Fluidized Bed Disposal of Secondary Sludge
High in Inorganic Salts

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ABSTRACT

During the course of design of an industrial wastewater treatment plant, consideration was given to the means of disposal of excess activated sludge. The primary sludges were inorganic and were disposed of by concentrating them in lagoons and then landfilling. However, a separate system had to be devised for the organic sludge disposal because of potential odor problems.

To obtain rapid and complete disposal without odors, incineration was chosen. Because of the fluidity of the sludge and the relatively small quantity, the fluid-bed reactor-type incinerator was selected for use. However, the water phase of the sludge contained combinations of salts at concentrations that presented potential clinkering and freezing problems in the fluid bed and also presented a potentially serious materials-of-construction problem.

This paper discusses the investigation into the applicability of the fluid-bed incinerator to this waste, the results of the investigation, and the design and operating features of the system.

INTRODUCTION

The heart of the activated sludge treatment facility consists of two parallel aeration basins in which primary-treated (neutralization and solids-removal) wastewater and biological cultures are thoroughly mixed and aerated by surface-type mechanical turbine aeration. Three simultaneous biochemical reactions occur; although in reality quite complex, they can be represented as follows:

\[
\begin{align*}
\text{Oxidation of Organic Matter} \\
C_xH_yO_z + \underset{\text{microbial cell enzymes}}{0_2} \rightarrow CO_2 + H_2O - \Delta H \\
\text{Synthesis of New Microbial Cells} \\
C_xH_yO_z + NH_3 + \underset{\text{microbial cell enzymes}}{0_2} \rightarrow (\text{New Cells}) + CO_2 + H_2O - \Delta H \\
\text{Destruction of Microbial Cells} \\
(\text{Cells}) + \underset{\text{microbial cell enzymes}}{0_2} \rightarrow \text{CO}_2 + \text{H}_2O + NH_3 - \Delta H
\end{align*}
\]

The first and third equations constitute a simple combustion equation, while the second represents the source of the disposal problem, i.e., excess activated sludge. Theoretically, synthesis and cell oxidation could be made to balance with a result of no excess sludge, but this situation is not practical in a plant-scale operation. The difference between synthesis and cell oxidation establishes the amount of sludge to be wasted in an equilibrium situation of liquid-waste treatment. The quantities produced are dependent on the BOD loading represented by \( C_xH_yO_z \) in the equations.

Disposal Problem

Sludge Quantities and Conditions

The excess sludge quantities given in Table 1 were calculated based on a design operating temperature of 40°C in the activated sludge system; lower
temperatures would result in larger quantities of sludge.

### Table 1

<table>
<thead>
<tr>
<th>BOD Applied lb/day</th>
<th>Net Excess Sludge to Waste lb/day (dry basis)</th>
<th>Probability of Occurrence</th>
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</thead>
<tbody>
<tr>
<td>74,500</td>
<td>8,000</td>
<td>50%</td>
</tr>
<tr>
<td>109,000</td>
<td>13,000</td>
<td>10%</td>
</tr>
</tbody>
</table>

In general, the activated sludge mass is a gelatinous substance notoriously difficult to dewater. Dewatering of the sludge was evaluated in the field, using pilot-plant sludge and a solid-bowl centrifuge. These tests indicated that the centrifuge was capable of concentrating the sludge to 22 percent solids. However, under these test conditions, the sludge contained large quantities of calcium carbonate, which may be expected to improve centrifuge operation. Prior experience with activated sludge handling indicated expected production of a cake with a range of 12 to 18 percent solids, with 15 percent solids fairly typical. On this basis, a design figure of 15 percent solids for the centrifuge cake was chosen.

#### Evaluation of Alternative Disposal Methods

After the process parameters for the activated-sludge system were established various methods of excess activated-sludge disposal were evaluated, including:

1. Off-site disposal schemes, such as hauling to a sanitary landfill or barging to sea or to a centralized sludge disposal facility;
2. On-site land disposal, such as lagooning the excess activated sludge in combination with the copious quantities of primary sludge; and
3. Incineration.

