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Project Summary

Autoheated, Aerobic Thermophilic Digestion with Air Aeration

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This 2-year study developed a new sludge treatment process capable of rapid stabilization, pasteurization, and heavy metal removals from dilute sewage sludge. A full-scale system (28.4 m³ reactor) demonstrated that simple self-aspirating aerators that used ambient air could achieve high oxygen transfer efficiencies and thereby allow conservation of the heat of oxidation to achieve autoheating to high temperatures. A one-stage digestion system using a continuous feed of primary and waste-activated sludge (3 to 6 percent total solids) resulted in autoheated reactor temperatures ranging from 45° to 65°C, even when air temperatures were 20°C and sludge temperatures were 0°C.

The relationship between process variables and the autoheating phenomena were examined at full-scale and bench-scale levels. The process variables included organic loading rate and dissolved oxygen concentration. It was observed that intermediate loading rates (12 to 15 kg TS/m³-reactor-day) and low dissolved oxygen residuals (≤ 1 ppm) allowed maximum temperature development.

Two different aerators were tested and were found to achieve oxygen transfer efficiencies exceeding 20 percent at reactor temperatures that often exceeded 60°C. Operational problems associated with these aerators as well as with the other equipment on the thermophilic digestion facility were identified and examined.

The potential of the autoheated thermophilic digester to inactivate pathogens was investigated. Virus inactivation was 100 percent in most cases, with bacterial and parasite indicator counts less than those found in the effluent from the full-scale, mesophilic anaerobic digester.

The dewaterability of the autoheated, thermophilic digester effluent deteriorated at all loading conditions studied. The aerobic, thermophilic-digestion process appears to increase the solubility of various heavy metals such as cadmium.

A computer model was developed from the full-scale data for predicting the reactor temperature under given loading conditions.

This Project Summary was developed by EPA's Municipal Environmental Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Sewage sludge and other waste organics should be used for beneficial purposes whenever such practices are safe and cost effective. Implementation of this policy usually results in the application of sludge to agricultural land for soil property improvement or for crop fertilization. If the land application rates of sewage sludge were limited by the plan nitrogen requirements, sewage sludge would provide the required plant nutrients for millions of acres of cropland. Present sludge management technology, however, often cannot guarantee public health protection or cost effective solutions. This report summarizes the results of a full-scale investigation of a simple sludge treatment system that has the potential of providing a stabilized, pasteurized sewage sludge at costs less than present aerobic processing systems.

Approximately 20 percent of the sewage sludges produced in the United States are used in agriculture, and this practice is expected to increase as ocean dumping and other disposal practices are terminated. Of course, alternative methods are known that stabilize and pasteurize sewage sludge, but few if any can achieve the high level of treatment required at a low cost without significant disadvantages.

Among the options available for a more effective sludge treatment approach is thermophilic biological treatment. Both anaerobic and aerobic treatment processes can operate in the thermophilic temperature zone of 43° to 70°C. Autoheated aerobic digestion discussed here refers to a process that uses the metabolic heat of oxidation of the organics to increase the temperature of the aerating slurry.

The theoretical energy input required to increase sludge temperatures to the thermophilic range would be about 40 Kcal/L of sludge processed and, at today's energy prices, would cost about $10/million gallons of sewage flow, or about $20/ton of dry sludge. If the thermal energy generated in aerobic digestion is conserved, a surprisingly small amount of substance needs to be biologically oxidized to reach the thermophlic range with no requirement for externally generated heat, and consequently no fuel cost. For a sludge containing 2 per cent volatile solids, oxidizing 50 percent of the volatile solids would produce 50 Kcal/L. Theoretically, this would provide the energy necessary to heat the cold sludge from 10° up to 60°C, assuming no heat losses. Thus, it would appear that aerobic treatment would have potential in this area. The challenge, therefore, is to manage the heat generated by microbial oxidation, primarily by controlling heat loss in the exiting vapor and liquid streams to maximize the autoheating capabilities of aerobic digestion.

The potential advantages of high-temperature, aerobic sludge treatment are thought to include:

- increased rates of oxidation, thus resulting in smaller digester volume require-ments; increased quantity of stabilized organics;
- destruction of most pathogenic bacteria, viruses, and parasites;
- significantly lower oxygen requirements because of the elimination of nitrification over ambient-temperature aerobic digestion;
- increased ease of liquid-solid separation; and
- destruction of weed seeds.

If these advantages were applied to sludge treatment with a little or no cost increase over conventional processes, it would represent a significant improvement in sludge treatment technology.

