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Abstract

The safe disposal of both high-level and low-level radioactive waste is a problem of increasing national attention. A full-scale incineration and solidification process to dispose of suspect-level and low-level beta-gamma contaminated combustible waste is being demonstrated at the Savannah River Plant (SRP) and Savannah River Laboratory (SRL). The stabilized wasteform generated by the process will meet or exceed all future anticipated requirements for improved disposal of low-level waste. The incineration process has been evaluated at SRL using nonradioactive wastes, and is presently being started up in SRP to process suspect-level radioactive wastes. A cement solidification process for incineration products is currently being evaluated by SRL, and will be included with the incineration process in SRP during the winter of 1984. The GEM

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alumnus author conducted research in a related disposal solidification program during the GEM-sponsored summer internship, and upon completion of the Masters program, received full-time responsibility for developing the incineration products solidification process.

Background

An incineration development program is in progress at the Savannah River Laboratory (SRL) in support of the waste management objectives of the Savannah River Plant (SRP) and the Department of Energy (DOE). Currently, solid waste contaminated with low levels of beta-gamma emitters is buried in shallow trenches in an onsite burial ground. This practice is consistent with current and past DOE regulations for waste disposal. However, future DOE waste management directives are anticipated to require that low-level waste be immobilized within a solidified monolithic wasteform which is buried in such a manner as to minimize groundwater and soil interaction and to greatly reduce the need for continual burial site maintenance. Incineration has been proposed as the primary method for waste volume reduction because 60 percent of the low level solid waste generated is combustible. Reducing the volume of waste material buried would greatly extend the usable life of current burial facilities. While studies have shown that the incinerator ash product is itself inert, solidification of the incinerator ash product into a monolithic wasteform will be an important step in minimizing groundwater and soil interaction, and improved burial site operation and maintenance.

In addition to solid waste, spent solvents used in the Purex process for the radiochemical separation of plutonium and uranium is stored at the SRP burial ground in underground tanks. Currently, there are 568 m^3 in storage with an annual generation rate of 7.6 m^3/year. The solvents are n-paraffin (a kerosene-like diluent), and tributylphosphate (TBP). The solvents are only slightly radioactive with the principal beta-gamma nuclides being ruthenium, cesium and strontium. The reference method for final disposal of these solvents is spray injection of a Purex solvent/lime slurry into the incinerator.

After a survey of the incineration processes being tested and demonstrated at nuclear installations in the United States and Europe, a full-scale facility based on a two-stage, controlled air incinerator was designed. The SRL demonstration facility was called the Solid/Solvent Waste Incineration Facility for Testing (SWIFT). The SWIFT facility was installed and operated at SRL for a one-year nonradioactive test program where the operating parameters of the unit were determined. Following the completion of the SRL testing phase, the unit was relocated to SRP. For the SRP phase of the program, the unit was upgraded for a two-year demonstration under actual production conditions where suspect level radioactive wastes will be incinerated.

A similar survey was conducted of waste solidification systems in place at nuclear installations and available from vendors specializing in radwaste solidification systems. A reference

process using portland cement as the solidification agent has been developed, and the design and fabrication of the automatic processing unit has been completed. The solidification unit will be tested at SRL using ash products generated by the incinerator in SRP during the startup phase, when only uncontaminated waste will be burned. Following the completion of the SRL testing phase, the solidification unit will be transferred to SRP as an addition to the incineration process.

Incinerator Operation

The incinerator is a two-stage controlled air unit manufactured by Environmental Control Products of Charlotte, North Carolina. The term "controlled air" denotes the incinerator design feature that permits control of the quantity and location of combustion air. In two-stage combustion, waste is semi-pyrolyzed in the fuel rich primary chamber. The low airflow into the chamber is introduced through several underfire air ports on the side of the hearth. Combustion airflow (100-200% excess) is supplied at the entrance to the secondary chamber in order to oxidize the partial combustion products to H_2O and CO_2. The oxygen concentration in each chamber is continuously measured with online analyzers. The facility is shown in Figures 1 and 2.

