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Project Summary

Engineering and Economic Assessment of Autoheated Thermophilic Aerobic Digestion with Air Aeration

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Engineering and economic analyses were made of test results obtained by W.J. Jewell, R.M. Kabrick, and J.A. Spada in experiments sponsored by the U.S. Environmental Protection Agency (EPA) on a modified sludge stabilization process termed autoheated aerobic thermophilic digestion (ATAD) with air aeration. The ATAD process tests had been conducted in 1979 at the Binghamton-Johnson City Sewage Treatment Plant in Binghamton, New York.

In this study, the Jewell *et al.* tests results were analyzed for system kinetics, heat balance, aerator transfer efficiency, pathogen destruction, dewaterability, and heavy metal interactions. Additionally, economic viability of ATAD was examined using very conservative criteria in application to facilities of 1-, 10-, and 100-mgd capacity.

ATAD was found to be a feasible process, readily interpretable by conventional measures of system efficiency and effectiveness, and a potentially economical sludge-digestion process at smaller size plants.

This Project Summary was developed by EPA's Municipal Environmental Research Laboratory, Cincinnati, OH 45268, to announce key findings of the research project which is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Aerobic digestion is a simple unit process for stabilizing sludge A major disadvantage of this process, however, is that its efficiency is greatly reduced during periods of cold weather. Treatment plant operators then must either provide very long detention times (e.g , up to two months to achieve a 40-percent reduction in volatile solids) or accept poorer reduction in volatile solids.

During the past decade, several researchers have investigated the possibility of controlling heat losses in aerobic digestion so as to conserve the energy generated by microorganisms as they degrade organic material When this heat energy is conserved, it becomes possible for the digester system to maintain its operating temperatures within the thermophilic range (45°C or higher) despite severe winter conditions. As a result, detention times can be cut to less than a week The first successful large-scale application of the ATAD process with air aeration (as opposed to aeration with high-purity oxygen) was completed by Jewell *et al* in EPA Project Number R804636 (1979) entitled, "Autoheated Aerobic Thermophilic Digestion with Air Aeration "

The purpose of this study was to analyze the results obtained by Jewell *et al.* and to determine whether the process could be competitive with other stabilization alternatives.

Basis of Analysis

Jewell *et al.* conducted tests of the ATAD process over an 18-month period, using a blend of primary and waste activated sludge that had been gravity-thickened to an average 4.5-percent total solids Testing was conducted in batch-scale reactors (which were used in tests to estimate the biodegradability of sludge), in semi-continuous and continuous bench-scale reactors, and in a 28-m^3 (1,000-cubic-foot) full-scale reactors. The batch- and bench-scale apparatus were maintained in a 50°C water bath, while the totally enclosed and insulated full-scale reactor was self-heated. Steady-state data were collected from 30 full-scale tests and 21 bench-scale tests and were grouped by hydraulic retention time (HRT) and averaged within the group.

Analysis of Test Results

Data from Jewell *et al* on system kinetics generally agree with those of other researchers. The rate of change in biodegradable sludge components is dependent on the concentration of biodegradable organics, as approximated in the first-order equation

$$R_s = -KS$$

where R_s = rate of change of components

S = concentration of biodegradable organics

K = reaction rate coefficient

Test results obtained by Jewell *et al.* show S for the following components to be as follows:

Component	Biodegradable Portion (%)
COD	46.4 - 76.5
Total solid	22.9 - 62.0
Total volatile solids	42.2 - 71.7
Total Kjeldahl nitrogen	57.0 - 85.0

The wide variation observed in these data (which are consistent with those of other researchers) can cause some uncertainty in design. The reaction rate coefficient K (using COD as a measure of biodegradable organics) is seen to vary with temperature as illustrated in Figure 1, which was compiled from several sources of data.