The first consideration was abandoned because of cost, the lack of suitable off-site facilities, and client reluctance to transfer the problem to another location.

On-site lagooning was eliminated on the basis of insufficient space to maintain a long-term program and because of serious potential odor problems.

With total combustion of the organic matter at temperatures that would preclude odoriferous stack gases, incineration was considered the practical solution for this problem. During the course of process design, several combustion techniques were considered, and the fluid-bed technique was selected for several reasons.

First, after dewatering, the sludge is expected to vary from 12 to 22 percent of dry solids (by weight) and, because of its gelatinous characteristic, will range from a borderline Newtonian fluid to a pseudoplastic. In either case, it would be relatively simple to handle in special pumps but difficult to handle with other feeders such as belts and screws. The pumpability feature lends itself to rejection into a fluid-bed incinerator.

Secondly, because of the relatively high water content and wide variation in solids content during any dewatering operational upsets, a large heat sink is desirable to preclude large swings in combustion temperatures. A swing to the low side could lead to incomplete combustion and odors, whereas a swing to the high side could damage the equipment. The bed media and the refractory in a fluidized-bed installation would provide considerably more flywheel effect than would the other processes evaluated.

Finally, the minimum space requirements, simplicity and dependability of the process and equipment, expandability, and relatively low capital costs were other factors favoring the fluidized-bed approach.

Since the facility is expected to operate 24 h a day and because labor for operation and maintenance is sometimes difficult to obtain, the dependability aspects of this process with its minimal number of moving parts was one of the more important considerations in the final selection.

It was recognized that the combination of inorganic salts present in the liquid phase of the sludge posed potential operating problems for a fluidized-bed system. Available phase diagrams indicated that the combination of inorganic salts (calcium carbonate, calcium chloride, calcium sulfate, and sodium chloride) could fuse the bed granules together and, hence, defluidize the bed. Consequently, pilot tests were deemed necessary, and selected vendors were invited to propose test programs to ascertain fluid-bed-incineration feasibility. The vendor submitting the most promising proposal was selected, and a test program was authorized to evaluate the ability of the vendor's equipment to incinerate the sludge.

#### Fluid-Bed Incinerator

The fluidized-bed system for combustion of sludges involves suspension of relatively fine particles (0.25 in. to 65 mesh) of solid material in a cylindrical reaction vessel in a stream of rising gas. The velocity of the gas flow is regulated so that a vigorous mixing action is maintained in the fluidized bed. The fluidized bed can be maintained at temperature if the fuel value of the combustible material is
sufficient to permit autogenous oxidation or is supple­mented by the addition of external fuel. Bed tem­perature is normally maintained at about 1,300 to
1,500°F to insure complete oxidation of the organic
matter in the sludge and to destroy any odorous com­pounds that may be present in the sludge or formed
during the sludge combustion.

The dewatered sludge is sprayed in a controlled
dispersion pattern into the free space (freeboard)
above the zone occupied by the fluidized-bed mater­ial. As it is forced through the freeboard section of
the furnace, the dispersed feed loses all (or a por­tion) of its contained water by evaporation through
direct heat exchange with the hot exhaust gases
rising through the freeboard from the fluidized bed in
the lower section of the furnace. As the sludge solids
continue their fall through the freeboard zone and
enter the fluidized bed, the organic content is ox­i­dized and converted to carbon dioxide and water
vapor, which pass out of the furnace in the exhaust
gases. The operation of the fluidized-bed furnace can
be adjusted to accentuate either entrainment of the
inorganic material in the exhaust gases or its reten­tion in the bed itself.

The material that constitutes the fluidized bed it­self generally is sand or some other inert material
inserted into the reactor on initial startup and re­plenished periodically as required. However, the bed
could be made up of inorganic materials from the
sludge feed, i.e., compounds like sodium or calcium
chloride, calcium carbonate or sulfate, or, more
likely, mixtures of such compounds. These com­pounds and mixtures can form the bed only if the
mixtures involved do not melt at the operating tem­peratures, because this would prevent fluidization of
the bed.

