used for a wide variety of applications including: on-site wastewater treatment (septic tanks), sludge stabilization, centralized municipal wastewater treatment, industrial wastewater treatment, municipal solid waste management, hazardous waste management, agricultural waste management, and biogas generation. These applications are in various stages of development—from proven technologies (e.g. septic tanks and sludge digestion), to developing technologies (e.g. use in hazardous waste remediation). Municipal and industrial wastewater treatment fall in between these extremes; they are developed, but not fully proven. This paper will concentrate on these two applications in terms of obstacles to their full implementation.

While much progress has been made, over the past 25 years, in our understanding of the anaerobic treatment process for liquid wastewater treatment using high rate reactors (such as the anaerobic filter and UASB process), and over 500 full scale plants exist, the development and implementation of the process has not been as quick as was expected by numerous researchers and practitioners. Possible reasons for this delay include: a decline in energy prices, several early negative experiences with these applications, the need for post treatment following anaerobic treatment in certain instances, a large previous investment in aerobic technology, and a perceived lack of credibility of the process.

Perhaps the most significant obstacle is lack of experience with the process. In reviewing the history and subsequent development of sanitary engineering, it can be seen that engineering practice often has to run ahead of basic science to resolve sanitation challenges. Because of this, there is often a long lag time between the implementation of technology and a rational design procedure for that technology. Rational design procedures are needed to build and operate reliable, economic wastewater treatment processes. This assures credibility for the engineers and the operators of such technologies. Rational design must depend on both advances in basic science as well as accumulated operating experience, and ultimately, this takes time.

INTRODUCTION

Microorganisms play a major role in the biogeochemical cycling of nutrients in the ecosphere. Central to cycling of all nutrients are the microbial activities involving the characteristic paths of carbon between the biotic and abiotic portions of the ecosphere (1). This cycling occurs on a global scale producing profound effects on the geology and present environment of our planet (2).

The microbially mediated decomposition portion of the carbon cycle can be coupled with oxygen or can occur with no external electron acceptor. With oxygen, respiratory metabolism occurs and results in higher energy yields than fermentative metabolism (no external electron acceptor). Therefore, when oxygen is present, aerobic degradation predominates over anaerobic fermentation (3). Nonetheless, anaerobic decomposition still plays a key role in the carbon cycle in the ecosphere due to ecological effects (i.e. anaerobic environments).

The use of these phenomena for the management of wastes is the key to biological waste management. Engineers attempt to harness the decomposition (catabolic) capabilities of microorganisms. Using fundamental science and appropriate engineering principles, bioprocess engineers strive to rationally design and control biological processes.

Modern sanitation began with the discovery by Snow that contaminated water can spread cholera, shortly followed by the pioneering work of Pasteur and Koch who elucidated the microbial nature of this contamination (4). Efforts for the purification of wastewater resulted in the development of several anaerobic processes (5,6) and later the trickling filter (7) and the activated sludge process (8). The anaerobic systems consisted of a solids capturing tank followed by a land application system. By capturing solids, the land application system performed in a more efficient manner. The early anaerobic processes (septic, Travis and Imhoff tanks) were successful in capturing solids, but poor for the removal of soluble BOD. These systems were abandoned with the development of more strict effluent standards.

For municipal wastewater treatment, emphasis was placed on aerobic treatment systems, and remains this way to this day.

It is interesting to note that all of these processes (anaerobic and aerobic) were developed in response to an acute problem and in fact the engineering of these processes preceded the fundamental understanding of the basic science. Dick (9) points out that this is often the case in sanitary engineering practice. In fact, a period of 50 years passed between the inception of activated sludge and the attainment of a rational design procedure.

Anaerobic treatment thus has a long history for waste management (5). This paper will discuss the numerous applications of anaerobic treatment technology, and note the state of development and usage of the technology for the various applications. It will then define and discuss the major obstacles which lessen the use of the anaerobic methane fermentation process for the treatment of liquid (municipal and industrial) wastewaters.