Problem Magnitude

One of the objectives of the Water Pollution Control Act Amendments in PL 92-500 is to provide all domestic wastewaters with a minimum of secondary treatment. For every 10,000 people, about 38 m^3/day (10,000 gallons/day) of sewage sludge will be generated (at about 4 percent dry solids concentration) with the application of secondary treatment. When this objective is achieved, the quantity of domestic sewage sludge that must be disposed of will be greater than 0.8 million m^3/day. If this material is to be distributed on private land, used for food production, or used indiscriminately by homeowners, the public health aspects of the material must be a prime concern.

Long-term anaerobic digestion at 35°C has been reported to control the majority of human pathogens effectively, but some may survive for long periods. In smaller, less well-operated sewage facilities, the sludge may not receive as effective treatment as in the larger plants with efficient anaerobic digesters. Also, because of the complexities of the anaerobic digestion process, many small town sewage facilities use the simpler aerobic digestion process. It is known that many groups of pathogens can survive the ambient temperature treatment received in many small aerobic digestion facilities.

Thus, it is clear that a simple process that would be capable of providing more effective sludge treatment and pathogen control at a cost not exceeding existing sludge treatment cost should have a high priority in new technology development. This study was undertaken to determine the prospects of adapting existing technology and knowledge to produce a new simple process capable of yielding a pasteurized, stabilized sludge without a large energy input.

Goals and Objectives

The general goal of this 2-year study was to demonstrate that a simple, autoheated aerobic-digestion process using full-scale equipment, shown to be effective with animal wastes, could be used to treat sewage sludge. Specific objectives of this study were to:

(1) demonstrate the feasibility of achieving autoheating to temperatures exceeding 43°C with typical primary and secondary waste-activated sludge using a simple air aeration system;
(2) estimate the practical operating problems of a full-scale system over an extended period of operation;
(3) develop the relationships between the sludge autoheating characteristics and the volumetric and organic loading rates, thereby enabling the predic-tion of the re-actor temperature;
(4) define the aeration requirements and heat balance needed to achieve autoheating with air aeration;
(5) measure the high-temperature treatment impact on the dewaterability of the sludge; and
(6) determine the effectiveness of the autoheated aerobic system on the destruction of major groups of pathogens and compare these results with the existing anaerobic digestion sys-tem at the sew-age treatment facility.

Materials and Methods

Initial investigations of the autoheated, aerobic thermophilic-digestion process using agricultural wastes were performed at Cornell University with bench-scale and pilot-scale reactors. Subsequently, a commercially available full-scale system was installed at Cornell University's Animal Science Teaching and Research Center, where the system's performance was studied using a dairy waste substrate over a 2-year period. Because of this successful demonstration of the autoheating concept, a single-stage digestion facility was designed and constructed at the Binghamton-Johnson City Sewage Treatment Plant in Binghamton, NY, where this study took place over a 2-year period. The Binghamton Sewage Treatment Plant is a modern, 1.5 X 10^5 m^3/d (40-mgd), activated sludge plant that was constructed in 1960.

The full-scale system was operated under conditions that would result in significant biodegradation but would reflect the advantages of high-temperature loading rates, with the majority of operation at less than 5-day hydraulic retention time. One set of conditions was maintained constant for periods up to 60 days to provide time to evaluate practical operation and maintenance problems as well as to measure the impact of sludge composition variations on the process.

Process Design and Construction

The system was designed to enable measurement of mass balances for flow and energy by providing large, completely mixed and insulated feed and effluent tanks, each one capable of storing a volume approximately equal to one hydraulic retention period. The reactor, a cylindrical tank, was 3.7 m in diameter and 4.3 m high. Equipment was first delivered to the site on March 21, 1977, and the unit was operational by May 18, 1977.

Aeration and mixing in the reactor were accomplished by one of two aerators tested. During most of the study, the DeLaval Separator Company Centrirator* (240 volt, 3 phase, 3.7 kW, 1750 rev/min) was used. This aerator was suspended in the liquid by four styrofoam blocks set equidistant from each other. Such a flotation system ensured that optimum immersion depth was maintained for the impeller. This aerator was of the self-aspirating type — that is, the vacuum created at the center of the aerator impeller draws air down the hollow air intake tube and draws liquid up from the center of the tank, thereby providing aeration of the liquid at the impeller. The other aerator studied was an LFE Corporation Midland-Frings (240 volt, 3 phase, 5.2 kW, 1750 rev/min) self-aspirating aerator. This aerator sat on a tripod 30 cm from the reactor bottom, with the impeller spinning against a stator plate to draw air down the intake tube and move the liquid mixture to the reactor perimeter. Note that on the Midland-Frings aerator, the impeller was encased between two stator plates, whereas the Centrirater impeller hung free in the liquid.