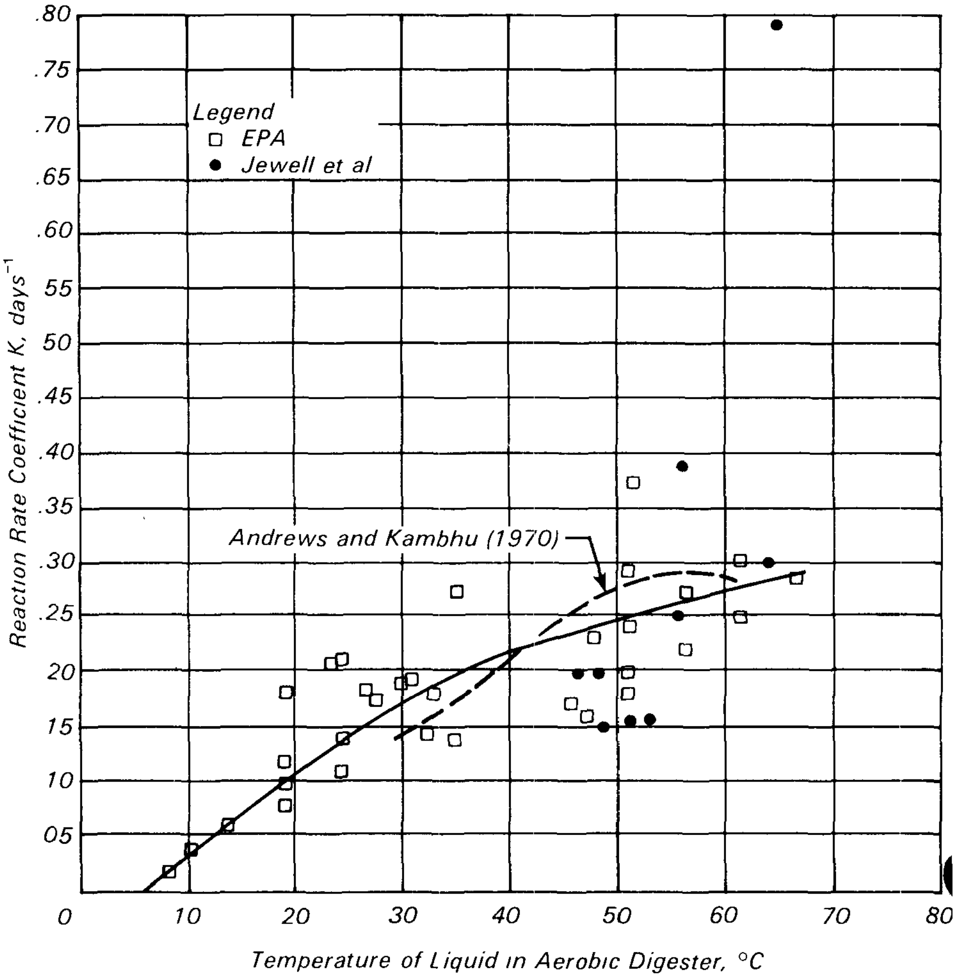

Figure 1. *Reaction rate coefficient versus aerobic digester liquid temperatures.*

Figure 2 illustrates the components of heat entering and leaving an aerobic digester. There are three sources of heat loss: loss to surroundings by convective radiation, loss through exiting of the moisture-laden exhaust gas (both through evaporation and loss of sensible heat), and loss through the exiting of digested sludge from the system. Design of an ATAD system requires that an overall heat balance be developed in order to calculate operating temperatures. Jewell *et al.* fit their data to satisfy a simplified, empirical heat-balance relationships as follows:

$$H_L = a\,(T_R - T_A)^b\, D_L C_{PL}$$

where H_L = heat loss coefficient, cal/m^3/hr

T_R = reactor temperature, °C

T_A = ambient air temperature, °C

D_L = liquid density, gm/ml

C_{PL} = specific heat capacity, cal/gm - °C

a = intercept coefficient

b = slope coefficient

This relationship does not apply to ATAD reactors in general, however, as in fact the only heat loss that is related to the difference between reactor and ambient air temperatures is the heat loss to the surroundings. Loss of heat by exiting gases depends on total air flow, relative humidity of the exhaust gas, and/or exhaust gas temperature. Loss of heat with effluent sludge depends on the volume and temperature of sludge leaving the system.