APPLICATIONS OF THE ANAEROBIC TREATMENT PROCESS

The anaerobic methane fermentation process, or anaerobic treatment, is the use of biological phenomena which result in the conversion of organic materials to methane and carbon dioxide in the absence of molecular oxygen. In the area of waste management, the anaerobic treatment process has many applications, including:

1. Septic tanks (for on-site systems)
2. Sludge digesters
3. Industrial wastewater treatment
4. Municipal wastewater treatment

5. Hazardous waste management
6. Municipal solid waste management, and
7. Agricultural waste management/Biogas generation.

These categories are not mutually exclusive, as there is overlap among several items (e.g. industrial wastewater treatment and hazardous waste management). As will be shown in this paper, the application of anaerobic treatment is also quite varied in terms of degree of development and usage among categories from widely practiced (septic tanks) to those in the experimental stage (application in hazardous waste management). Each of these applications is briefly discussed in the following paragraphs.

1. **Septic tanks.** McCarty (5) discussed the early history of the anaerobic wastewater treatment process involving the development of various types of reactors which combined hydrolysis, sedimentation, and fermentation within a simple unit (i.e. the septic, Travis, and Imhoff tanks). Of these, only the septic tank is still in use today, but primarily for on-site, individual household, treatment. According to the United States Environmental Protection Agency, approximately 18 million housing units, or 25% of all housing units in the United States dispose of their wastewater using on-site wastewater treatment and disposal systems. These systems include a variety of components and configurations, the most common being the septic tank/soil adsorption system (10). The number of onsite systems has increased since the time of that estimation. Jewell (6) noted that a properly designed septic tank (with multiple compartments) is able to achieve good BOD and suspended solids removal.

2. **Sludge digestion.** The processing and disposal of sludge which results from conventional wastewater treatment operations (e.g. primary sedimentation and activated sludge) is perhaps the most complex problem facing the engineer in the field of wastewater treatment (11). Numerous sludge operations and processes are used to reduce the water and organic content of the sludge and/or used to prepare the sludge so that it is suitable for final disposal or reuse. One of the major categories of treatment is stabilization. Sludges are stabilized to 1) reduce pathogens, 2) eliminate offensive odors, and 3) inhibit, reduce, or eliminate the potential for putrefaction. Anaerobic sludge digestion continues to be the dominant sludge stabilization process (11).

3. **Industrial wastewater treatment.** While the use of anaerobic processes for wastewater treatment is old (5), major development of the technology for large volumes of liquid wastewater treatment has only been over the past 20 years. Earlier digester designs (mainly batch and continuous stirred tank reactors) achieved effective contact between organisms and waste, but needed lengthy retention times, and consequently, large digester volumes. These type of designs were acceptable for high strength particulate wastes such as sludges, and for low volumes of liquid wastewaters (such as on-site systems) but not for large volumes of liquid wastewaters. Major progress was made when researchers began to understand the importance of designing anaerobic reactors which could maintain high solids residence times (with a buildup of high active biomass concentrations) for good process efficiency and stability, with low hydraulic retention times for system economy. This resulted in the development of the high rate reactors such as the anaerobic filter, the upflow anaerobic sludge blanket, and the fluidized or expanded bed reactors. There are numerous other types of high rate configurations (12). A recent workshop was held to highlight the advances made in the development of anaerobic treatment processes for this application (13). Over 500 full scale facilities exist at the present time, so this is obviously a well developed application of anaerobic treatment technology, but it remains to be accepted as a fully proven application among many design engineers.

4. **Municipal wastewater treatment.** As was mentioned previously, anaerobic systems consisting of solids capture/fermentation tanks followed by soil application, were the early choice of wastewater treatment systems, however, these systems were abandoned with the development of stricter effluent standards. However, researchers continued to investigate the use of anaerobic processes for municipal wastewater treatment.