The effluent tank was identical to the influent tank with the exception that it was set approximately 1.5 m into the ground to facilitate gravity overflow from the reactor and thereby provide the required effluent volume (28.4 m^3). An entire retention period's effluent was collected before it was sampled and analyzed. This enabled collection of samples that were representative of the entire test period and minimized variations during the test period. The gravity overflow system consisted of a 15-cm diameter black steel pipe, 2.0 m in length, and set at a 40-degree angle to the reactor wall, with one-half of the pipe length extending from the reactor and connecting to a 30-cm diameter polyvinyl chloride (PVC) pipe. The PVC pipe acted as a trough to carry liquid and foam from the overflow pipe to the effluent tank. Mixing of the effluent tank for sampling purposes and subsequent wasting was accomplished by a centrifugal pump.

Continuously and semicontinuously fed laboratory-scale reactors were operated in conjunction with the full-scale reactor under similar conditions. The temperature in the reactors was maintained by water baths operated at 55°C. Hydraulic retention times (HRT) of 2 to 7 days were studied. The reactor volumes varied from 15 to 21 L.

A series of 14 long-term batch biodegradability studies was conducted using 3-L reactors maintained at 50°C. These studies were intended to measure the maximum biodegradable fraction of the wastewater sludge and to monitor the variability of the sludge as related to the time of the year.

Pathogen Sampling and Analyses

During most of the steady-state conditions, samples were collected for virus enumeration, bacterial analyses (coliforms and enteric pathogens), and parasites (viable and nonviable ova). Several laboratories were contracted to perform these analyses. Their complete methodology for analysis is presented in the Project Report. Typically, samples were collected, aseptically transferred to sterile containers, packed in dry ice (virus samples) or cold packs (pathogenic bacteria and parasites), and shipped via air freight to several laboratories.

Results and Conclusions

This 2-year demonstration focused on operating a full-scale system for sludge treatment for populations exceeding 5,000 people. Mixtures of thickened, waste-activated sludge and primary sludge were autoheated to temperatures in excess of 43°C for all conditions tested. Self-aspirating air aerators and well insulated tanks were used with a full-scale reactor volume of 28.4 m^3 during 1.5 years of operation. Autoheated slurry temperatures normally exceeded 50°C and reached a maximum of 65°C.

These results indicate that a simple aerobic digestion system can achieve autoheating to thermophilic temperatures with typical sewage sludges (50 percent biodegradable total volatile solids (TVS) or greater) at concentrations greater than 2 percent total solids under cold weather conditions. Use of heat exchangers would enable even more dilute sludges to be autoheated to high temperatures.

Start-Up

Thermophilic sewage sludge aerobic reactors are easily started and will achieve temperatures in excess of 40°C in approximately 10 days when sludge temperatures are as low as 0°C and air temperatures are -10°C.

Kinetics, Oxygen Transfer, and Dewaterability

Maximum autoheated temperatures were obtained at daily loading rates of between 3 and 10 kg biodegradable COD (BCOD) per m^3, with the maximum organic removal rate (6.5 kg BCOD/m^3) obtained at a daily loading rate of 8 kg BCOD/m^3 for the Midland-Frings aerator. Approximately 75 percent of the biodegradable organics were oxidized at this loading rate. This corresponded to a 5-day HRT at total solids concentrations of approximately 5 percent.

The efficient conservation of the heat of organic oxidation was achieved using two kinds of self-aspirating aerators that were shown to be capable of achieving greater than 20 percent oxygen transfer efficiency. At high loading rates, oxygen transfer efficiencies exceeded 23 percent with air aeration for both aerators tested with organic slurries up to 5 percent total solids at temperatures exceeding 50°C. Normal oxygen transfer analysis using compar-

*Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

ative tap water testing does not apply to these kinds of aeration systems.

The dewaterability of the treated sludge deteriorated significantly at all HRT's tested (3 to 11 days).

The conservation of nitrogen through the system was observed at all conditions tested and was a function of high temperature inhibition of nitrification and minimal volatilization of ammonia.

