FULL SCALE LIQUID COMPOSTING OF ANAEROBICALLY DIGESTED SLUDGE FOR PATHOGEN AND HEAVY METAL REMOVAL

by

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ABSTRACT

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The autoheated aerobic digestion process using air aeration was tested with anaerobically digested municipal sludges from four municipalities. Batch autoheating tests in the 63 cubic meter reactor confirmed that autoheating to achieve between 50°C and 70°C could be achieved. This data was supported by laboratory scale tests of organic matter conversion rates and efficiencies.

The patented Cornell University heavy metal removal process achieves metal solubilization from sludge using sequential oxidation-reduction potential modification followed by acidification. This was applied to the four sludges tested and the fate of cadmium, lead, copper, nickel and zinc was monitored. Cadmium concentrations ranged from 10 to 115 ppm (dry basis) in the feed sludges. Cadmium removal efficiencies were consistently greater than 90 percent, with one sludge approaching background levels found in cow manure. Zinc removals were comparable to cadmium, and more than 76 percent of the remaining metals were removed. Chemical costs were estimated to be as low as $20 per dry ton of solids for an optimized application.
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FOR PATHOGEN AND HEAVY METAL REMOVAL

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INTRODUCTION

Pathogens and toxic metals occur at low concentrations in municipal wastewater, but many of these materials are concentrated thousands of times in the resulting primary and secondary biological sludges. A process that could eliminate the toxic constituents of sludge would be of benefit to many municipalities and industries.

Aerobic digestion, with unique highly efficient self-aspirating aerators, was shown to be capable of autoheating sludges to pasteurization temperatures (50°C+) in a full scale facility in 1979.¹ This high temperature aerobic digestion process has been termed "liquid composting".² Modifications to the process have the potential of removing pathogens and toxic metals in a cost-effective, simple process. This study was conducted to provide large-scale verification using a 63 m³ (16,600 gallon) pilot reactor with an operating volume of 28 m³ (7,400 gallons). This effort focused on using sludges previously stabilized by anaerobic digestion.

Examples of concentrations of metals as derived from surveys of several hundred municipal sludges are shown in Table 1. Federal agencies recommended maximum concentrations for three constituents for use in application of sludge to land in vegetable and fruit production - 25 ppm of cadmium, 1,000 ppm of lead, and 10 ppm of PCB's.³ The median concentrations emphasize that many sludges would not have acceptable cadmium and lead concentrations.

Specific objectives of the study were to estimate autoheating potential with air aeration of anaerobically digested municipal sludges (mixtures of primary and waste biological sludges) in a
Table 1. Survey concentrations of metals in several hundred municipal sludges as compared to typical cow manure. 4,5,6 All values in ppm dry weight.

<table>
<thead>
<tr>
<th>Metal</th>
<th>Average Conc.</th>
<th>Typical Median Values</th>
<th>Range Conc.</th>
<th>Cow Manure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Sommers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cadmium</td>
<td>110</td>
<td>16</td>
<td>3-3,410</td>
<td>0.8</td>
</tr>
<tr>
<td>Copper</td>
<td>1,210</td>
<td>850</td>
<td>84-10,400</td>
<td>62.0</td>
</tr>
<tr>
<td>Lead</td>
<td>1,360</td>
<td>500</td>
<td>13-19,700</td>
<td>16.0</td>
</tr>
<tr>
<td>Nickel</td>
<td>320</td>
<td>82</td>
<td>2-3,520</td>
<td>29.0</td>
</tr>
<tr>
<td>Zinc</td>
<td>2,790</td>
<td>1,740</td>
<td>101-27,800</td>
<td>71.0</td>
</tr>
</tbody>
</table>
63 m³ reactor, define settling and dewatering characteristics, measure the efficiency of heavy metal removals, and estimate the system feasibility.

