THE EFFECTS OF FACILITATED GAS RELEASE ON THE ANAEROBIC FIXED FILM BIOLOGICAL PROCESS

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Summary

The primary objective of this research was to develop operating conditions and reactor configurations which would optimize the anaerobic fixed-film treatment process. A secondary aim was to assess the treatability of swine production wastewaters with the anaerobic fixed-film process.

To realize these objectives, three anaerobic fixed-film biological reactors were constructed and used for treating high-strength wastewaters from the Oklahoma State University swine barn. The control reactor was of conventional design and utilized a vertical flow regime. One of the experimental reactors was identical to the control, with the exception that its flow regime was horizontal rather than vertical. The other experimental reactor was also horizontally oriented but, in addition, was subjected to periodic mixing. In this way, the effects which mixing and reactor configuration have on the gas production and treatment efficiencies could be examined.

It was found that, despite efforts to optimize the process, mixing was detrimental in all instances. With even minimal amounts of mixing, solids were lost from the system, resulting in poor effluent quality. As regards the effects of reactor configuration, it was found that the horizontal orientation resulted in the best

effluent and, correspondingly, the highest gas production. The reactor employing the conventional vertical configuration produced effluents which were quite similar, though slightly lesser, in quality as compared to the horizontal reactor. Reasons for the findings were hypothesized and further research is being conducted to verify the proposed causes.

Statement of the Problem

On June 26, 1984, the U.S. House of Representatives passed a bill entitled the Water Quality Renewal Act of 1984.[1] Included in the bill were clauses which addressed the problem of nonpoint source pollution from agricultural and silvicultural practices. Recently identified as the principle cause of water quality problems in six out of the ten Environmental Protection Agency regions,[2] nonpoint pollution had long been recognized as a major factor affecting the nation's stream quality yet, until passage of the Water Quality Renewal Act, had not received proper legislative attention.

Through this act, state governments are directed to identify and control nonpoint sources of pollution and to administer a $150 million per year grant program which was established for the purpose of implementing nonpoint control projects. According to the directives, up to 50% of a state-funded project and from 50 to 60% of a locally-funded project are to be paid for by the grant program. The added incentive for local projects is hoped to encourage remedial action at the source which, according to the Water Pollution Control Federation, is the preferential point of control.[3]

In Oklahoma, as in most agricultural states, nonpoint pollution resulting from animal wastes presents a problem which is most easily controlled at the source. In particular, swine waste produced in confinement units offers an opportunity to not only reduce the pollution potential at the source but, in all likelihood, to also prove economically advantageous. As swine production becomes more centralized, hogs are being raised in confinement pens which minimize land requirements and improve meat quality. Waste products are generally removed by hydraulically flushing them into a drain system which then empties into a lagoon. From there, the contaminated water may either evaporate, percolate into the subsurface systems, or drain into nearby surface waters. If serious efforts are to be made to control nonpoint pollution, this type of minimal treatment will not remain satisfactory.

Fortunately, a promising technology exists which, in addition to significantly reducing the pollutant risk, is capable of producing valuable byproducts. Anaerobic treatment has been proven by recent research to be a practical method of pollution control for liquefied swine waste as well as a means of producing methane gas and digested sludge. The gaseous product can be used for either heating purposes or electricity generation and the digested sludge can serve as a quality soil amender.

One hog farm near Austin, Texas, has become practically energy self-sufficient by integrating its treatment of manure wastewater into the rest of the farm operation.[4] The wastewater is treated in an anaerobic digester which produces both methane gas and a nutrientrich effluent. The gas is used to heat the digester and to fuel other farm equipment. The effluent is applied as fertilizer to a crop of milo, which in turn is used as feed for finishing pigs and cattle.

Another potential byproduct resulting indirectly from anaerobic treatment is recycled waste. To minimize reactor size, it is a common practice to first screen the liquid waste to remove large solids. These solids consist mostly of undigested feedstuffs which, when supplemented with vitamins and minerals, may be recycled as a relatively inexpensive feed.[5]

In previous decades, anaerobic treatment was accomplished with suspended-growth systems. These reactors worked fine at removing pollutants but were necessarily large in size so that a sufficient solids detention time could be provided. In the past few years, attention has been drawn to fixed-film reactors which are capable of maximizing the solids detention time while minimizing the hydraulic residence time and, therefore, the reactor size. Though still in the experimental stages, all evidence points to the increased use of fixed-film systems.