It should also be noted that anaerobic ponds can be considered anaerobic reactors as well and are viable parts of a waste stabilization lagoon or pond system for wastewater treatment in warmer climates. In general, however, very large land areas are needed for these systems, but they may be economically viable where inexpensive land is available (14). Alaerts *et al.* (15) estimated that land must cost less than \$5 (US \$) per square meter for ponds to be economically feasible.

Similar to industrial wastewater treatment, major progress was made in the area of anaerobic treatment of municipal wastewaters with the development of the newer generation of high rate anaerobic reactor configurations. The application of these reactors to sewage treatment has been discussed by Switzenbaum and Grady (16) and Jewell (6).

A key factor in the performance of any of the newer high rate anaerobic reactors treating sewage is temperature. It is the general consensus of most researchers and practitioners, that anaerobic treatment processes are only applicable to sewage treatment in warmer climates. This is somewhat fortuitous in that much of the tropical world is without any basic sanitation, and therefore anaerobic technology, being relatively simple and inexpensive, is most applicable for tropical areas. This has led to several demonstration and full scale projects, including Cali, Colombia; Bucaramanga, Colombia; and Kanpur, India (Schellinkhout and Collazes (17)). In addition to on-site (individual households) and central wastewater treatment facilities, anaerobic reactors can also be used on an intermediate scale (communal anaerobic reactors) for sanitation programs. Alaerts *et al.* (15) proposed the use of anaerobic reactors in combination with shallow or small bore sewers for local pretreatment. The anaerobic pretreated effluent would then be transported outside of the city where land is less expensive, via a cheap sewer or drain pipe. Since most of the settleable solids have been removed, off site treatment by ponds or application on inexpensive land is possible. The authors state that this alternative may be economical for densely populated, unplanned residential areas.

Several research labs continue to develop anaerobic processes for sewage treatment, in temperate climates. For example, van der Last and Lettinga (18) report on the development of the expanded granular sludge bed reactor (EGSB). Other researchers are looking at anaerobic reactors for upgrading overloaded conventional activated sludge treatment plants. (19, 20). Nonetheless, anaerobic sewage treatment while possible in certain locations, is not accepted as a proven treatment technology.

5. Hazardous waste management. Given time for organism acclimation, there is a broad range of compounds which can be degraded anaerobically. Aromatic compounds such as phenol, catechol, and benzoic acid are known to be anaerobically degradable, and at one time were believed to be nondegradable under anaerobic conditions. In addition, numerous chlorinated hydrocarbons can be degraded anaerobically. In some cases, anaerobic conditions may be the only way to degrade so-called recalcitrant compounds (21). Degradation of compounds as a means of hazardous waste treatment offers the advantages of detoxification or even destruction of an undesirable compound. This is often preferable to immobilization of compounds in terms of costs, and long term liability issues.

Of particular interest in hazardous waste management are the halogenated compounds. Vogel *et al.* (22) and Tiedje *et al.* (23) discuss the extant literature and known breakdown pathways for halogenated aliphatic and aromatic compounds, respectively, in anaerobic systems.

The application of anaerobic treatment for hazardous waste treatment is still in the early stages of development. The potential applications for groundwater, soils, and industrial wastewaters contaminated with hazardous contaminants is high. Further studies are necessary to define optimal conditions.

6. Municipal solid waste management. Municipal solid waste management presents a problem. Large amounts are generated (approximately 200 million tons per year in the U.S.) and most is landfilled (about 67%) (24). Since landfilling is becoming expensive and capacity is diminishing, many municipalities are looking at alternative management practices such as recycling, composting, and anaerobic methane fermentation of the organic fraction of the waste stream.

Anaerobic digestion was used from 1936 to the mid 1950s by several communities in commercial scale digesters for treatment of municipal solid waste (25). These generally were abandoned due to unfavorable

economics and poor performance. Over the past 20 years, however, there has been significant progress made in understanding the role of anaerobic treatment in municipal solid waste processing.