BACKGROUND AND LITERATURE

The development of the autoheated thermophilic aerobic digestion system (ATAD) has been on-going for about two decades and has a strong international character. A summary of some of the events in its development are shown in Table 2. Andrews and Kambhu⁷ provided the theoretical basis for the ATAD system in the late 1960's, a German team developed a unique self-aspirating aerator (Fuch's unit) and Popei⁸,⁹,¹⁰,¹¹ and his colleagues demonstrated the potential at full scale with animal wastes and sewage sludge, and Jewell’s team developed the first U.S. full scale demonstration studies for animal wastes and sewage sludge.¹,² The detoxification concept that combined pathogen destruction and heavy metal removals was developed in 1980. Today, the ATAD system is commercialized in Europe (17 ATAD systems existed in Germany and Switzerland in 1985, and more than six units were in operation in the United Kingdom).¹² No full-scale commercial systems in the U.S. are known to the author.

In 1981, the ATAD sludge treatment alternative was determined to be more cost-effective than conventional aerobic or anaerobic digestion with capacities up to ten MGD.¹³ Wolinski and Bruce¹⁴ determined that it was the most cost-effective at all scales with low cost electricity. Deeny, et al.¹² prepared uniform cost comparisons between ATAD, conventional aerobic digestion, and anaerobic digestion using actual costs of the European systems. Capital cost comparisons are shown in Figure 1. In all cases, ATAD was the lowest cost alternative, and in most cases, the capital costs were about half the cost of anaerobic digestion.

Maintenance of sludge for 24 hours at 50°C or greater should destroy most pathogens in sewage sludge. Comparison of pathogen survival between the full scale mesophilic anaerobic digestion effluents and those in the effluent from autoheated aerobic systems has been reported.¹,¹⁵ Virus and parasite concentrations in the ATAD effluent were below detectable limits in most cases, whereas the anaerobic digester effluent always contained some viruses and
<table>
<thead>
<tr>
<th>Year</th>
<th>Activity</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mid-1960</td>
<td>Mathematical modeling indicates potential for increased temperatures and relation to efficient O₂ transfer.</td>
<td>7, 21</td>
</tr>
<tr>
<td>Mid-1960 on</td>
<td>Early experimental work conducted by Popel and co-workers. Process demonstrated with Fuch's self-aspirating high shear field aerator (the &quot;umwalzbelufter&quot;) at full scale with animal wastes and sewage sludge.</td>
<td>8, 9, 10, 11</td>
</tr>
<tr>
<td>1975</td>
<td>Autoheating with pure oxygen shown in small pilot unit by Union Carbide.</td>
<td>22</td>
</tr>
<tr>
<td>1974-78</td>
<td>First U.S. full scale demonstration of liquid composting of animal waste with German Fuch's aerator.</td>
<td>2</td>
</tr>
<tr>
<td>1972</td>
<td>DeLaval Company initiates marketing of LICOM System (short for &quot;liquid composting&quot;) in the U.S. powered by the self-aspirating Fuch's aerator mainly for agricultural waste treatment.</td>
<td>---</td>
</tr>
<tr>
<td>1977</td>
<td>First full scale demonstration ATAD with sewage sludge at Binghamton, NY using two different self-aspirating aerators - Fuch's and the Midland-Frings aerator.</td>
<td>1, 22</td>
</tr>
<tr>
<td>1981</td>
<td>Feasibility analysis comparing ATAD to conventional aerobic digestion and anaerobic digestion. ATAD found to be least cost alternative up 10 MGD for sludge stabilization.</td>
<td>13</td>
</tr>
<tr>
<td>Late 1970's</td>
<td>New self-aspirating aerator based on vortex concept developed by the English Electric Research Council. Presently marketed as VO₂ aerator by T.G. Macquire Co., United Kingdom.</td>
<td>26</td>
</tr>
<tr>
<td>1982</td>
<td>First full scale ATAD at Ponthir Sewage Treatment Works, Welsh Water Authority in United Kingdom.</td>
<td>27</td>
</tr>
<tr>
<td>1984</td>
<td>Economic analysis indicates ATAD most cost-effective sludge treatment system at all scales when electricity costs are low and air is used.</td>
<td>14</td>
</tr>
<tr>
<td>1985</td>
<td>Approximately 23 full scale ATAD plants in operation in Europe (17 in West Germany and Switzerland, and six in the United Kingdom).</td>
<td>12, 32, 34</td>
</tr>
</tbody>
</table>
Figure 1.
Estimated capital costs of sludge stabilization alternatives as developed from full-scale systems. Values in 1984 $ for complete system (including prethickening, the reactor, post storage, pumping system, concrete slab for tanks).
parasites. The application reported here may achieve high temperatures in a batch mode with large pH changes. This should assure complete pathogen destruction. No pathogens were monitored in this study.

