

Coolside Waste Management Studies— Final Report

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**COOLSIDE WASTE
MANAGEMENT STUDIES—
FINAL REPORT**

By

**M. M. Wu
R. A. Winschel**

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EXECUTIVE SUMMARY

The Coolside process is a developing technology for the desulfurization of flue gases from coal-fired electric utilities. Its technical feasibility has been demonstrated at the 1 MW scale. A demonstration of the process at the 100 MW scale is planned at Ohio Edison's Edgewater Station, beginning in early 1989. The purpose of the work reported here was to determine the properties of the Coolside solid waste in order to support plans to dispose of the waste produced during the demonstration test by landfilling. The solid-waste samples used here were originally produced in Consol's pilot unit.

The test program consisted of seven elements. The first six were laboratory tests and the seventh was a small-scale field test in which the waste was exposed to the weather for about six months. Because of the different natures and completion dates of the laboratory and field tests, this report is divided into two parts. Part 1 provides the results of the laboratory tests. Part 2 provides the results of the small-scale field tests. Both Part 1 and Part 2 include independent Introduction, Summary, Experimental, Results and Discussion and Reference sections. Tables and Figures are also numbered separately in the two parts. The major findings of the laboratory tests are summarized below.

- The optimum moisture content (ASTM D-698) of Coolside waste is about 30 wt % (dry basis). At this moisture content, the material has the appearance of moist sand and its dry bulk density (ASTM D-698) is 66.8 lb/ft³.
- The unconfined compressive strength (ASTM D-1633) of Coolside waste is as high as 251 psi depending on moisture content and curing time.

- Leachate toxicity was measured by the EP procedure and by the same procedure except using only deionized water. The leachates are within RCRA limits and the concentrations of trace elements, sulfate and TDS are less than 30 times the EPA primary and secondary drinking water standards.
- Permeability coefficients (EM-1110-02-1906) ranging from 10^{-5} to 10^{-6} cm/sec were obtained on Coolside waste which was prepared according to ASTM D-698 and which contained the optimum moisture content.
- The wetting of Coolside waste results in only a minor ($\leq 10^{\circ}\text{F}$) increase in temperature.

The waste piles which were used in the field tests were compacted only mildly. Because of the mild compaction, the waste piles remained soft, loose and permeable for the duration of the test. As a result, the field tests were not good simulations of commercially landfilled Coolside waste. Nevertheless, several important observations were made.

The experimental design was such that the drainage water quality results obtained in this study are probably worst case values. In all cases, the concentrations of the trace elements in the drainage water were less than 30 times the EPA primary and secondary drinking water standards. Though several of the early drainage samples had high TDS and sulfate concentrations, all later drainage samples had acceptable levels. The pH of the drainage water varied widely (7.4 to 12.4) depending on the relative amount of percolation and run-off and on atmospheric CO_2 absorption. Sodium concentrations in the bulk waste piles were reduced by about 90% confirming that much of the precipitation percolated through the unconsolidated waste piles.

These results suggest that Coolside waste should be suitable for landfill disposal. However, the final decision on this matter needs to be made

by the appropriate landfill operator with consideration of the data reported herein.

PART 1

COOLSIDE WASTE MANAGEMENT STUDIES-
FINAL REPORT ON LABORATORY TESTS

INTRODUCTION AND OBJECTIVES

Coolside desulfurization is a dry sorbent injection technology for SO₂ removal from the flue gas in the duct work and particulate collection system (baghouse or electrostatic precipitator (ESP)) downstream of the air preheater in a coal-fired power generation unit. The technology can provide attractive retrofit control options because of its low capital and overall SO₂ removal costs. The key elements of the Coolside process are injection of a dry sorbent, such as hydrated lime, and spraying of atomized water for flue gas humidification (Figure 1). Water soluble additives, such as NaOH or Na₂CO₃, can be injected into the flue gas in solution with the humidification water to enhance SO₂ capture and sorbent efficiency. The feasibility of this Coolside concept was first determined by Consolidation Coal Co. in 1983 through a literature survey and a theoretical analysis of the relevant kinetics and transport phenomena. The process concept was first developed by Consol through laboratory tests. Its technical feasibility was demonstrated in 1 MW field tests made in 1984 using a slipstream unit installed on an industrial boiler. The unit was installed with a pilot humidifier (with approximately 2 sec. gas residence time) and ESP. The pilot ESP was tested since most utility stations burning high sulfur eastern coals use ESPs. The key results of the tests, using hydrated lime and NaOH as the sorbent and additive, respectively, were up to 80% SO₂ removal with up to 40% sorbent utilization, acceptable ESP and humidifier operation, and excellent ESP particulate removal efficiency. The high sorbent utilizations were observed at 20-25°F approach to adiabatic saturation and 0.1 NaOH/Ca(OH)₂ wt ratio. The excellent ESP efficiency, which approached the theoretical maximum efficiency of the pilot system, was an important result for the process, implying that an existing ESP in a utility station may not need to be upgraded to handle the increased solids loading resulting from sorbent injection. Humidification by water spraying is highly effective for conditioning the flue gas to enhance ESP performance.