The fluid-bed incinerator selected for test was
capable of two basic methods of operation. The first
of these methods involves "agglomerative operation"
of the fluidized bed. In this method, the inorganic
residue of the sludge is deposited on the particles
making up the fluidized bed, and these particles
grow in size. All of the inert material introduced into
the freeboard zone is not immediately deposited on
the bed particles, but a portion is produced as fine
particulate matter, which is entrained in the exhaust
gases and carried from the furnace. This material is
separated from the exhaust gases in a cyclone
separator and returned directly to the fluidized bed to
serve as nuclei for continued deposition. When these
nuclei have undergone a number of recirculation
cycles and have grown to such a size that they are
not entrained in the exhaust gases, they remain in the

bed. The initial bed material is finally replaced by
inorganic particles, and the excess material is with­drawn continuously or intermittently from the bed to
maintain a constant volume of bed material in the
furnace. The second method of operation is a
nonagglomerative system where the inorganic salts
are elutriated from the sand bed and entrained in the
exhaust gases from the furnace. The exhaust gases
are passed through dust collection equipment
(cyclone and wet scrubber), where the entrained
particulates are separated prior to disposal.

TEST PROGRAM

The primary objectives of the test program were to
determine

(1) conditions for complete oxidation of the
organic fraction of the sludge and

(2) conditions necessary to handle the inorganic
fraction of the sludge without defluidizing the bed.

Preliminary laboratory tests were directed at de­termining the physical and chemical characteristics
of various inorganic salt mixtures. The salt mixtures
used were designed to represent the extreme of varia­tion that might be encountered in the sludge to be
incinerated. Thirty mixtures of calcium carbonate,
calcium oxide, sodium chloride, calcium sulfate, and
calcium chloride were prepared for analysis. The
melting points and decomposition temperatures for
these mixtures were determined on a Differential
Thermal Analyzer (DTA).

These tests indicated that, in many of the mix­tures, melting occurred between 930°F and 980°F,
which was interpreted as evidence of a solid solution
of sodium chloride and calcium chloride. A higher
temperature endotherm (1380°F to 1475°F) was noted
and interpreted as a phase change involving a ternary
or quaternary system. The lower temperature endo­therm was well below the lowest anticipated fluid-bed
operating temperature, and the upper endotherm was
within the expected operating range.

Inspection of the DTA samples indicated that
some fusion occurred in some of the salt mixtures
within the anticipated operating temperature range.
However, the mixtures were fritted and friable rather
than completely fused and hard. The nature of the
frit indicated the turbulent action of the fluid bed
could prevent formation of large agglomerates that
could defluidize the bed. The tests also indicated
sufficient fusion to coat bed particles and cause
progressive size growth of particles in the bed.

The laboratory (DTA) tests indicated that the
various inorganic salt mixtures would not prevent
satisfactory operation of a fluidized-bed incinerator; hence, pilot-scale tests were scheduled.

The pilot fluid-bed furnace was 22 in. in diameter with a 28-in. diameter freeboard. The pilot reactor system was complete with a primary cyclone and venturi scrubber. Because sludge from the activated sludge treatment facility was not available, a simulated feed material was used for the pilot tests. The sludge (composition given in Table 2) selected for the pilot test was prepared by using an available domestic-sewage sludge to provide the organic content and then by adding limestone, calcium chloride, calcium sulfate, and sodium chloride in the required amounts to simulate the expected sludge feed composition.

<table>
<thead>
<tr>
<th>Material</th>
<th>Percent</th>
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<tbody>
<tr>
<td>Volatile Matter</td>
<td>12.80</td>
</tr>
<tr>
<td>CaCO₃</td>
<td>5.59</td>
</tr>
<tr>
<td>NaCl</td>
<td>1.53</td>
</tr>
<tr>
<td>CaCl₂</td>
<td>0.15</td>
</tr>
<tr>
<td>CaSO₄</td>
<td>0.03</td>
</tr>
<tr>
<td>Water plus inert materials and</td>
<td></td>
</tr>
<tr>
<td>balance of inorganics</td>
<td></td>
</tr>
<tr>
<td>Total:</td>
<td>100.00%</td>
</tr>
</tbody>
</table>