Numerous metal removal studies have been conducted, and most have achieved little success.\textsuperscript{16,17,18,19} Processes such as the "hot acid treatment" have been estimated to add \$300 per ton (dry) to the sludge treatment costs.\textsuperscript{20}

The process developed at Cornell University uses pH reduction in conjunction with redox potential manipulation (U.S. Patent Numbers 4,277,342 and 4,370,233). In the aerobic digestion of anaerobic feed sludges, the single most important change that may affect the solubility of heavy metals is exposure to a higher oxidation-reduction potential (ORP). Lowering the pH for anaerobic sludge will not result in a shift in cadmium solubility from the insoluble sulfide form to the soluble ionic form, unless acidification is preceded by a rise in sludge ORP. Aerobic treatment, on the other hand, would produce a substantial rise in ORP, thereby establishing favorable equilibrium conditions for the formation of cadmium carbonate. At ORP values above +100 mv, a shift to the divalent cadmium ion would be achieved by lowering the pH below 4.0, thus achieving metal solubility.

As with cadmium, the solubilization of copper, lead, nickel, and zinc in sewage sludge can best occur when the metals are first brought into equilibrium with their carbonate, hydroxide and phosphate forms at elevated ORP's (aerobic conditions), and then acidified to pH's below 3.0 - 4.0.\textsuperscript{23} Chromium is an exception, since this metal predominates as the trivalent hydroxide at neutral pH's, and as an ionic soluble species at low pH's, regardless of whether the sludge is aerobic or anaerobic.

Initial attempts to confirm the above hypothesis were highly successful\textsuperscript{24,25} Nearly complete cadmium removal sewage sludge was achieved, and greater than 80% removal of lead, nickel, zinc and copper was also reported. The system was also tested with sludges previously stabilized by anaerobic digestion and found to be effective.
Once the metals are solubilized, they must be separated from the solids and then recovered from the liquid. The soluble metals can be removed by elutriation of the acidified sludge. Several processes are available for recovery of the soluble metals.28,29,30,31

The hypothesized pathogen and heavy metal removal system using the ATAD is summarized in Figure 2. Although lime addition for precipitation of the metal is shown, it is not a recommended metal recovery alternative because of the large amount of lime sludge that is generated.

METHODS

The general approach of this study3 was to develop additional information on the most common potential application of the process in large sewage treatment facilities, i.e., to use it to detoxify and decrease the volume of anaerobically digested sludge. No full scale data exists for treatment of anaerobically digested sludge, even though Macguire32 has reported significant autoheating and a 50% volume reduction in this application.

The general work plan consisted of short term batch tests (less than 30 days each) of four municipal sludges in the full scale unit, and comprehensive bench-scale testing of settleability, biodegradability, metal removal by acidification (and measurement of the effects of variables such as pH and varying periods of aeration before and after acidification).

A bench scale study was set up to determine the biodegradable fraction of anaerobically digested sludge under aerobic digestion conditions. Experiments were conducted at both mesophilic (35°C) and thermophilic (55°C) temperatures. The reactors were run in batch mode.

A second bench scale study was set up to provide aerated sludge for heavy metals removal testing and to examine the physical effects of aeration on previously anaerobically digested sludge. This study was conducted separately from the biodegradability study. The study was conducted simultaneously at both mesophilic (35°C) and thermophilic (55°C) temperatures.

Settling tests were done using two liter graduated cylinders 8 x 50 cm, the tests were run on samples from both reactors and in the respective constant temperature rooms. The graduated
Figure 2. Sequential steps used in the Cornell University sludge stabilization process for pathogen and heavy metal removals.
cylinder was filled with two liter sludge samples collected at the predetermined aeration times and the sludge interface was monitored over time. Settled volume was measured at (0, 1, 2, 3, 6, 12 and 24 hours) settling time. This settling test was used only as a comparison between samples and an estimate of the relative settleabilities.

