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Project Summary

Aqueous-Phase Oxidation of Sludge Using the Vertical Reaction Vessel System

This study provides plant-scale operating data on the wet oxidation of municipal wastewater sludge by the Vertical Reactor Vessel* (VRV) system. An important consideration in the evaluation was the effect of the return flow from the wet oxidation process on the operation of the wastewater treatment plant. The investigation was carried out at the Longmont, CO, Wastewater Treatment Plant (WWTP).

The VRV system consists of a series of long concentric tubes placed in the earth using conventional oil field technology. The reason for using vertical construction is to produce a large hydrostatic head at the bottom of the system. The pressure is needed to prevent boiling at the temperatures required for wet oxidation. By utilizing hydrostatic pressure, pumping is required only to overcome frictional losses. The need to add energy for pressurization is eliminated. Sludge is introduced along with air or oxygen into the multiphase fluid downcomer which is the second concentric space from the outside. It is pumped down this space where it is heated by hot oxidized sludge rising in the outermost concentric space within the vessel. In the bottom of the vessel, temperatures of 250°C or higher are attained and the oxidation of organic materials takes place with resulting heat production. At the center of the reaction vessel is a tubular heat-exchange system which can either extract excess heat or provide heat for startup of the process.

At temperatures above 260°C it was possible to achieve total chemical oxygen demand (COD) reduction of about 80% and total volatile solids reductions of over 90%. For the 25-cm reaction vessel installed at Longmont, the capacity of the system using air was limited to 5 metric tons per day. Using oxygen it was possible to increase capacity to about 30 metric tons per day. Returning the supernatant liquid from the process to the wastewater treatment system did not have a significant effect on the effectiveness of that system.

This Project Summary was developed by EPA's Water Engineering 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

Treatment and disposal of municipal wastewater treatment plant sludge is expensive, with the cost constituting as much as one-half of the total cost for wastewater treatment. In addition, disposal of the sludge after treatment is becoming an increasing problem in many locations. There is growing resistance to disposal in landfills because of possible groundwater contamination, and strong resistance to increased ocean disposal from communities near the coasts. Incineration, which accomplishes disposal except for a relatively small volume of residual ash, is being questioned because of possible air pollution problems.

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

Wet oxidation of sludge, which is similar in some ways to incineration, produces a greatly reduced volume of a material similar to ash. It has a significantly reduced air pollution potential, but does produce a liquid waste stream containing low molecular weight organic materials, especially acids. This liquid waste stream can be sent to the main treatment system and does not cause a disposal problem. Although the technical feasibility of wet oxidation for sludge treatment has been recognized, the process is expensive and has not been widely used. In the 1970's the concept of carrying out wet oxidation in a vertical reactor placed in the ground was investigated. Using conventional oil field technology, a very long reaction vessel, over 1,000 m, could be constructed which would provide high pressure at the bottom from the hydrostatic head. Sufficient pressure could be developed to prevent vaporization of water at temperatures above the 250°C required to carry out sludge oxidation. This vertical configuration eliminated the need to provide energy for pressurizing the wet sludge. A system of concentric tubes was developed which provided an annulus for pumping the sludge down the reactor and another annulus where the sludge returned to ground level. In addition, tubes were provided for circulation of a heat-transfer fluid down the reactor to add heat during startup and to remove excess heat during operation. The economics of this vertical configuration appeared reasonable because of the elimination of an expensive above-ground pressure vessel, the need for only a small land area, and reduction of pumping energy to only that needed to overcome wall friction.

A pilot test of the vertical configuration was carried out in the late 1970's at the Lowry Bombing Range near Denver. The depth of the system was only about 460 m, and did not produce high enough static pressure to prevent boiling without pressurizing the system at the surface. The results of this study were sufficiently encouraging to test an improved design at a municipal wastewater treatment plant. The size of the system needed to be sufficient to treat all the sludge from the treatment plant.

The full-scale evaluation of a VRV system was carried out at the Longmont WWTP. The overall objective of this study was to provide plant-scale operating data on sludge oxidation. Two specific goals were:

- To determine operating parameters for the process which would result in effective reduction of COD and total suspended solids (TSS).
- To determine the effects of the return of wet oxidation supernatant on the biological treatment in the Longmont system.