Of the three sources of heat loss, the more important losses are via the exhaust gas and the effluent sludge. Convection losses from the vessel and pipeline are significant, but of less importance; these can be controlled by insulation and covering of the digester The two major sources of heat loss can be controlled, respectively, by (1) providing efficient aerators (e g., of 15 percent efficiency or better) to reduce air flow through the reactor, and (2) thickening the sludge fed to the reactor in order to reduce the total quantity of material to be processed (thickening of sludge to 3-percent solids or greater has been recommended by several researchers). Jewell *et al.* obtained poor dewatering of sludge processed by ATAD in the full-scale reactor; the researchers observed a substantial increase in capillary suction time (CST). It is possible that the high rotational speeds required by the self-aspirating aerator used in the full-scale digester caused a deflocculation of the sludge that would affect dewatering characteristics. Deflocculation would not be expected with a submerged turbine aerator (which also would provide high aeration efficiency), so in the economic study described below it was assumed that a submerged turbine aerator would be used

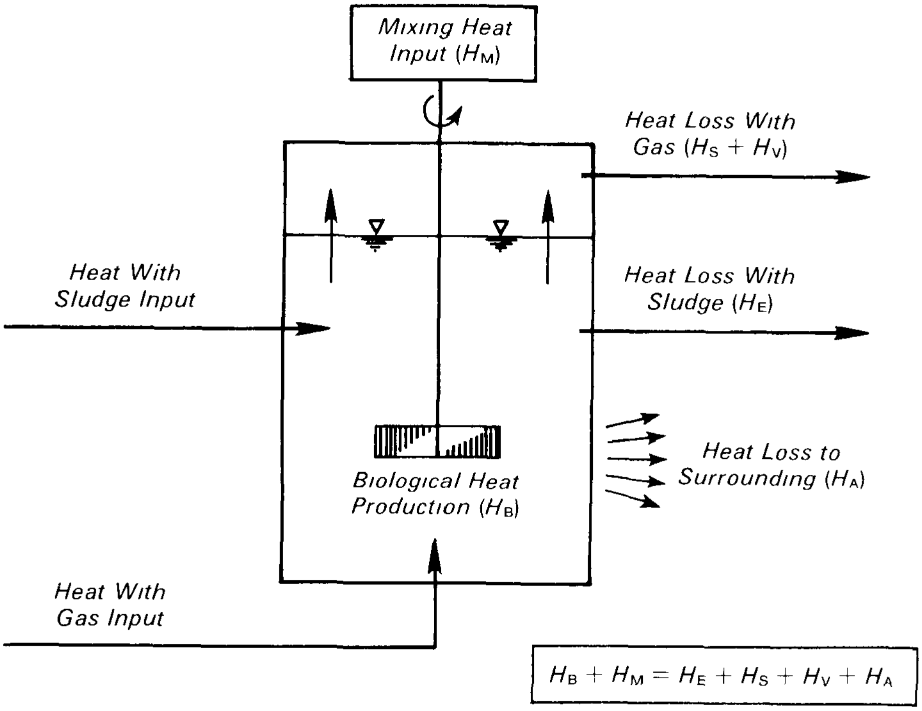

Figure 2. *Heat balance components for aerobic digestion.*

Analysis of Process Economics

The costs of the ATAD process were compared with those of aerobic digestion at ambient temperatures and of mesophilic anaerobic digestion. The comparison was conservative, in that it was assumed that influent sludge would be at 3-percent solids. As discussed above, this level is the minimum acceptable for efficient ATAD operation.

Costs were examined in detail for a 3,800-m³/d (1-mgd) plant and compared also for plants of 38,000-m³/d (10-mgd) and 380,000-m³/d (100-mgd) capacity Estimated sludge production from the 1-mgd plant is 0.9 dry tonne per day; a peaking factor of 50% was assumed. Economic criteria used in the comparison were as follows:

Capital cost base	3,140 (ENR April 1980)
Capital cost amortization	20 years, 7% (equipment) 40 years, 7% (structures)
Salary	$10 per hour (including benefits)
Electricity	$0.06 per kWh

Facilities were sized to achieve a 40-percent reduction of total volatile solids, on sludge assumed to have a 70-percent volatile fraction of which 70 percent was biodegradable. The desired reduction in volatile solids would require detention of 7.5 days, assuming aerator efficiency of 15 percent.