Capillary suction tests were done using the Triton-W.P.R.C. type 92/1 CST apparatus. Sludge was placed in a steel cylinder (1.7 mm diameter x 2.6 mm length) testing upright on Whatman 17 Chr. chromatography paper in the CST apparatus. The time it took water to travel horizontally 0.7 cm by capillary action through the chromatography paper was measured.

Final sludge volume was measured after the sludge had been put through the metals removal process and allowed to settle for 24 hours. Several samples from neutralized and detoxified sludge were also tested for settleability and dewaterability. Also, samples of the metal precipitated lime sludge were also analyzed.

Metal removal experiments were designed to examine the effects of aeration before and after acidification from previously anaerobically digested sludges. Metal removals were analyzed for cadmium, copper, lead, nickel and zinc.

Aeration of the acidified aerated sludge was done in the respective constant temperature rooms. Elutriant was prepared beforehand with tap water acidified to pH 1.5. Subsamples of acidified sludge were taken from the aerating beakers after varying periods of aeration (0, 1, 3, 6 and 12 hours). The elutriation was done in three stages with a total elutriant volume five times that of the sludge being elutriated.

Experiments were conducted to quantify the amounts of sulfuric acid and hydrated lime required for the metals removal process. The effects of pre-aeration on these requirements was also examined. The requirements were calculated using the results from potentiometric titrations for acidity and alkalinity. The required amounts of acid and lime were also measured directly during the testing of the metals removal process. Samples tested for the metals removal process were pre-aerated for periods ranging from 0 to 20 days.
Subsamples were analyzed for total cadmium, zinc, copper, nickel and lead using an atomic absorption spectrophotometer. The facility utilized was an EPA-approved facility and used approved standards in each test.

Alkalinity, acidity, total solids (TS) and VS were determined in accordance with Standard Methods. Potentiometric titration curves were constructed to express the requirements in actual quantities of acid (sulfuric 93% technical grade) and hydrated lime (147.5% CaCO₃ equivalent). The TCOD was measured in accordance with procedures developed by Knechtel.

PILOT PLANT ANALYSIS

The pilot unit consisted of a 63 m³ reactor vessel with an operating liquid volume of 28.9 m³. This was the same reactor used in earlier studies. The full scale study was designed to test the effects of the high shear field aerator on the auto heating and on the metals extraction processes.

Aeration and mixing were accomplished by the Framco Midland-Frings (240 volt, 3 phase, 2 hp) self-aspirating aerator. The aerator was mounted six inches above the reactor bottom. Foam control was accomplished with the DeLaval mechanical foam cutter (240 volt, 3 phase, 2 hp, 1,750 rpm). The foam cutter impeller operated four feet above the liquid level in the reactor.

The reactor was run in a batch mode under two operational schemes, with pre-aeration (autoheating) and without. Initially, 38 m³ (10,000 gal.) to 61 m³ (16,000 gal) of sludge were placed in the reactor. After a 24-hour settling period, the reactor was decanted to a volume of 38 m³ (7,400 gallons). The aerator and foam cutter were then started. If autoheating was to be monitored, a ten to 29-day pre-aeration period was used. Only if the effects on the metals extraction process were being monitored, was the reactor immediately acidified. The sludge was acidified as follows: sulfuric acid (93% technical grade) was pumped into the aerating reactor from 15-gallon drums via a hand pump at a rate of approximately one gallon per minute, until a pH of 1.5 was reached in the sludge. Aeration was continued after acidification for three to 11 days.
RESULTS

General characteristics of the anaerobically digested sludge tested both at laboratory and pilot scales are summarized in Table 3.

Settling Characteristics

The first unit process in the detoxification system is a long-term sedimentation or a decant process to obtain maximum solids concentrations. A 50% to 60% volume reduction was measured with two sludges. The more concentrated anaerobic digested sludges received from Ithaca and Chemung County (at a total solids concentration of seven to eight percent) showed no reduction after 24 hours.