Normal operating temperatures are 800° to 900°C in the primary chamber and 1000°C in the secondary chamber. The control system maintains these temperatures by modulating two diesel fired burners and the combustion air flows. The burners are used mainly to heat the incinerator to minimum burning temperature. During waste

feeding the heat of combustion released from the burning material serves as the primary heat source. The amount of air entering the chambers is then used to control the temperatures.

Off-gases from the secondary chamber pass through a refractory lined duct before entering the spray quench. In a spray quench, the incinerator off-gases are cooled from 1000° to 180°C using two air-atomized water sprays. The gases leaving the spray quench are maintained above the dewpoint so that no secondary liquid waste stream is generated. The cooled gases are then filtered using a baghouse that contains envelope-type Normex fabric bags. The filter efficiency is rated at 98% for particles one micron in diameter.

Two sixty horsepower induced-draft blowers maintain a negative pressure in the process and exhaust the off-gases to the atmosphere through a 60-foot stack.

Solid waste is fed to the incinerator in 0.38 and 0.61 m/side boxes. These boxes are prepared before each run so that the waste compositions, packing densities, and box weights are known. The boxes are then fed to the primary chamber of the incinerator with a hydraulic feed ram. Feed rates up to 180 kg/hour are demonstrated. Tables 1 and 2 summarize the types of waste incinerated during the test campaigns.

The primary components of the solvent feed system are an agitated feed tank and two pumps. Uncontaminated Purex solvent and calcium hydroxide fixative are slurried in the feed tank, and a

centrifugal pump draws the slurry from the bottom of the tank and recirculated it back. This recirculating pump is used to suspend the solids in the slurry and to supply solvent to the inlet of the feed pump.

A piston-type metering pump is used to feed solvent to the incinerator. The solvent flowrate is varied by manually controlling the speed of the feed pump. The solvent slurry is sprayed into the primary incinerator chamber at the reference feedrate of 0.14 m^3/hour.

Incineration Results

The key process elements demonstrated during the one-year research program were:

1. The system proved flexible enough to burn a wide variety of materials with a wide range of heat release values and instantaneous air demands at the reference feedrates.
2. Process temperatures and vacuum were controlled automatically and the process operation parameters were optimized.
3. The phosphorous released by burning tributylphosphate was fixed by using calcium hydroxide as a fixative.
4. Ash was removed from the incinerator on a semicontinuous basis.
5. Volume reduction ratios were determined for both solid and solvent incineration. The volume reduction for solids was 20:1, a 95% reduction in volume; solvents were reduced by a ratio of 7:1, a 86% reduction in volume.

The system proved flexible enough to burn a wide variety of materials with a wide range of heat release values and instantaneous

air demands at the reference feedrates. Pure polyethylene was burned at 180 kg/hr to determine operating characteristics of the SWIFT under the highest anticipated heat release conditions. Red rubber (SBR) which was used to simulate latex incineration, has a high instantaneous air demand. Red rubber was burned at the reference rate of 180 kg/hr to check if the incinerator air capacity was sufficient to maintain the stack off-gas oxygen level of 5%. Other unique materials that were incinerated include polyvinyl chloride (PVC) and the degreaser 1,1,1-trichloroethane (TCE) which release hydrochloric acid, and a slurry of Purex solvent and calcium hydroxide. In all cases, the SWIFT pressure and temperature process controls functioned as designed.