Procedure

A VRV system was sized to treat the approximately 3,600 kg/day of sludge produced by the Longmont plant and was installed on the treatment plant grounds. A diagram of the total sludge treatment system is shown in Figure 1 and indicates the path of the sludge through the reactor. The section of the reactor containing heat transfer oil consists of an outer and inner tube. Insulation between the tubes reduces heat transfer between them. The diameter of the reactor is 25 cm and the length is 1,600 m. It was intended to operate the system using air for oxidation, but this procedure limited capacity and reduced the effective hydrostatic head because of the presence of relatively insoluble nitrogen bubbles. A source of oxygen was added to allow operation over a range of oxygen contents up to 100%. A Lamella Solids Separator, which is a variety of tube settler, was used to separate the oxidized, ash-like residue from the wet-oxidation supernatant. Provision was made for returning the supernatant to the wastewater treatment plant.

The system was operated during most of 1984 and 1985 under a variety of operating conditions. COD removals obtained are shown in Figure 2. Although COD reduction is plotted as a function of temperature, the effect of other variables is also included and appears as scatter in the data. Ranges for these variables are shown in the table included on the figure. Figure 3 shows volatile suspended solids reduction as a function of temperature. Just as for the COD plot, this plot includes data covering a range of other variables as indicated by the table on the figure. These results indicate that at temperatures above 260°C very good reduction of COD is obtained, and most of the volatile suspended matter is both solubilized and largely oxidized. The process is, therefore, quite effective for producing a low-volatile-content, ash-like material. Return of the supernatant from the oxidized product after solids separation did not have a significant negative effect in terms of effluent biochemical oxygen demand (BOD) or suspended solids content. There was a slight increase in ammonia content in the treatment plant effluent. The degree of oxidation was not greatly affected by the amount of excess oxygen available. Good operation should be possible with only slightly more than the stoichiometric amount required for COD reduction.

Conclusions

1. With the use of air, the system capacity was limited to 5 metric tons per day for the Longmont 25-cm reaction vessel. The use of oxygen increased system capacity to a maximum of 30 metric tons per day.
2. For bottomhole temperatures of 260°C and above, COD reductions of 75% to 80% were achieved and reproducible. Temperature had the largest effect on COD reduction. By recycling the effluent, the reduction in COD was increased about 5%.
3. BOD in the VRV effluent stream was readily biodegradable, showing a 140% increase in the efficiency of the trickling filter that served as a roughing treatment upstream of a rotating biological contactor. As a result, the Longmont WWTP was able to process all the recycled BOD and still meet its NPDES discharge limit, even during periods when additional sludge was hauled in.
4. During autogenous operation, that is, operation in which heat produced by oxidation was sufficient to maintain the reactor temperature, total volatile suspended solids reductions averaged 96.5%, and total volatile solids reductions averaged 93.9%. Total suspended solids reductions averaged 78.7%, and COD reductions averaged 76.3%.
5. An industrial hygiene survey indicated that trace components in the off-gas were usually about 2 orders-of-magnitude below the permissible limit for an 8-hr worker exposure.
6. A metallurgical inspection of the reaction vessel by Material Science Corp. showed insignificant corrosion, consistent with a 20-year life. Materials of construction for the VRV and the surface equipment proved satisfactory.
7. Based on the Longmont demonstration, it was possible to establish operating and maintenance costs for a 25-cm reaction vessel operating at maximum capacity. Operat-