In prior anaerobic thermophilic treatment, some deterioration of the settleability and dewatering characteristics occurred. In this testing, the additional chemical conditioning was thought to have the potential of reducing the sludge volume further and providing enhanced dewaterability. This was confirmed in all cases. The final sludge concentrations achieved after relatively short settling periods following detoxification treatment (acidification, metal solubilization, elutriation and neutralization) approached ten to 13% total solids (dry matter). This resulted in a total slurry volume reduction varying from 30% with high solids sludges, such as that produced in the Ithaca plant, to 85% slurry volume reduction, when influent solids were low (one to two percent total solids).

Biodegradability

It had been anticipated that one of the more difficult problems would be to achieve autoheating to temperatures that would cause pasteurization of the sludge (50°C), since anaerobic digesters produce a well-stabilized sludge. Note that in order to autoheat from 35°C, (the temperature of the anaerobic mesophilic digesters that would be influent for an ATAD retrofit unit) it would require a minimum of a 15°C rise in temperature, plus enough heat to account for evaporation and wall losses from the reactor. This temperature differential would require the
Table 3. Summary of general characteristics of anaerobically digested sludge used in the Phase I test program and the initial heavy metal concentrations in ppm (dry weight basis).

<table>
<thead>
<tr>
<th>New York Municipal Treatment Facility</th>
<th>Type Treatment Facility</th>
<th>Anaerobic Digesters</th>
<th>Digested Solids Effluent Concentration % Wet Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Binghamton/Johnson City</td>
<td>Activated Sludge</td>
<td>One stage, 15 day HRT</td>
<td>2.52</td>
</tr>
<tr>
<td>Onondaga County (Syracuse, NY)</td>
<td>Activated Sludge</td>
<td>Two stage, 20 day HRT</td>
<td>1.73</td>
</tr>
<tr>
<td>Chemung County (Elmira, NY)</td>
<td>Activated Sludge</td>
<td>Two stage, 60 day HRT</td>
<td>7.33</td>
</tr>
<tr>
<td>Ithaca, NY</td>
<td>Trickling Filter (old units)</td>
<td>One stage, inefficient operation</td>
<td>8.02</td>
</tr>
</tbody>
</table>

INITIAL SLUDGE METAL CONTENT

<table>
<thead>
<tr>
<th></th>
<th>Cadmium</th>
<th>Zinc</th>
<th>Copper</th>
<th>Nickel</th>
<th>Lead</th>
</tr>
</thead>
<tbody>
<tr>
<td>Binghamton</td>
<td>16.1</td>
<td>2,900</td>
<td>749</td>
<td>482</td>
<td>247</td>
</tr>
<tr>
<td>Syracuse</td>
<td>27.4</td>
<td>620</td>
<td>871</td>
<td>88</td>
<td>195</td>
</tr>
<tr>
<td>Chemung County</td>
<td>115.0</td>
<td>2,500</td>
<td>960</td>
<td>43</td>
<td>244</td>
</tr>
<tr>
<td>Ithaca</td>
<td>9.6</td>
<td>1,170</td>
<td>565</td>
<td>305</td>
<td>264</td>
</tr>
</tbody>
</table>
oxidation of at least four grams per liter of organic matter expressed as chemical oxygen demand. This would be equivalent to an additional conversion of 15% of the organic matter for typical anaerobic digested effluents. Small scale batch biodegradability tests showed that this amount of organic matter was available under both mesophilic and thermophilic conditions (Figure 3). All four sludges contained sufficient remaining biodegradable matter to theoretically achieve the required autoheating.

Of the four sludges tested in the pilot reactor, two were allowed to autoheat to the maximum level and the two other sludges were immediately acidified. Autoheating occurred at a rate of between 1°C and 4°C per day, thus indicating that the removal rates exceeded 1 gm COD/l-d in these reactors. The lowest biodegradability tested was the Binghamton sludge. It achieved nearly a 9°C temperature change in approximately five days, thus indicating that the mesophilic anaerobic digester effluent should be capable of autoheating to thermophilic conditions. This test was done when the air temperature was below freezing much of the time, thus indicating substantial autoheating potential throughout much of the year. The Ithaca sludge achieved the greatest degree of autoheating resulting in a temperature of 54°C, a temperature rise of nearly 35°C over the ambient temperature. These full scale batched tests confirmed that autoheating is easily achieved with the high shear field aeration systems, even with previously stabilized sludges.