The dry off-gas system eliminates secondary liquid waste streams that would require treatment. The dry off-gas system also simplifies operation. The main component of the dry off-gas system is the spray quench. The test program demonstrated that the spray quench could control the baghouse inlet temperature within design specifications. During the burning of PVC and TCE, aqueous sodium carbonate spray drying to neutralize the gaseous HCl generated by burning these materials was attempted, however this proved to be unnecessary because the ash produced during solids incineration was found to neutralize greater than 90% of the HCl released without sodium carbonate addition. The baghouse utilized pulse blowback for removing flyash from the bags. The semi-countinuous blowback was capable of maintaining the baghouse pressure drop below 500

Newtons/meter^2. In general, the material balance for ash yielded a total system DF or 1400 and a baghouse DF of 210. Particulate and gaseous (NO_x, SO_2, CO and HCl) emissions as determined by an EPA Method 5 sampling train were well below South Carolina state standards and all anticipated Federal emission regulations (Table 3). A key feature of the SWIFT design that was demonstrated is the automatic vacuum control system. This system maintains a vacuum of 249 Newton/meter^2 in the secondary incinerator chamber by means of induced draft blowers and an automatic vacuum control valve. When the incinerator is put into radioactive service during the SRP demonstration period, the unit must be maintained under vacuum at all times. One area of difficulty caused by vacuum operation was that air in-leakage adversely affected temperature control. After air in-leakage points were closed, a much higher degree of temperature control was achieved by underfire air modulation.

In the burning of TBP, phosphorous is released to form phosphoric acid. Phosphoric acid would cause long-term equipment corrosion and blinding of the baghouse filters. To minimize acid formation, calcium hydroxide was slurried with the TBP/n-paraffin solvent prior to spray injection of solvent into the incinerator. During incineration the phosphorous reacts with calcium and oxygen to form various calcium-phosphorous oxides. All of these products are refractory solids that de-entrain in the incinerator primary chamber or are filtered from the off-gases by the baghouse.

Initial tests proved that the original ash pusher ram was inadequate for removing ash from the ash drop. The original ash pusher was a short ram of hollow metal construction. The concept of this design was to displace cooled ash from the cooling duct and into a drum by pushing newly formed ash behind it. This method of ash displacement was not successful because ash compacted and plugged in the ceramic-lined cooling duct. A new ash pusher ram was designed and installed. This ram was designed to stroke all but the last 0.8 meters of the removal duct and provide positive displacement for the ash. The ram was also ceramic-filled for improved dimensional stability. The new ash pusher successfully removed ash on a semi-continuous basis during operation.

Volume reduction ratios were determined for both solid and solvent incineration. In general, the volume reduction for solids was 20:1, and the ratio for solvents was 7:1. Volume reduction for solvent was less than for solids due to calcium hydroxide addition. It should be noted that the primary objective of solvent incineration is to provide a means for permanent disposal and the elimination of underground tank storage. Table 4 summarizes the volume reduction factors found for different test runs.

Solidification Process

The primary objective of the ash solidification (Ashcrete) process is to encapsulate the incinerator ash product into a solid, free standing monolith. This concept will meet anticipated DOE requirements for the disposal of low-level radioactive waste. After

a detailed survey of the literature and radwaste vendor systems, Stock Equipment Co. was identified as the primary vendor for the Ashcrete process equipment. The basic Stock system provides a proven, off-the-shelf process technology that was easily adapted to ash solidification. The Ashcrete process equipment is a modified version of the basic Stock tumbler unit used at commercial power reactor sites. The process unit is contained in a stainless steel enclosure and has a number of automatic handling features to minimize operator interaction and exposure.

Formulation

The formula used for solidification depends on the type of ash to be solidified: solid waste ash, Purex solvent ash, or baghouse filter flyash. The formulas for solid waste ash and Purex solvent ash have been determined by initial work at SRL, and additional studies conducted by Stock Equipment Co. The solidification formulas for solid waste ash and Purex solvent ash are detailed in Table 5. The formula to solidify baghouse flyash is still under study.

Processing Steps

Ash is removed from the incinerator by means of two internal rams. Solid waste ashes are displaced onto the incinerator hearth area by freshly fed waste boxes. Ash is removed from the hearth area on a timed cycle by a hyduralic ram, which displaces the ash into a cooling duct. Another ram within the cooling duct (the ash pusher) pushes ash from the cooling duct into a 0.2 m^3 (55 gallon)

drum. This ash drum is then removed from the incinerator ashout port, and placed within the solidification process unit.