As with all new methodologies, research is needed to optimize the process. Anaerobic fixed-films treating wastewaters high in solids content are susceptible to plugging and short-circuiting. One proposed solution is to intermittently mix the contents. Besides preventing the above mentioned problems, mixing is believed to benefit anaerobic processes in another way. Finney and Evans[6] propose that the gas bubbles generated during methanogenesis inhibit transfer of substrate into intracellular spaces by enveloping the bacterium and imposing a barrier to diffusion. Therefore, they conclude that agitation, which reduces the surface tension between the bubble and the particle and allows for buoyant release at a smaller bubble diameter, would minimize the inhibitory effect, thereby making greater gas production rates possible. However, the findings by Finney and Evans were not conclusive and results reported by other researchers have been quite mixed.[7]

Another effort to optimize the anaerobic process has been to change the reactor profile from vertical to horizontal.[8] With a two-stage fixed-film anaerobic reactor, of which the methanogenic stage was horizontal, Messing attained up to 89% COD reduction and, more impressively, product gas containing more than 90% methane. Messing credited the exceptional gas composition, in part, to the horizontal configuration which allowed for a greater fluid-to-gas interface. Tait and Friedman[9] operated an anaerobic RBC (AnRBC) on synthetic wastewater and found the design, which incorporated both the mixing and horizontal concepts, to be both practical and feasible. However, no studies pertaining to the effects of rotation alone were conducted. McCarty and Bachmann[10] are reported to have done so with an AnRBC of their own design and to have found no improvement in efficiency due to rotation. However, followup research by McCarty and Bachmann resulted in the development of an anaerobic baffled reactor which also utilized the horizontal flow scheme. COD removal efficiencies and methane generation rates were reported to have been at least as good as conventional designs.

Therefore, in spite of the cited attempts to optimize and understand the anaerobic fixed-film process, the actual role of mixing and reactor orientation were still unknown. Also, the feasibility of using fixed-film technology for treating liquefied swine waste was in need of further study in order that full-scale implementation of such a system could be confidently performed.

Materials and Methods

To accomplish the goals of this research, three anaerobic fixed-film reactors were built and operated in a side-by-side fashion. The external shell of each reactor was made from 8" diameter PVC pipe with 3/8" walls. Into each reactor were placed an equal number of 1" diameter pall rings, providing an internal media surface area of approximately 25 ft^2. The liquid volume in each reactor was 13.3 liters and liquid temperatures were maintained at 36°C (± 1°C).

The control reactor was conventionally designed in that it was vertically oriented and had an upflow feed system. The two experimental reactors were identically constructed, possessing a cage mounted on a horizontal shaft. The pall rings were placed inside the cage which itself was placed inside the horizontal reactor. The liquid level in the two experimental reactors was maintained at two-thirds depth, similar to the operational procedure of an RBC. The one difference between the horizontal reactors was that one of the shafts was attached to a variable-speed motor whereas the other one remained unattached. In addition, all reactors were made air-tight.

Pig manure collected from the OSU swine barn served as the organic feed source. Manure was periodically collected from finishing hogs and stored at 4°C. When feed was to be made, the manure was diluted to the desired concentration and then large solids removed using a screen with 1/16" openings. Diluted feed was kept in a converted refrigerator from which the research units were directly fed.

The reactors were initially seeded with digester sludge from the City of Stillwater's wastewater treatment plant. After filling with seed, each unit was purged of oxygen by passing several volumes of nitrogen gas through the liquid. Two months were allowed for the reactors to attain steady-state.

Parameters monitored included influent and effluent volatile fatty acids, total and volatile solids, COD, alkalinity, pH, temperature and total gas production. Volatile fatty acid components and gas composition were determined by gas chromatography using flame ionization and thermal conductivity detectors, respectively.