Dewatering Effects

In most cases, anaerobically digested sludge is difficult to dewater. The municipalities that use dewatering filters or presses often use large quantities of chemical dewatering aids. The initial average dewaterability, as measured by the capillary suction time, always exceeded four minutes for all of the sludges tested. A CST of less than one minute is desirable for good dewatering. It was thought that the detoxification process using acid and lime treatment would have a highly beneficial effect on dewatering and settleability. This was confirmed in the testing program. The dewaterability of the treated sludges had a CST varying from one second up to a maximum of 60 seconds, or reductions below that needed for dewatering systems applied without dewatering aids.
Figure 3.
Laboratory evaluation of the rate of removal of organic matter from anaerobically digested sludge under batch conditions at two different temperatures.
Metal Removals

Extensive laboratory parametric testing was conducted with all four sludges to determine the effects of temperature, pH, acidification periods and aeration periods on metal solubilization. Examples of this testing are shown in Figure 4 for the Binghamton sludge. Cadmium removal efficiency approached 94%; copper 70%; lead 60%; nickel 90%; and zinc removal as high as 94%. The cadmium content of the treated sludge was as low as one ppm (dry weight) or a value approaching a background cadmium content of some natural organic matter such as cow manure. Aeration prior to acidification did not appear to assist in the metal solubilization process. Conversely, it had a negative impact on the system with one sludge.

In general, the efficiency of metal removal was greater than 80%. However in some cases, the acidification time was quite long in order to achieve this high efficiency. With the Binghamton sludge, cadmium removals at 55°C approached one ppm in the sludge after six hours of acidification, but 24 hours of acidification was required to reduce the cadmium content from over 100 ppm to 15 ppm in the Chemung County sludge. The removal of lead was minimal in two cases. This suggests that lead is tightly bound to the organic suspended solids. It should be noted that the lead concentration of all the sludges tested was relatively low.

The metal solubilization in the pilot unit was equal to or greater than that observed in the bench scale tests (Tables 4 and 5). Large quantities of foam were generated at bench scale, thus requiring a limited amount of mixing and oxygen in the small scale units. This resulted in some variability in removal efficiency, and perhaps a conservative estimate of the solubilization of metals. In addition, the effects of the aerator’s high shear field on the physical solubilization might be significant.

The quantity of acid required to achieve a pH of 1.5 in the full scale reactor was less than that reflected by the small scale titration curves. The total quantity varied between five and ten gallons of technical grade sulfuric acid per 1,000 gallons of sludge treated. The effects of pre-aeration were not as obvious at the pilot scale. However, the sludge that autoheated to maximum temperatures (the Ithaca sludge) had some unique characteristics. It was a highly concentrated
Figure 4. Effects of aeration prior to acidification (cross-hatching refers to pre-aeration periods of 0, 2, 3, 6, 12 and 24 hours from left to right, respectively) and after acidification to a pH of 1.5.
Table 4. Summary of maximum metal removal efficiencies achieved with full scale testing on anaerobically digested municipal sludges.

<table>
<thead>
<tr>
<th>MUNICIPALITY</th>
<th>Cadmium</th>
<th>Zinc</th>
<th>Copper</th>
<th>Nickel</th>
<th>Lead</th>
</tr>
</thead>
<tbody>
<tr>
<td>Binghamton</td>
<td>84</td>
<td>92</td>
<td>72</td>
<td>88</td>
<td>72</td>
</tr>
<tr>
<td>Syracuse</td>
<td>91</td>
<td>89</td>
<td>72</td>
<td>89</td>
<td>76</td>
</tr>
<tr>
<td>Chemung County</td>
<td>92</td>
<td>97</td>
<td>86</td>
<td>77</td>
<td>15</td>
</tr>
<tr>
<td>Ithaca*</td>
<td>39</td>
<td>63</td>
<td>48</td>
<td>29</td>
<td>24</td>
</tr>
</tbody>
</table>

*Physical problems were experienced with this sludge since about 20% was sand and grit.