The process unit is a self-contained enclosure which contains a number of special handling features. The unit has a water addition nozzle, dry sand and cement addition nozzle, hoppers, and screw conveyors, drum uncapper and recapper, and drum tumbler. Ash solidification is achieved by tumble mixing within the drum ash, water, cement, and sand. A mixing bar is added to the drum at the incinerator ashout to aid the efficiency of tumble mixing. At the process unit the drum is loaded onto a transfer car which transports the drum between steps within the enclosure. The 4-inch cap in the center of the drum lid is removed by the automatic uncapper/recapper, and the drum is placed under the water nozzle to add the required amount of water. The drum is then recapped and end-over-end tumbled for 15 minutes. Dry cement is then added to the drum, and the drum is tumbled again for 10 minutes. Then dry sand is added to the drum, and the drum is tumbled again for 5 minutes. The drum is then removed from the process unit and placed in storage until burial in about 4 days. Figures 3 and 4 illustrate the solidification process steps and equipment.

The feasibility of using this process to solidify ash has been demonstrated in small, intermediate, and full-scale tests using 1200 pounds of actual ash obtained during cold tests. Analysis of the full-scale test drums showed that the final product was a solid, well-mixed, rock-like material of good structural integrity.

Figure 5 is an open cross-section of a drum of Purex ash which was solidified by the above process.

Future Studies

The solidification process unit will be tested at the semi-works area of SRL. This test period will be from October 1983 to April 1984. Incinerator ash products obtained from nonradioactive waste burning will be used initially. All of the automatic handling and control features of the unit will be tested, along with additional formulation, mixing, and concrete product curing tests. Following the SRL testing period, the process unit will be relocated to SRP as an addition to the incineration process.

Conclusions

An incineration and ashproduct solidification system have been developed at the Savannah River Laboratory (SRL) to meet the anticipated future requirements for burial of low-level radioactive waste of the Savannah River Plant (SRP), and the Department of Energy (DOE). The incinerator has been tested in a one-year program at SRL where 15,700 kg of simulated waste was burned. Also burned was 5.7 m^3 of Purex solvent. These test runs demonstrated that the incinerator process controls, vacuum system, dry off-gas system, and semicontinuous ash removal systems will perform as designed. A volume reduction of 20:1 was obtained for solid waste incineration, and a volume reduction of 7:1 was obtained for Purex solvent burning. The ash solidification system was shown to yield a final monolithic wasteform of good structural integrity with no free standing liquids or solids which meets anticipated future burial requirements.

TABLE 1

Summary of Solid/Solvent Waste Burning Campaigns

Run Number	Duration of Incineration(hrs)	Amount of Waste Burned Weight(kg)	Volume(m^3)	Type of Waste Burned
Solid 1	4	972	10	Computer paper
Solid 2	20	8028	28	Computer paper/cotton
Solid 3	38	4776	43	Waste mix w/o PVC
Solid 4	21	2724	30	Red rubber/waste mix/PE
Solvent 1	7	--	0.76	n-Paraffin
Solvent 2	6	--	1.0	n-Paraffin
Solvent 3	8	--	1.1	Purex slurry
Solid 5	82	4169	41	Waste mix w/PVC
Solvent 4	19	--	2.8	Purex slurry w/TCE
Totals	155	15,668	152 solid 5.7 solvent	

TABLE 2

Solid/Solvent Waste Compositions

Component	Solid Waste mix w/o PVC (wt %)	Solid Waste Mix w/PVC (wt %)
Polyethylene (PE)	23	23
Red rubber (SBR)	19	19
Cotton fiber	29	25
Computer paper	29	--
Polyvinyl chloride (PVC)	--	8
Brown reinforced paper	--	25

Component	Purex Slurry (%)	Purex Slurry w/TCE (%)
n-Paraffin ($C_{12}H_{26}$)	75 volume	72.2 volume
Tributylphosphate (TBP)	25 volume	25 volume
Calcium Hydroxide [$Ca(OH)_2$]	18 weight	36 weight
1,1,1-Trichloroethane (TCE)	--	2.8 volume