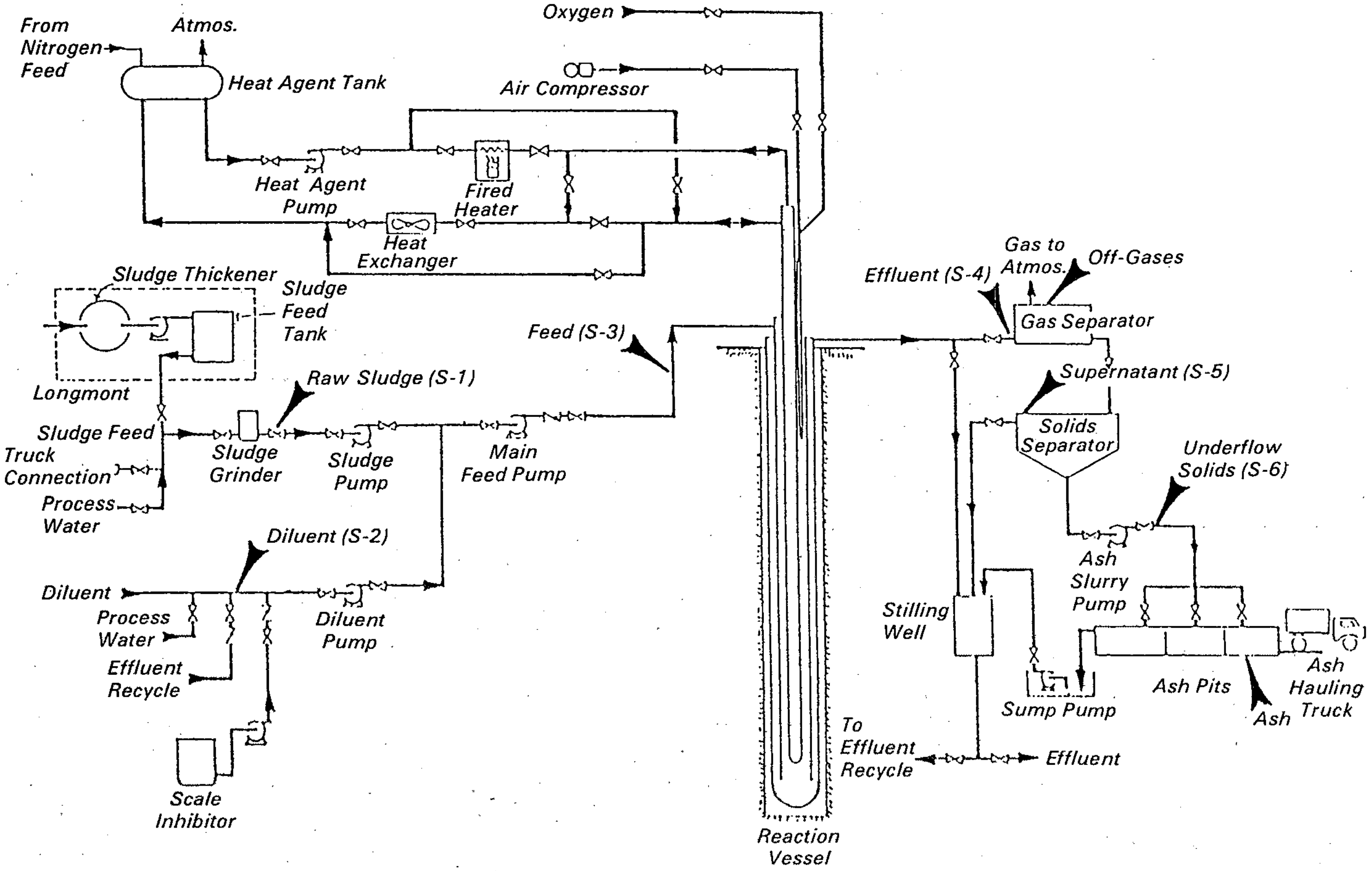


Figure 1. *Process flow diagram.*

ing and maintenance costs for a Longmont-sized unit are below $100 per metric ton with an energy recovery credit of $17 per metric ton.

8. The ash is nonhazardous. Leachates from the EP Toxicity Test were typically 2 orders-of-magnitude below limits set by EPA.
9. Ash in the VRV effluent was easily dewatered. Solid contents of 40% to 75% were obtained after dewatering by a centrifuge without any optimization of centrifuge operation.
10. The system operated from non-autogenous to extraction of heat. Operation in the autogenous mode was extremely smooth. Wash-out heat was limited to a temperature rise between influent and effluent of 11-17°C (20-30°F) during autogenous operation.
11. High mechanical availability (96.7%) of the system and its components did not limit the test program in any substantial way.
12. COD reduction for the full-scale system at Longmont was successfully predicted from laboratory batch reactor (LBR) tests.
13. VRV operation was consistent and reproducible at fixed operating parameters.