Deposition and agglomeration of inorganic salts on the bed material were shown by analysis and by photomicrographs. The agglomerating rate was considered controllable by operational procedures, principally involving variation of the feed-nozzle conditions to permit either of two modes of fluid-bed operation. An agglomerative system would use a high salt-capture rate in the bed and permit replacement of the initial sand bed with particles composed wholly of inorganic salts. A nonagglomerative system would minimize salt retention in the bed. Fluid-bed grain size would be controlled in either case by wasting a controlled amount of bed material. Nonagglomerative operation would also require the addition of fresh bed material to replace that wasted. The organic odorant added to the sludge was used as a tracer to judge organic destruction. Samples of exhaust gases were analyzed by mass spectrographic techniques, and the odorant concentration was found to be below the detection level. Subjective tests also failed to detect the tracer odorant.

During the pilot tests, the bed material, primary cyclone catch, and venturi scrubber liquid were periodically sampled. During the final portions of the run, the scrubber exhaust gases were sampled. Variations in sludge composition and bed temperature were limited, but no operational difficulties were encountered that would indicate bed fusion or uncontrolled agglomeration of bed particles.

The fluid-bed incinerator tests continued for approximately 72 h, interrupted by brief downtimes to effect repairs or to modify equipment. Initially, sewage sludge without inorganic additives was fed to establish steady state conditions at a bed temperature of 1500°F. Next, the simulated sludge (Table 2) was fed, and the bed temperature, maintained at 1500°F (the anticipated maximum operating temperature), was lowered to 1300°F (the anticipated minimum operating temperature), and later an organic odorant was added to the simulated sludge. Finally, bed temperature was increased to 1500°F again, and the simulated sludge composition was altered by eliminating the calcium carbonate and doubling the amount of sodium chloride used.

The pilot-plant tests indicated virtually complete organic destruction without odor problems when bed temperatures were maintained between 1300° and 1500°F. All the test data indicated that a fluid-bed incinerator could be used to destroy a biological sludge containing mixtures of inorganic salts. Both the agglomerating and nonagglomerating systems of operation seemed to be feasible. The agglomerating system would have the capability of reducing loadings to the scrubber and producing salt pellets that could be disposed of easily.

**SYSTEM DESIGN**

Figure 1 is a block diagram showing the unit operations used in preparing, incinerating, and disposing of the sludge, ash, and stack gases. The process diagram indicates that activated sludge is delivered from the main treatment facility to an aerated holding basin, which helps to maintain that sludge in an "aerobic" state. The sludge so conditioned enters a 40-ft-diameter gravity picket thickener, which should give underflow sludge concentrations of 2 percent solids. The thickener-sludge storage zone is the last surge-storage location for the sludge prior to incineration. (Surge storage of centrifuged sludge would provide an operational advantage, but it would be very difficult to recall centrifuged sludge from storage.)

Underflow sludge is passed to a battery of three solid-bowl centrifuges at controlled rates by means
of variable-speed, positive-displacement, progressive cavity pumps. The addition of flocculant aids at the centrifuge is necessary to obtain the desired recovery and maximum cake concentration. The centrifuges discharge into special open throated pumps to feed the dewatered sludge into the incinerator. The sludge is dispersed in the reactor freeboard in a conical pattern by means of a specially designed feed gun, which uses steam to assist in forming the pattern.

The reactor gases and entrained particulates leave the freeboard and pass through a cyclone separator. The fine solids from this cyclone can be discharged to a quench tank and thence transferred to a lagoon as inorganic ash, or they could be picked up by an ejector and reintroduced into the reactor on a recycle basis. The former mode of operation represents the nonagglomerative mode, in which the startup sand with subsequent makeup will always be the bed material. The recycle could be used to agglomerate the naturally fusing salts and thence form a bed of particulate salts. The stack gases leaving the cyclone pass to the high-energy wet scrubber for removal of any remaining fines. The scrubber uses recirculated water to minimize consumption and to maximize the salt concentration in the blowdown.