TABLE 3

Typical Off-Gas Analysis

Component	Solid Waste Burning* Air Quality (g/m^3)	Solvent Waste Burning Air Quality (g/m^3)	South Carolina State Air Quality Standard (g/m^3)
NO_x	0.4	1.1	100
SO_2	4.4	2.5	1300
HCl	2.4	2.9	not specified
CO	<160	<160	40000
Particulates	0.02	0.04	60

* Values were calculated for a point one kilometer from a ten meter stack using a dilution factor of $1 \times 10^{-4} s/m^3$

TABLE 4

Summary of Ash Collected From Incinerator Runs

Run Number	Ash Fraction Reaching Baghouse	Reduction Ratio Weight	Reduction Ratio Volume
Solid 1	--	22	45
Solid 2	0.07	12	22
Solid 3	0.11	9	17
Solid 4	0.10	3	15
Solid 5	0.21	8	22
Solvent 3	0.17	8	7
Solvent 4	0.17	5	8

TABLE 5

Solidification Formulas For Solid Waste Ash and Purex Ash

Component	Solid Waste Ash (weight percent)	Purex Ash (weight percent)
Ash	33.1	27.9
Water	19.7	27.8
Cement	33.1	19.9
Sand	14.1	22.4

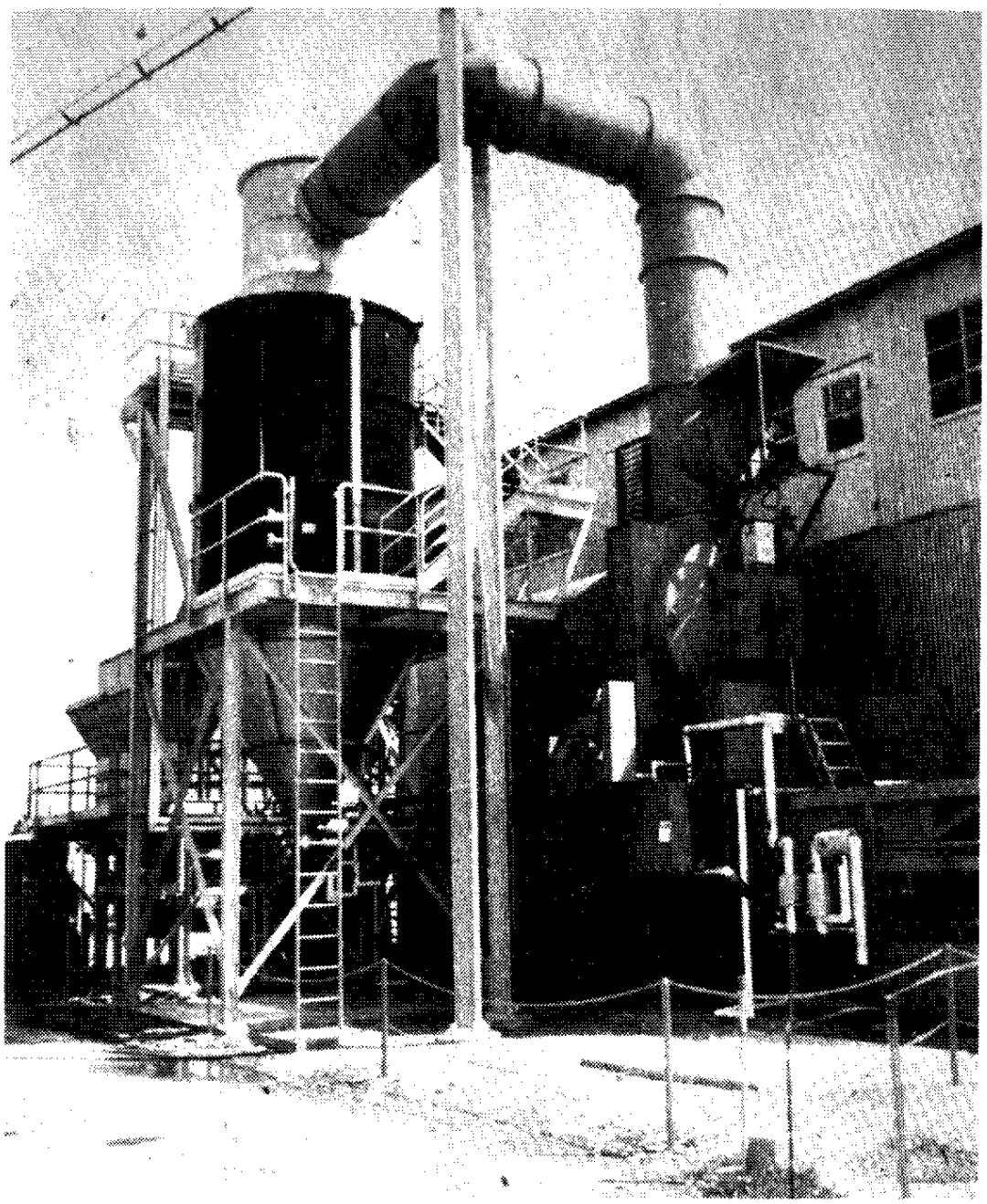