Pathogen Control

The thermophilic aerobic digester exhibited a high degree of pathogen control with respect to bacteria, viruses, and parasites. Complete inactivation, that is, below the limits of detection, of *Salmonella* sp. and total plaque-forming units (viruses) was observed for all but one test date. Parasite numbers (viable ova) were significantly reduced by the aerobic thermophilic system, but not completely.

Practical Considerations

Practical operational and maintenance problems were found to be minimal and a function of the temporary nature of the digestion facility.

Daily operational requirements of the aerobic thermophilic system are minimal.

Process Design Criteria and Suggested System

Major requirements for autoheated aerobic digestion of sewage sludge include a minimum biodegradable organic concentration, an insulated reactor, and the use of efficient aerators such as the two tested in this study. The potential for autoheating can be predicted using energy and mass balances. The following equation was developed for the prediction of the autoheated reactor temperature:

$$PT_R = \frac{HRT\ K_T\ BCOD_e\ R}{D_L\ C_{PL}} - [0.0407\ (T_R - T_A)^{1.2765}]\ HRT + T_O$$

where:

PT_R = predicted reactor temperature, °C

HRT = hydraulic retention time, day

K_T = reaction rate coefficient, day^{-1}

$BCOD_e$ = biodegradable COD in the effluent, g/L

R = heat released during microbial respiration, Kcal, g COD

D_L = density of the liquid sludge, g/L

C_{PL} = specific heat capacity of the liquid sludge, cal/g-°C

T_R = reactor temperature, °C

T_A = ambient temperature, °C

T_O = feed sludge temperature, °C

The reaction rate coefficient, which is needed for solution of this equation, was found to be a strong function of temperature. For the conditions of these experiments and within the temperature range of 47° to 62°C, K_T is approximated by the following relationship:

$$K_T = (0.022)\ 1.076^{T_R - 20}$$

The best practical system for maximum organic stabilization and minimum aeration requirement includes using a bottom-mounted, self-aspirating aerator, a daily organic loading rate of around 15 kg of BCOD/m^3, and an aerator input of 0.18 kW/m^3 of reactor.

The autoheated, air-aerated-sewage-sludge digestion system would appear to be more economical than other aerobic or anaerobic digestion facilities at equal solids conversion efficiencies.

Design Procedure

Based upon the information developed by this study, a full-scale, thermophilic aerobic-digestion facility can be designed for the organic stablization and pasteurization of municipal sewage sludges and other waste organic slurries. The following approach is recommended for the design of a thermophilic aerobic digestion facility:

1. The organic slurry that is to be digested should be characterized with respect to total chemical oxygen demand (TCOD), fraction that is biodegradable, and solids concentration. The TCOD value of the slurry would give an indication of the autoheating potential of the slurry since approximately 3.5 Kcal are released when 1 g of TCOD is oxidized. A review of the history of the slurry, that is, its age, source, and other available characteristics would yield an approximate range of expected biodegradability.

2. The reactor(s) should be sized according to the desired level of organic treatment efficiency and operating temperature, both of which are determined by the organic loading to the reactor. A loading rate of 12 to 15 kg TS/m^3 reactor-day was found to allow maximum temperature development (55° to 62°C) and maximum organic removal rate.

3. The reactor should be shaped to provide efficient mixing and should be covered and insulated. The insulation selected should provide maximum resistance to heat loss, specifically, the insulation should have a thermal conductivity of about 0.019 cal/sec · cm · °C and be applied at a thickness to yield an $R > 25$.

4. Self-aspirating aerator(s) of the type studied here should be installed in the reactor(s) to provide approximately 0.15 to 0.20 kW/m^3 of reactor. This rate of aeration was found to provide efficient mixing and oxygen transfer. No other aerator should be substituted unless it is shown to be capable of oxygen transfer efficiencies exceeding 20 percent in sewage sludge at 60°C.

5. Foam produced in the reactor(s) should be controlled with mechanical foam cutter(s) of the type studied here, and applied at the rate of 0.1 kW/m^2 surface (slurry) area. A backup foam cutter(s) should be available on an automatic activation basis for control of excess foam such as occurs during changes in loading conditions.

Recommendations

Information on the autoheated, aerobic-digestion process should be made available to engineering firms involved in the design of sludge treatment facilities where the ultimate disposal method would be land application. Effluent from the autoheated process was shown to be well stabilized and pasteurized, thereby minimizing the public health risks associated with land application of this type of sludge.

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The complete report, entitled "Autoheated, Aerobic Thermophilic Digestion with Air Aeration," (Order No. PB 82-196 908; Cost: $27.00, subject to change) will be available only from:
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