Table 5. Typical metal concentrations in detoxified sludge and process efficient. Values in ppm dry weight basis.

<table>
<thead>
<tr>
<th>MUNICIPALITY</th>
<th>TYPICAL SLUDGE METAL CONTENT OF DETOXIFIED SLUDGE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cadmium</td>
</tr>
<tr>
<td>Binghamton</td>
<td>1.4</td>
</tr>
<tr>
<td>Syracuse</td>
<td>3.1</td>
</tr>
<tr>
<td>Chemung County</td>
<td>11.9</td>
</tr>
<tr>
<td>Ithaca</td>
<td>5.1</td>
</tr>
</tbody>
</table>

TABLE 4

TYPICAL SLUDGE METAL REMOVAL EFFICIENCIES, % of initial concentration removal

<table>
<thead>
<tr>
<th>MUNICIPALITY</th>
<th>Cadmium</th>
<th>Zinc</th>
<th>Copper</th>
<th>Nickel</th>
<th>Lead</th>
</tr>
</thead>
<tbody>
<tr>
<td>Binghamton</td>
<td>91</td>
<td>93</td>
<td>63</td>
<td>87</td>
<td>66</td>
</tr>
<tr>
<td>Syracuse</td>
<td>89</td>
<td>77</td>
<td>77</td>
<td>76</td>
<td>86</td>
</tr>
<tr>
<td>Chemung County</td>
<td>87</td>
<td>80</td>
<td>58</td>
<td>30</td>
<td>7</td>
</tr>
<tr>
<td>Ithaca</td>
<td>50</td>
<td>11</td>
<td>37</td>
<td>17</td>
<td>77</td>
</tr>
</tbody>
</table>
sludge produced from an old trickling filter plant. Mixing and aeration were inhibited by large quantities of grit (at the end of the test, the reactor contained 20\% by volume sand with this sludge).

Effects of pH on Metal Solubilization

In order to test the possibility of minimizing the acid requirement, metal solubilization was tested for two sludges at pH values of 1.5, 2.5 and 3.0. This data showed that a pH of 1.5 was required and that relatively little solubilization of cadmium and other metals occurred at a pH of 2.5 and 3.0. This data also suggests that the efficiency of metal solubilization measured in the laboratory and in the full scale runs might have been somewhat limited by pH shifts that occurred during aeration after acidification. In general, after the pH was reduced to 1.5 in the pilot reactor, a relatively rapid increase of pH to between two and three occurred. The impact of this change in pH was not quantified.

In all cases, the efficiencies of heavy metal removals were significantly improved at the thermophilic conditions. Where 75\% of the metals were removed at 35°C, an increase up to 85\% would be observed at the higher temperature.

Chemical Requirements

The chemical needs of the detoxification process represent one of the greatest costs of the system. On the average, it took 17 gallons of concentrated technical grade sulfuric acids to lower 1,000 gallons of sludge to a pH of 1.5, and 187 pounds of hydrated lime to precipitate the metals from the elutriant used to process the 1,000 gallons of sludge.

It was anticipated that the effect of aeration would minimize the amount of acid required to lower the pH by removal of the buffering capacity of the sludge, i.e., stripping of CO₂ and ammonia from the liquid. Such was shown to be the case. The above acid requirement was reduced by a factor of ten in several laboratory tests using pre-aeration.
DISCUSSION

Considering the general magnitude of sludge stabilization and disposal problems, it is surprising that few technologies are capable of converting sludge into a safe material for land application. Experiences in the United States and Europe have shown that sludge can be a highly desirable material for land application in agriculture, for land reclamation, and for topsoil restoration. Present regulations emphasize minimal concentrations of toxic substances in the sludge and limit accumulation of materials, such as cadmium, in the topsoils where sludge is applied.