One significant advance has involved various efforts to enhance gas recovery from landfills including recycling of leachate (26). Another significant development has been the development of the dry digestion process (27). Dry digestion may be defined as digestion of materials present at total solids concentrations greater than 25%. Several dry digestion systems are currently marketed as commercial processes including the Biocel process (28), the Dranco process (29) and the Valgora process (30). The processes are able to divert the organic fraction of municipal solid waste from landfills (thus reducing pollution from landfills and extending the life of landfills), and to generate useful products -methane and the residual compost. Their usage is at present quite small but the potential of anaerobic treatment for municipal solid waste processing (including leachate recycle) is promising. Saw (31) concluded that insufficient information is currently available to encourage full scale exploitation of this technology, however given the advances in feedstock preparation, and reactor system design (along with the environmental benefits compared to incineration and landfilling) development of anaerobic treatment of municipal solid waste should be encouraged.

7. Agricultural waste management/Biogas generation. The anaerobic methane fermentation process can also be applied to other organic substrates such as plant biomass, animal manure, and industrial organic solid wastes (32). Similar to sludge digestion, manure digestion is practiced for solids destruction and stabilization. The key to successful economic implementation of manure digestion involves a holistic view of its uses for pollution control, recovery of valuable resources in the digestion residue, and utilization of energy in the biogas. In addition, the methane produced is most valuable if it can be readily used, rather than converted into a liquid, stored on site, or purified and sent via pipeline to another site (33).

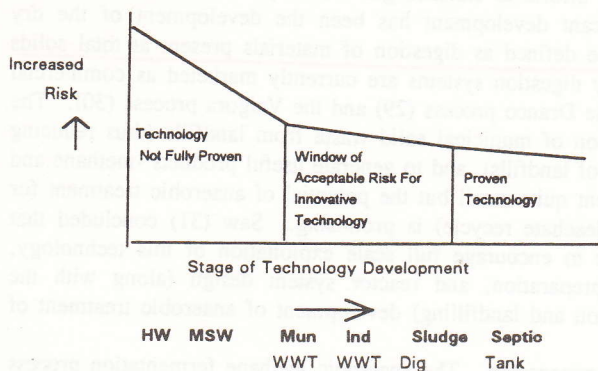
Others have looked at agricultural crops as biomass for biogas generation (34,35), but this practice is not generally considered a competitive energy process at current energy prices. However, it is a renewable source of energy, and biogas from waste materials is used in some developing countries (36).

DISCUSSION

It is obvious that there are a wide variety of anaerobic treatment technology applications. The various applications have in common a similar fundamental microbiological and biochemical basis (they produce methane as an end product). However, the rheology of the feedstocks (dilute wastewaters, concentrated wastewaters, semisolid residues, high solid residues) and treatment goals (detoxification of hazardous contaminants, creation of a dischargable effluent, stabilization of an organic residue, etc.) are quite different. In addition, some of the applications are quite old and thus are documented by a large amount of operational experience (such as sludge digestion, and on-site treatment) while others (such as hazardous waste management) are very new, and have very little or no operational experience.

The present status of the application of anaerobic treatment technology thus varies from technologies which are not fully developed to those which are proven technologies. Traditional engineering practice has always dictated a low element of risk for construction of full scale facilities. The diagram shown in Figure 1 shows that risk of failure is high for developing technologies. This figure was developed by the USEPA (37) to promote innovative technologies (designs leading to greater cost and energy savings). Innovative technologies can be thought of as reasonable developed technologies which are not fully proven, but which pose a good possibility for success. Superimposed on the EPA figure (along the bottom axis) are the various anaerobic treatment applications.

Figure 1. Stages in the Development of Anaerobic Treatment Technology.



This discussion will focus on anaerobic treatment technology of municipal and industrial wastewaters. Note that the application of the newer generation high rate reactors, municipal and industrial wastewater treatment, fall into the innovative range. In terms of these applications, Iza *et al.* (38) in summarizing an international workshop on anaerobic treatment technology (held in 1990) concluded that anaerobic digestion has a sound foundation

(scientific and engineering) and a solid base of operational experience and therefore it can be regarded as a mature technology.