The scrubber water blowdown is transmitted to disposal with other inorganic wastes.

The adjustable-throat, high-energy, venturi-type scrubber is capable of high performance over the full operating range. The scrubber was guaranteed to
limit stack emissions to less than 0.1 grains of particulate matter per dry standard cubic foot adjusted to 12 percent CO₂, or 0.05 grains per cubic foot at actual stack conditions, depending on which was more stringent. Venturi-scrubber test data from the pilot tests were made available to the scrubber vendors to permit design and guarantee of the scrubber system. The pilot tests had established virtually complete destruction of organics; therefore, the scrubber manufacturer was primarily concerned with collecting solid particulates.

The fluid-bed incinerator was designed to handle 15 percent total solids and to burn 12,000 lb/day (500 lb/h) of dry solids, at a superficial velocity of 3 ft/sec. Figure 2 shows furnace capacity for feed concentrations ranging from 12 to 18 percent solids by weight and limiting superficial velocities of 2.0 and 4.0 ft/sec. Defluidization of the bed is expected to begin at about 2.0 ft/sec, and excessive loss of bed material is expected at 4.0 ft/sec; hence, the normal operating range was stipulated as approximately 2.4 to 3.6 ft/sec, to stay well within the limits set. Provision for a possible future capacity increase was built into the furnace by providing a layer of removable refractory in the fluid-bed zone. Removal of this refractory would increase the bed diameter by 1 ft and increase capacity by 36 percent.

Furnace capacity turndown is virtually infinite. The lower normal capacity (Fig. 2) is largely an economic consideration, inasmuch as it is determined by the design minimum superficial velocity necessary to provide combustion air and ensure a fluidized bed. Removal of this refractory would increase the bed diameter by 1 ft and increase capacity by 36 percent.

FIG. 3

STARTUP CONSIDERATIONS

Design and construction of the secondary treatment plant, including the aerated holding tank, thickener, and centrifuges, were proceeding while the sludge disposal problems were explored. Therefore, by the time the incinerator facility is completed, sufficient experience with centrifuge operating parameters will have been accumulated to eliminate the centrifuges as an unknown factor in startup considerations.

The fluid-bed incinerator design chosen, in addition to the mechanical features of the installation, will permit operation at the extreme turndown condition that is anticipated as being necessary to accommodate variations in sludge quantity and quality. Although the pilot tests indicated the feasibility of fluid bed incinerator destruction of the sludge, definitive operating conditions and mode of operation were not determined.

The flexibility built into the full-scale installation will permit operation with either a fully agglomerating or a nonagglomerating bed. Operational controls with either mode will permit operation at bed

![Diagram](image-url)
temperatures 100°F beyond each extreme of the pilot test range of 1300°F to 1500°F. Bed material may be removed or added at will to monitor and control bed particle-size distribution. The fluidizing velocity can be varied independently of other variables. It will be possible to observe the operating bed, and the sludge feed gun will provide control of sludge droplet size, bed penetration, and dispersion of the sludge into the freeboard and bed of the furnace. Adjustment of the feed gun affects freeboard temperature and largely determines the capture of inorganic salts in the fluid bed.

The best mode of operation and actual operating combinations will have to be determined after startup of the full-scale system.

**CONCLUSIONS**

Incineration at temperatures high enough to preclude odoriferous stack gases was selected as the most practical means of disposing of the waste activated sludge, because of cost considerations and the lack of suitable on-site and off-site facilities for other means of disposal.

Fluid-bed incineration was selected in preference to other incineration methods because of advantages with respect to equipment dependability, minimum space requirements, capital costs, sludge-handling characteristics, and the substantial heat sink effect of the fluidized bed and refractory lining.

The laboratory program indicated that the fused material would be friable rather than completely fused and hard.

Pilot scale tests indicated virtually complete organic destruction without odor problems, when bed temperatures were maintained between 1300°F and 1500°F. The tests also indicated the feasibility of operation either with a sand bed (nonagglomerating) or with a bed formed from the inorganic salts in the sludge (agglomerative).