FIGURE 1. SRL Incinerator

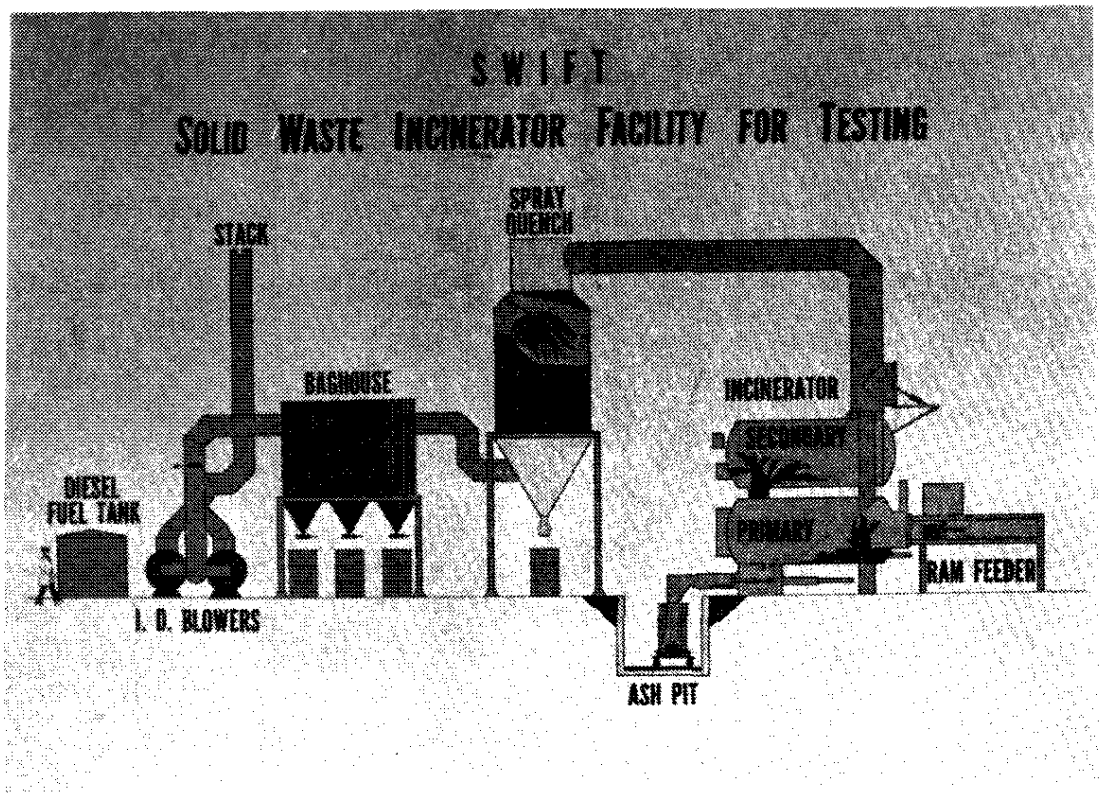

FIGURE 2. Schematic of SRL Incinerator Process

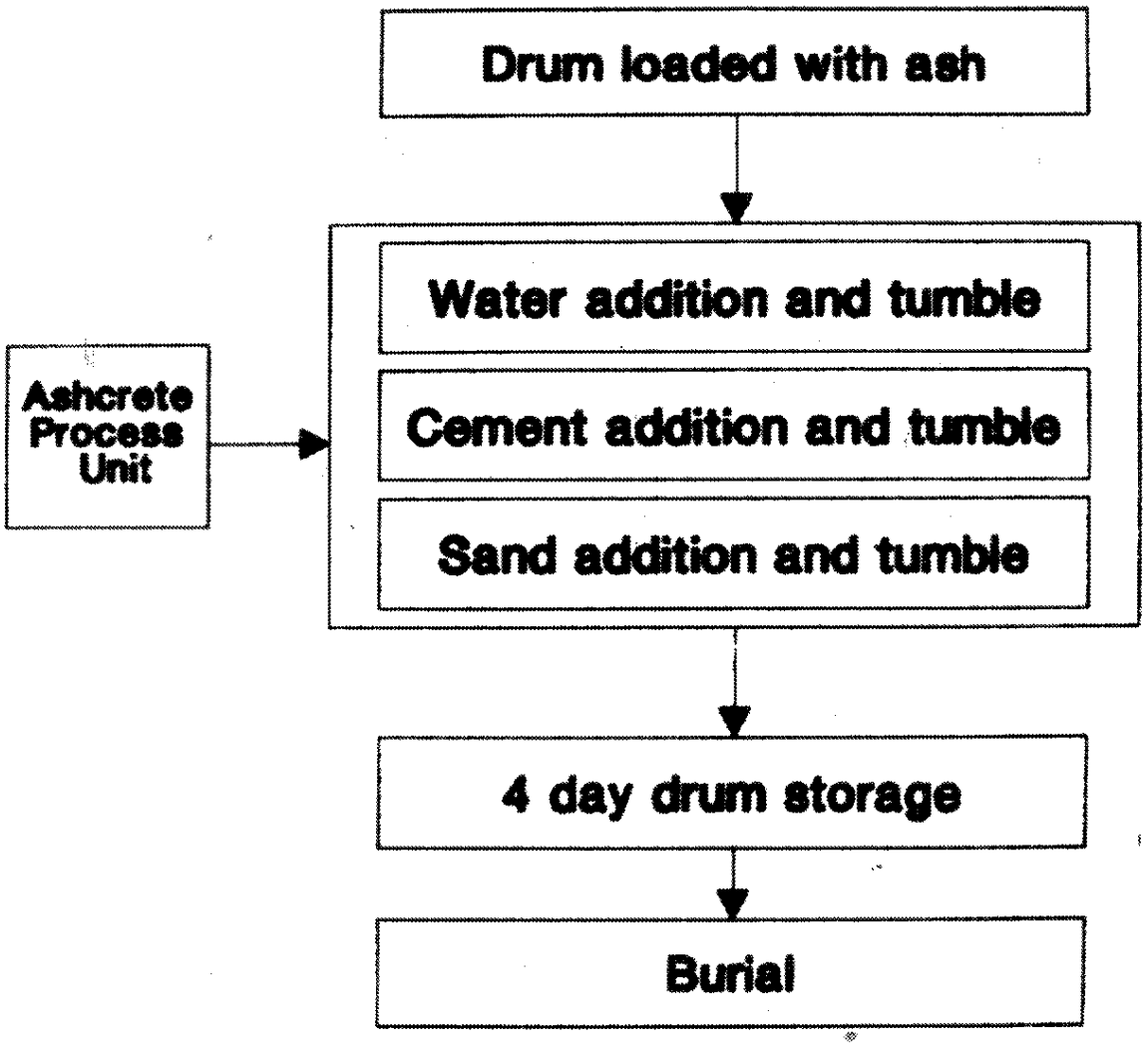

FIGURE 3. Ashcrete Process Flowsheet

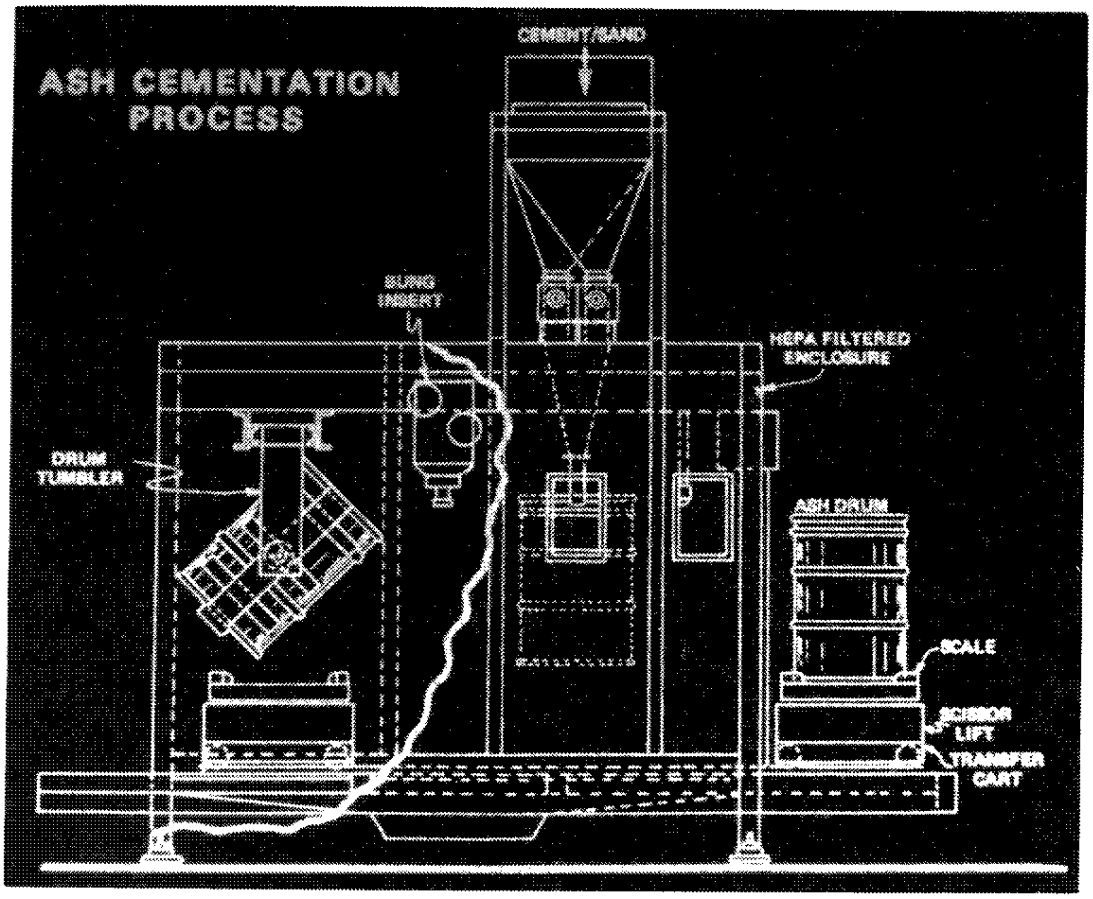

FIGURE 4. Schematic of Ashcrete Process Unit

FIGURE 5. Sectioned Drum of Purex Ashcrete