Unit costs for ATAD were found to be $160 per tonne for the 3,800-m³/d (1-mgd) plant, this being derived from total capital costs of $385,000 and total annual costs of $53,000. Major operating expenses were in power and labor.

Unit costs for ATAD for the 38,000-m³/d (10-mgd) and 380,000-m³/d (100-mgd) facilities were found to be $90 per tonne and $80 per tonne, respectively.

At the 1-mgd facility, ATAD costs are substantially lower than those projected, using the same criteria, for ambient aerobic digestion ($260 per tonne) and for mesophilic anaerobic digestion ($220 per tonne). As shown in Table 1, however, the low net power costs for anaerobic digestion at large-scale facilities—where recovery of methane digester gas is sufficient to power the digestion process virtually free of charge—tend to make anaerobic digestion the system of choice at the plants of 10- and 100-mgd capacity.

In summary, the ATAD process costs for a 3,800 m³/d (1-mgd) plant are only about 62 percent of those of ambient aerobic digestion and 73 percent of those of anaerobic digestion, on a unit-cost basis.

Conclusions and Recommendations

Autoheated thermophilic aerobic digestion with air aeration is feasible on a thickened municipal sludge. The process' favorable economics at plants of 3,800 m³/d (1-mgd) capacity merit serious consideration in planning for design of sludge processing facilities at such plants.

Some problems observed in the tests conducted by Jewell *et al.*—specifically, the less-than-complete mixing of digester contents and the poor dewaterability of the digested sludge—might be solved by use of submerged-turbine aerators or other systems with efficient oxygen transfer characteristics. Testing is recommended.

In general, the characteristics of sludge processed by ATAD to a 40-percent reduction in volatile solids should be similar to those of sludge processed by ambient aerobic digestion or mesophilic anaerobic digestion Jewell *et al.* observed better reductions

Table 1. *Economic Comparison of ATAD, Aerobic Digestion and Anaerobic Digestion Treatment Systems*

Plant Size	*Sludge Digestion Process*	*Capital Cost*	*Annual Operating Cost*	*Amortized Annual Cost*	*Unit Cost (per tonne)*
3,800-m³/d (1-mgd)					
	ATAD	*385,000*	*21,500*	*53,000*	*$160*
	Aerobic Digestion	*550,000*	*42,000*	*88,000*	*260*
	Anaerobic Digestion	*700,000*	*14,000*	*73,000*	*220*
38,000-m³/d (10-mgd)					
	ATAD	*1,200,000*	*200,000*	*290,000*	*90*
	Aerobic Digestion	*2,500,000*	*910,000*	*930,000*	*200*
	Anaerobic Digestion	*1,700,000*	*42,000*	*190,000*	*55*
380,000-m³/d (100-mgd)					
	ATAD	*6,200,000*	*1,200,000*	*2,500,000*	*80*
	Aerobic Digestion	*14,000,000*	*9,000,000*	*10,000,000*	*180*
	Anaerobic Digestion	*9,400,000*	*310,000*	*1,100,000*	*35*

of pathogens in their test ATAD facilities than in the full-scale anaerobic digesters at the wastewater treatment plant where their tests were conducted. This is probably due to the fact that addition of sludge to the test units was stopped for 12 to 24 hours before the sludge was sampled for pathogens. This practice is typical at smaller plants; at larger plants, where continuous feed of sludge is the practice, pathogen reduction would probably be less effective.

It is possible that use of heat exchangers (pre-warming influent sludge with excess heat from effluent sludge) and series operation of ATAD equipment would further improve process efficiency. There are not at present sufficient data to predict the results of instituting either measure. At plants where pure oxygen is readily available and being used for other purposes, such as supply for pure-oxygen activated sludge process, the potential increased efficiency possible through oxygen aeration of ATAD units, and the concomitant 25-percent reduction in digester volume requirements, make this process option worth considering.

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***Roland Villiers** is the EPA Project Officer (see below)*

The complete report, entitled "Engineering and Economic Assessment of Autoheated Thermophilic Aerobic Digestion with Air Aeration," (Order No PB 82-102 310; Cost: $6.50, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
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Telephone: 703-487-4650

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