Results and Observations

The targeted feed concentration for this phase of the research was set at 20,000 mg/L. Initial flow rates were set at 140 mL/min, resulting in a loading rate of approximately 5 kg COD/m^3/day. Corresponding volatile solids concentrations and loading rates were 10,000 mg/L and 2.5 kg VS/m^3/day, respectively. The control reactor was capable of removing 60% of the COD and 56% of the volatile solids under these conditions. In comparison, the horizontal nonmixed reactor removed 66% of the COD and 57% of the volatile solids whereas the mixed reactor removed only 52% of the COD and 47% of the volatile solids.

These results were disturbing in that it had been expected that the mixed reactor would yield the best results. The findings to the contrary suggested that, though having been proven to be beneficial for suspended growth systems, mixing was detrimental to anaerobic fixed-film units. However, before making such a conclusion, efforts were made to correct the situation. Originally, the mixing had been continuously applied with the exception of being shut off for ten minutes during feed cycles. Feeling that perhaps this nonmix interval was not long enough for the solids to settle in the reactor, the interval was increased from ten minutes to 29 minutes of a 30 minute cycle. In other words, mixing was applied for only one minute every 30 minutes. In addition, the degree of mixing was reduced from five RPM's to two RPM's, the lower limit of the variable speed motor. Seeing no significant improvement in effluent quality, the decision was made to provide only minimal mixing (15 seconds every 30 minutes) and to reduce the organic loading from 5 kg COD/m^3/day to 1 kg COD/m^3/day. It was believed that, by minimizing the stress on the system, the loss of solids in the effluent would be reduced. The reduction in organic loading was made for all reactors so that equal comparisons could still be made.

Indeed, removal efficiencies were improved, though the mixed reactor continued to exhibit the worst treatment. COD removal for the mixed reactor increased from 52% to 71%, with volatile solids removal increasing from 47% to 55%. At the same time, however, the other two reactors also improved considerably. The control reactor was capable of removing 90% of the COD and 84% of the volatile solids and the nonmixed horizontal unit removed 93% of the COD and 88% of the volatile solids.

At this point, mixing was considered to be of no use to the anaerobic fixed-film process. As a final measure of establishing the claim, the mixing motor was removed from the mixed reactor and attached to the nonmixed system. In doing this, the effects of mixing on a well established and highly efficient system were examined. In addition, the previously mixed unit was monitored for any changes in effluent quality or gas production.

The results were not surprising. The effluent solids concentration from the previously mixed reactor improved from an average of 5780 mg/L to 3010 mg/L. The newly mixed reactor's effluent deteriorated almost instantly once the mixing motor was engaged. The solids concentration rose from an average of 3120 mg/L to a high of 90,000 mg/L. This value dropped steadily for the next few weeks but never attained the previous low concentration. Gas production from the newly mixed reactor initially surpassed that of the nonmixed unit (218 mL/hr and 186 mL/hr, respectively) but, within a week, returned to expected values (220 mL/hr for the newly mixed and 241 mL/hr for nonmixed). Most likely, this change was due to gas entrainment in the liquid phase of the nonmixed reactor.

All of these findings point to the belief that the microorganisms in anaerobic systems do not attach themselves to media surfaces in the same way as do aerobic microorganisms. Successful applications of rotating fixed-film aerobic systems are commonplace and, in fact, are what suggested their use in anaerobic treatment. However, current debate exists as to whether anaerobes attach themselves to the media or are merely entrapped by it. At the recent International Conference on Fixed-Film Biological Processes, a few papers were presented on the use of fixed-films in mixed systems. Discussion arose as to the effects of mixing yet no concensus could be attained. It should be noted that none of the researchers had performed a side-by-side study as is presented here but, rather, were relating experiences of work with solitary reactors. Since mixing was known to be beneficial to aerobic systems, several had assumed the benefit and not experimented with it.

As regards the configuration aspect of this research, more favorable findings have been obtained. From the work completed thus far, it appears that the horizontal orientation offers a distinct advantage over the vertical. At the two loadings studied, the horizontal reactor was capable of attaining higher organic removal efficiencies and slightly greater gas production rates than the vertical unit.