Recommendations

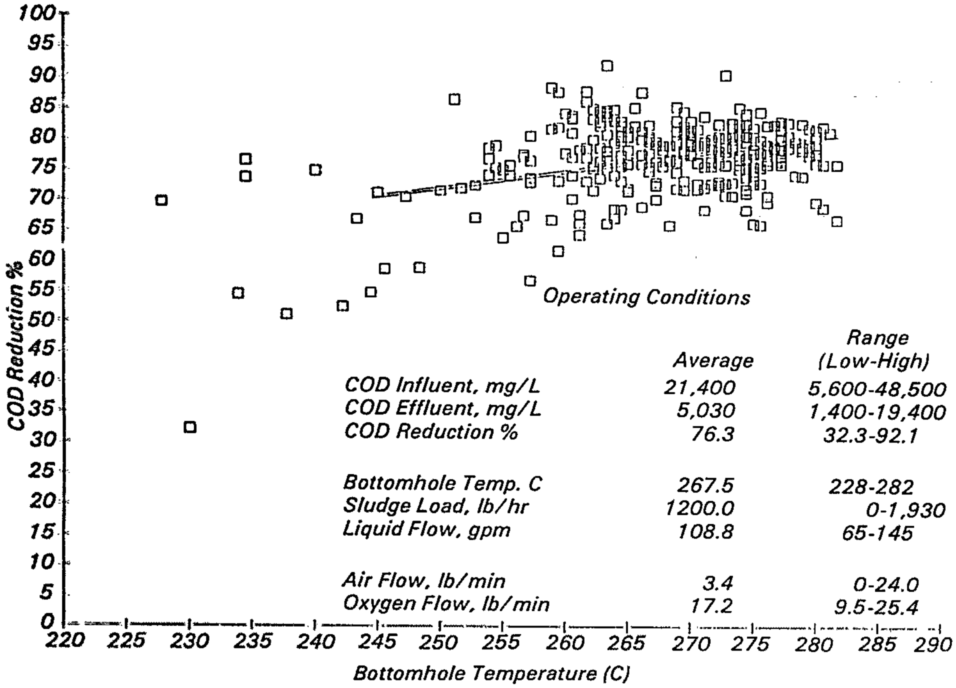
The following are recommendations for improving system design, based on the results of the demonstration period:

1. Biological treatment of the reaction vessel effluent should be further investigated to optimize COD reduction. Benefits of anaerobic polishing should be tested.
2. The VRV effluent return appeared to influence the biological speciation and caused more rapid reduction of BOD. Identification of biological species before, during, and after oxidation system operating periods should be included in future tests.
3. Returning the VRV effluent stream to the headworks of the Longmont WWTP would provide flow equalization and reduce concentration prior to undergoing biological degradation. An option should be provided to allow VRV effluent return either to the headworks or to the trickling filters.
4. The unit installed at Longmont was oversized. A new reaction vessel more closely matching Longmont's sludge generating capacity should be installed and tested.
5. Higher influent heat transfer fluid temperatures were required for startup due to welding failures which occured in four sections of the insulated tubulars. Coupling design also contributed to greater heat loss than expected. However, the system was still able to reach

required bottomhole temperatures. Improved insulated tubular design should eliminate failures in future installations. The performance of the insulated tubular has minimal effect during autogenous operation.

6. Pressure measurement tubing caused organic fouling and suffered mechanical damage during installation and operation. Organic fouling limited the length of operating runs. This fouling is not anticipated to occur in a commercial reaction vessel, since downhole pressure measurements will not be required for VRV operation.
7. Mechanical dewatering of the ash slurry should be installed. Polymer addition should be optimized to reduce dewatering costs.
8. The use of ash as a filler material for brick manufacture was demonstrated and could be implemented at future installations where appropriate.
9. The VRV should be insulated or constructed so as to reduce heat losses to the formation. High-boiling-temperature oil should not be present in the annular space between the reaction vessel wall and the primary casing string. These improvements will reduce initial heat-up and time to restart after a shutdown, and will increase heat recovery.