The vast majority of the 500 full scale anaerobic treatment plants are for industrial wastewater treatment. Very few are for municipal wastewater treatment. Thus, most of the operating experience is for industrial wastewater treatment. This had been noted by Switzenbaum and Grady (16) in summarizing a specialized workshop held on anaerobic sewage treatment (held in 1985). The authors stated that anaerobic sewage treatment has great potential-especially in tropical climates. However, they noted that design methodologies are not as well developed as for industrial applications. Since the time of that workshop, several full scale facilities have been put into operation, but still broad scale application of the process is lacking. Therefore while both municipal and industrial application fall into the innovative area of development, it is clear that anaerobic industrial wastewater treatment is much closer to being a proven technology than anaerobic sewage treatment.

While much progress has been made over the past 25 years in terms of our understanding of the anaerobic treatment process for liquid wastewater treatment using high rate reactors, and many successful case studies can be documented, and over 500 full scale plants exist, the development and implementation of the process has not been as great as expected by many researchers and practitioners. The rest of this discussion will focus on possible reasons for this situation.

1. *Research and Development Needs.* Since these applications are not fully proven, there are obviously numerous R&D concerns with the technology. These needs, including such items as proper nutrition, startup of reactors, and formation of granules, have been elucidated by Switzenbaum and Grady (16) and Iza *et al.* (38).
2. *A decline in energy prices.* During the time of the initial development of the high rate anaerobic processes, in the 1970s, energy prices were very unstable and rising due to the so called oil crisis. Many experts believed that the prices would keep rising. However, the cost of energy has actually declined since that time and has been quite stable over the recent past. This fact has reduced the possible revenues from gas production from wastes, and has also offset the advantage of lower operation costs (compared to aerobic treatment). Thus one of the main advantages of anaerobic treatment over aerobic treatment (lower energy costs) has been minimized.
3. *A long lasting economic recession.* Much of the world has been coping with a persistent economic recession over the past 5 years. This has delayed industrial interest in implementing newer waste management techniques, and has slowed enforcement of regulations.
4. *Anaerobic treatment is not necessarily the most economical solution to a problem.* In some cases, where land is available and inexpensive, waste stabilization ponds are the most economical solution. Industries will not justify investments with long payback periods when other means are possible.

5. *Proper role of anaerobic treatment.* Iza *et al.* (38) noted that anaerobic treatment should be considered as one of many waste treatment technologies (such as aerobic treatment, membrane processes, *etc.*). It is thus another tool for the design engineer to be used alone or integrated with other technologies in the treatment sequence. Like any process, it has limitations, and the choice of any process for a given wastewater is often influenced by specific conditions. No system is applicable for every waste in every situation. The proper role of anaerobic processes is not always clear in terms of waste applicability, treatment goals, and byproduct usage.

6. *Need for preprocessing and post treatment.* Closely related to the previous item is the need for unit operations preceding and following the anaerobic reactor in the treatment train. This situation must be carefully considered in the application of anaerobic technology (or for that matter any technology). For example, anaerobic sewage treatment, while playing an important role in basic sanitation, may not produce an acceptable effluent for discharge into a surface water, in terms of BOD. In addition, the anaerobic process will not remove very much nitrogen or phosphorus, which is becoming more and more necessary.

7. *Previous investment in aerobic technology.* In terms of industrial wastewater treatment, many industries have already invested in aerobic, conventional technology and (related to items 3 and 4) are not eager to spend more money building a new anaerobic process.

8. *Early failures.* With the development of the high rate anaerobic reactors, a great deal of discussion was held concerning the simplicity of the process (especially the UASB reactor). While the UASB is relatively simple, it still (like any wastewater treatment process) requires care in the design, construction, and operation of the process. There were several early failures of UASBs due to scale up problems, absence of pilot studies, poor choice of materials, *etc.*. This has caused some to be skeptical about anaerobic treatment.

9. *Odors.* Odor management is a most important consideration for any waste management facility. This is especially so with anaerobic processes when the potential and perception of odors is great.