Two reasons for these results are hypothesized. First, due to liquid depth, a greater partial pressure is exerted on the dissolved gases in the vertical reactor, resulting in higher gas solubilities. This being the case, more gas would remain dissolved and gas production rates would be lower in the vertical than in the horizontal reactor. The second reason, as suggested by Messing[8], is that the liquid-to-gas interface is increased with the horizontal reactor, thereby enhancing gas transfer from one phase to another.

With these hypotheses in mind, the second phase of the research has begun. The reactors are being modified and a new unit being built which will enable a more accurate test of the hypotheses to be made. The new unit will lie horizontal and be made of 6" PVC pipe instead of the 8" used for the other reactors. All reactors will be the same length and contain the same volume of liquid and 1" pall rings. In this way, the 6" unit will be nearly full with liquid whereas the 8" horizontal unit will be only a little over half full. This will provide a significantly different liquid-to-gas interface between the two reactors but only a minimal change in liquid depth. In addition, all three reactors (8" vertical, 8" horizontal, and 6" horizontal) will be fitted with ports which will enable either a vacuum or pressure to be applied. During the course of the experiment, the reactors will be exposed to atmospheric pressures as well as pressures above and below atmospheric. In this way, the effects of partial pressure may be more clearly understood.

Benefits and Contributions

The findings of this research should benefit all groups which must find a means of economically treating high strength organic wastes. Anaerobic fixed-film technology is already receiving preferred status for the treatment of such wastes and the knowledge gained through this work should enable the process to become more efficient in both gas production and organic removal. None of the modifications being examined (configuration and application of vacuum or pressure) would be costly to employ and, therefore, should not receive opposition if proven to be effective.

On a more specific scale, both the hog farmers and all downstream users should benefit. If stricter nonpoint pollution laws are enacted, as is expected, the hog farmer should find the anaerobic methodology the most economical to use. In addition, stream quality will definitely improve upon reduction of the organic load into it.

Even though the mixing phase of the project did not result in any technological improvements, it did produce some valuable information. It had been postulated that mixing would benefit fixed-film processes, yet never before had its effects been so thoroughly examined. This research contributes greatly to the argument that anaerobic bacteria do not firmly affix themselves to media surfaces as do the aerobes. With this in mind, media developed for anaerobic treatment should not necessarily be of the same design as that used for aerobic treatment. Further research will be needed to optimize the designs.

Meetings Attended

39th Purdue Industrial Waste Conference, May 8-10, 1984, West Lafayette, Indiana

International Conference on Fixed-Film Biological Processes, July 10-12, 1984, Arlington, Virginia

Note

This research is being carried out as partial fulfillment for the PhD degree. Upon completion of all research pertaining to this subject, a more thorough completion report will be submitted. The expected date of completion is Spring, 1985.

References Cited

1. Congressional Record, 98th Congress, 2nd Session, (June 26, 1984), 130, p. H6859.

2. Washington Notebook (1984). Jour. Water Poll. Control Fed., 56, p. 238a.

3. Washington Notebook (1984). Jour. Water Poll. Control Fed., 56, p. 364a.

4. Murphy, M. (1984) Manure Fuels This Texan's Fire. Hog Farm Management, April, pp. 20-30.

5. Schommer, N. (1984) Reclaiming 98 Dollars Per Day. Hog Farm Management, April, pp. 11-21.

6. Finney, C. D., and Evans, R. S. (1975) Anaerobic Digestion: The Rate-Limiting Process and the Nature of Inhibition. Science, 190, pp. 1088-1089.

7. Stafford, D. A., Hawkes, D. L., and Horton, R. (1980) Methane Production from Waste Organic Matter. CRC Press, Inc., Boca Raton, FL, p. 102

8. Messing, R. A. (1982) Immobilized Microbes and a High-Rate, Continuous Waste Processor for the Production of High BTU Gas and the Reduction of Pollutants. Biotech. and Bioeng., 24, pp. 1115-1123.

9. Tait, S. J. and Friedman, A. A. (1980) Anaerobic Rotating Biological Contactor for Carbonaceous Wastewaters. Jour. Water Poll. Control Fed., 52, pp. 2257-2269.

10. Josephson, J. (1982) Fixed-Film Biological Processes. Environ. Sci. and Technol., 16, pp. 380A-384A.