Federal regulations also require additional pathogen control when sludges are applied to land. Pathogen control technologies can represent substantial additional costs. The cost of solid state composting, for example, may exceed $300 per dry ton, in most cases, and add a considerable amount of maintenance problems.35

The detoxification process studied in this program is relatively simple and the economics appeared to be attractive. The simple self-aspirating high shear field aerators used to achieve slurry autoheating result in a sludge that is highly stable in a minimum reactor volume. Autoheated temperatures to 50°C or greater were demonstrated under cold climate conditions, thus offering the potential of efficient pathogen destruction.

The increased redox potential which results in the autoheated slurries should enable many of the heavy metals to be rapidly removed with acidification. After acidification, the sludge is washed by elutriation which carries the soluble heavy metals into another reactor. The final sludge is then settled and disposed or applied to land as a detoxified material. The combined impact of aeration, acidification, elutriation, and neutralization, results in substantial slurry volume reduction, as well as production of an easily dewatered sludge.

Autoheating and Biodegradability

Both the batch laboratory digestion studies at 35°C and 55°C and the full scale runs confirm that the high shear field aerators can achieve autoheating to 50°C or greater with anaerobically
digested sludges. A review of the kinetics indicates that a three- to five-day hydraulic retention time reactor would be capable of achieving 50°C with most sludges previously stabilized with anaerobic digestion. Higher temperatures could be achieved with heat exchanges. The liquid composting concept could replace the solid state composting systems and may be more economically attractive.

Metal Solubilization

In terms of efficiency of removal, cadmium and zinc were often at 90% or greater, copper and nickel being 65% removed, and lead being 50% or less. Maximum metal removal is achieved at the highest temperature and at a pH of 1.5. This indicates that an autoheating process that could achieve 50°C or greater would increase the potential for metal removal. Pre-aeration should also minimize chemical requirements due to the removal of CO₂ and ammonia from sludges, especially anaerobically digested sludges. The pH values of the pilot runs initially were around 7.0 and after several days' aeration, they gradually increased to over 8.0: pH values typical for thermophilic aerobic sludge treatment.

Although the high shear field aerators appeared to increase the efficiency of metal removal, the data is inconclusive in terms of the impact of these aerators on the solubilization reaction. The energy level input of 0.07 kW/m³ was adequate to provide oxygen and mixing to the 60 cubic meter reactor operated approximately half full. It is anticipated that slightly larger aeration requirements would be necessary for the biological reaction, but even lower energy requirements would be necessary to maintain aerobic conditions in an acidified reactor.

A recent study may assist in explaining the high removals obtained by our treatment approach. Gibbs and Angelidis examined the difference in metal extractability in digested (both anaerobic and aerobic) and undigested sewage sludges, using different chemical treatments. Undigested sludges had a larger fraction of crystalline or residual metals, but the total amount of metals that were extractable in digested sludges were always high. The total extractable metals in anaerobically digested sludge ranged from 84.8% to 92.4% for Cd, Cr, Cu, Pb, and Zn. Except
for lead and chromium, the maximum metal solubilization efficiency achieved here agrees with the chemical extraction results given by Gibbs and Angelidis. Their results also suggest that undigested sludges would be less successfully treated. The crystalline metal fractions were about 20 to 30% of the total in undigested sludges.

Chemical Requirements for Detoxification

The total chemical requirements for acidification and neutralization of sludge would cost between $20 and $40 per dry ton of treated sludge. These costs would be higher if the anaerobically digested sludge is treated without a period of aeration to remove some of the buffering capacity of the sludge prior to acidification. In addition, the quantity of lime sludge produced with heavy doses of acids required without pre-aeration is unacceptable. Pre-aeration reduces the chemical requirements to approximately five gallons of concentrated technical grade sulfuric acid per 1,000 gallons of sludge treated and 150 pounds of hydrated lime or less for neutralization and metal precipitation.

Pre-elutriation of the sludge prior to the detoxification process would assist in limiting chemical requirements. However, this would also eliminate large quantities of heat energy that would be useful in obtaining additional pathogen destruction and biological stabilization.

Alternatives to metal removal from the elutriation washwater would improve the process. Median contaminated sludge would generate approximately one ton per year of total recoverable heavy metals. If these could be captured and concentrated, it might be possible to recycle them and generate a significant revenue. Existing metal recovery technology, such as sulfide precipitation, should be considered in future work.
REFERENCES


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