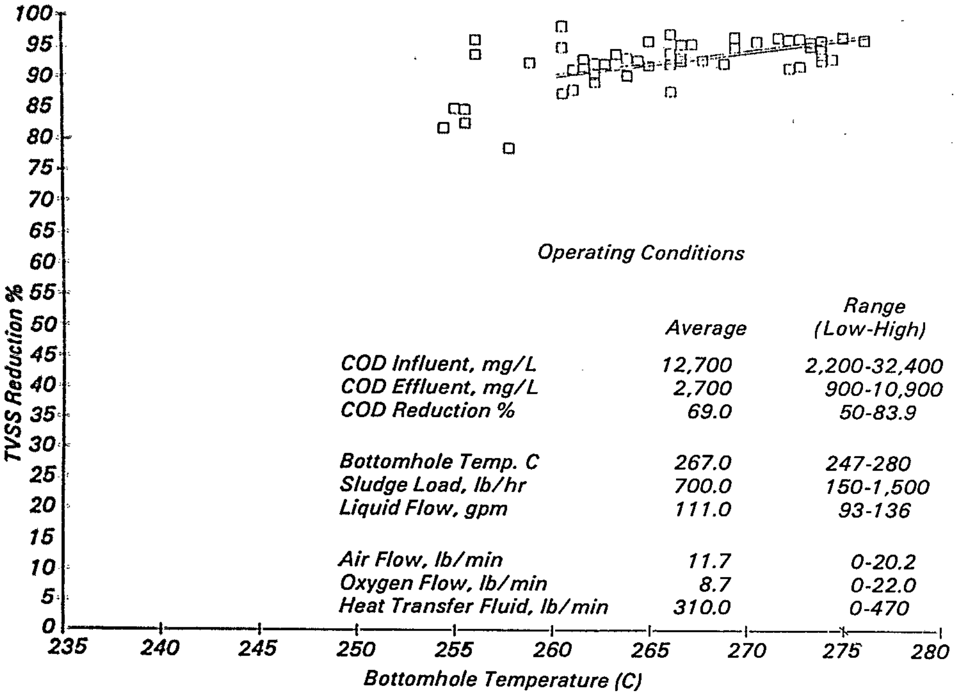
The full report was submitted in fulfillment of CS-809337-01 by The City of Longmont, CO, under the partial sponsorship of the U.S. Environmental Protection Agency.



Operating Conditions

	Average	Range (Low-High)
COD Influent, mg/L	21,400	5,600-48,500
COD Effluent, mg/L	5,030	1,400-19,400
COD Reduction %	76.3	32.3-92.1
Bottomhole Temp. C	267.5	228-282
Sludge Load, lb/hr	1200.0	0-1,930
Liquid Flow, gpm	108.8	65-145
Air Flow, lb/min	3.4	0-24.0
Oxygen Flow, lb/min	17.2	9.5-25.4

Figure 2. CODT reduction vs. bottomhole temperature.



Operating Conditions

	Average	Range (Low-High)
COD Influent, mg/L	12,700	2,200-32,400
COD Effluent, mg/L	2,700	900-10,900
COD Reduction %	69.0	50-83.9
Bottomhole Temp. C	267.0	247-280
Sludge Load, lb/hr	700.0	150-1,500
Liquid Flow, gpm	111.0	93-136
Air Flow, lb/min	11.7	0-20.2
Oxygen Flow, lb/min	8.7	0-22.0
Heat Transfer Fluid, lb/min	310.0	0-470

Figure 3. TVSS reduction vs. bottomhole temperature.

This Project Summary was prepared by staff of the City of Longmont, CO 80501.
***Edward J. Opatken** was the EPA Project Officer (see below).*
The complete report, entitled "Aqueous-Phase Oxidation of Sludge Using the Vertical Reaction Vessel System," (Order No. PB 87-170 320/AS; Cost: $18.95, subject to change) will be available only from:
National Technical Information Service
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Telephone: 703-487-4650
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