10. *Credibility.* Pohland (39) in 1971 reported that.. "reports on the application of anaerobic processes for waste treatment have indicated difficulties with process stability which have resulted in pessimism concerning the future value of anaerobic treatment to water pollution control." Saw (31) twenty seven years later reports on a credibility problem with anaerobic treatment in the United Kingdom. In spite of numerous advances and application of anaerobic treatment technology, this pessimism and lack of credibility continue to delay the implementation of the process.

A common theme among the ten reasons cited above is lack of experience. This is perhaps the most significant obstacle. With more design and operating experience, the proper role of anaerobic treatment will become clearer, pre- and post-treatment needs will be better understood, and many of the problems such as odor control, choice of construction materials, and system startup will be resolved. Along with experience, designers will gain expertise in anaerobic treatment and appreciate its benefits—especially in terms of lower sludge production. Indeed the magnitude of the sludge disposal problem and its associated cost and environmental impact from activated sludge has been slow in being recognized. In fact, it has been accepted as a normal consequence of wastewater treatment.

In reviewing the history and subsequent development of sanitary engineering, it can be seen that engineering practice often has to run ahead of basic science. Because of this, there is often a long lag time between the implementation of technology and a rational design procedure for that technology. Consider that over 50 years passed between the invention of activated sludge and a rational design procedure for the process. Even today, there are still some major operational problems such as chronic bulking (40). Rational design procedures are needed to build and operate reliable, economic wastewater treatment processes. This assures credibility for the engineers and the operators of such technologies. Parallel research and development paths are needed to secure rational design procedures for anaerobic treatment technology. Many fundamental questions can only be answered by controlled laboratory studies (such as the role of hydrodynamic factors on biofilm density and thickness, the fate of various organic waste fractions, and the interaction of both with temperature). Practical design information such as how a

structure should be configured for optimum gas/liquid separation, can only be learned from demonstrations and full scale systems. Both types of studies are needed.

Rational design is dependent on a clear understanding of the chemical, physical, and biological phenomena occurring in a reactor. Such information can be assembled into mathematical models which can simulate the process and be used to understand how a process works. Often, better understanding of a process can be obtained this way on a real-time basis. However, given the extremely complicated nature of the phenomena in an anaerobic reactor, all of the pertinent phenomena can never be totally described, so rational design must also depend on operating experience. Unfortunately, it takes considerable time to gain this experience.

SUMMARY AND CONCLUSIONS.

The anaerobic methane fermentation process is able to be used for a wide variety of applications including: on-site wastewater treatment (septic tanks), sludge stabilization, centralized municipal wastewater treatment, industrial wastewater treatment, solid and hazardous waste management, agricultural waste management, and biogas generation. These applications are in various stages of development-from proven technologies (e.g. septic tanks and sludge digestion), to developing technologies (e.g. use in hazardous waste remediation). Municipal and industrial wastewater treatment fall in between these extremes; they are developed, but not fully proven. They can be considered innovative technologies.

While much progress has been made, over the past 25 years, in our understanding of the anaerobic treatment process for liquid wastewater treatment using high rate reactors (such as the anaerobic filter and UASB process), and over 500 full scale plants exist, the development and implementation of the process has not been as quick as was expected by numerous researchers and practitioners. Possible reasons for this delay include: a decline in energy prices, several early negative experiences with these applications, the need for post treatment following anaerobic treatment in certain instances, a large previous investment in aerobic technology, and a perceived lack of credibility of the process.

Perhaps the most significant obstacle is lack of experience with the process. In reviewing the history and subsequent development of sanitary engineering, it can be seen that engineering practice often has to run ahead of basic science to resolve sanitation challenges. Because of this, there is often a long lag time between the implementation of technology and a rational design procedure for that technology. Rational design procedures are needed to build and operate reliable, economic wastewater treatment processes. This assures credibility for the engineers and the operators of such technologies. Rational design must depend on operating experience as well as advances in fundamental aspects of anaerobic treatment. We are gaining in both areas with time.

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