The objective of this study is to obtain the technical information required to support disposal of Coolside waste by landfilling during the Coolside process demonstration at the Edgewater station (scheduled to begin in early 1989). The disposal of Coolside waste is an important element of the Coolside process demonstration. Coolside waste differs from bituminous coal fly ash in that it has a high calcium content (25 to 40 wt % determined as CaO) and may have an elevated sodium content (2 to 4 wt % determined as Na₂O). As shown by the Consol Martinsville field tests, the major components of Coolside waste, excluding fly ash, are Ca(OH)₂, CaSO₃ and CaSO₄. Minor components include Na₂SO₃, Na₂SO₄ and CaCO₃. The presence of these components could make the physical and chemical properties of Coolside waste different from the wastes generated from other dry flue gas desulfurization (FGD) processes such as the Limestone Injection Multistage Burner (LIMB), lime spray dryer (LSD) and fluidized bed combustion (FBC) processes. Physical and chemical properties of wastes from these emerging dry FGD processes have been studied and reported elsewhere (1,2,3). Some waste properties (density, compressive strength, leachate compositions, permeability, and reactivity upon wetting) have direct effects on handling, transportation and disposal of the waste.

In order to address these concerns, a test plan was formulated by Consol and approved by Babcock and Wilcox (B&W). The final "Test Program for Coolside Waste Management" was issued to Babcock and Wilcox on June 2, 1987 (4).

The characteristics of the Coolside waste to be determined by this test program include:

- Task 1 - Moisture-density relationship
- Task 2 - Compressive strength
- Task 3 - Leachate toxicity
- Task 4 - Permeability
- Task 5 - Reactivity
- Task 6 - Chemical composition
- Task 7 - Run-off simulation

Properties such as the moisture-density relationship, compressive strength and permeability are important in forecasting the structural integrity and behavior of the Coolside waste during landfill disposal. Both state and local environmental regulations often require leachate toxicity testing. Reactivity upon wetting is relevant for handling and transportation of the Coolside waste. Chemical component characterization can provide a better understanding of property changes related to waste disposal. The run-off simulation test addresses the effects of weathering (the natural exposure to the atmosphere, rain and wind) on disposed waste. The Coolside waste samples used in this study were obtained from Consol Coolside pilot plant tests made under simulated Edgewater process demonstration conditions. All seven tasks were performed with waste produced with the sodium hydroxide additive. Several of the tasks were also performed with waste produced without the sodium hydroxide additive.

Test results and conclusions of Tasks 1 through 6 are included in Part 1 of this report. Results of Task 7, the run-off simulation test, appear in Part 2 of this report.

CONCLUSIONS

Coolside waste appears to be suitable for landfill disposal based on this study. Major conclusions from each task are summarized below.

- The optimum moisture content to achieve the maximum dry bulk density of the Coolside waste (produced with the sodium hydroxide additive) is about 30 wt % dry basis, i.e., 30 lbs water to 100 lbs dry solids. At this moisture content, the waste has the appearance of moist sand. At the optimum moisture content, the dry bulk density is 66.8 lb/ft³, and the loose and tapped bulk densities are 30.5 lbs/ft³ and 39.4 lbs/ft³, respectively.
- Unconfined compressive strengths were measured on Coolside wastes produced both with and without the sodium hydroxide

additive. Compressive strengths increase with increasing moisture content (over the range 20 to 32 wt %, dry basis) and curing time (up to 28 days). After 28 days curing at the optimum moisture content, measurements indicated that the compressive strength (251 psi) of the wetted waste is adequate to permit landfill disposal. In the absence of the sodium hydroxide additive, the compressive strength at the same conditions was 200 psi.

- Leachate toxicity was measured using the EP procedure and by the same procedure using only deionized water instead of aqueous acetic acid. Wastes produced both with and without the sodium hydroxide additive were tested. The leachates are within RCRA limits and the concentrations of trace elements, sulfate and total dissolved solids (TDS) in the leachates are less than thirty times the EPA primary and secondary drinking water standards (Ohio EPA requirements) using both leaching methods on Coolside wastes produced both with and without the sodium hydroxide additive. Good material balances (based on measured and calculated TDS) and charge balances (based on concentrations of anions and cations) were obtained in these leachate composition measurements. Nitrate, fluoride and chloride could not be determined on the standard EP leachates because of interferences from the acetate ion. However, their concentrations were well below Ohio standards when using the deionized water leaching method. The leachates from the waste produced without the sodium hydroxide additive have reduced sodium, sulfate and total dissolved solids concentrations, but are otherwise similar to those from the samples produced with the additive. One test using a sample that was first cured for 28 days then ground and leached showed that curing did not significantly affect leachability.
- Permeability coefficients ranging from 10^{-5} to 10^{-6} cm/sec were obtained using ASTM D-698 to prepare Coolside waste (produced with the sodium hydroxide additive) containing the optimum

moisture. Materials with permeability coefficients in this range are generally considered to be suitable for landfill disposal. Curing time appears to reduce permeability slightly.

- Only a slight temperature increase ($\leq 10^{\circ}\text{F}$) was observed in Coolside waste after mixing with 10 to 30 wt % added water. Thus, wetting Coolside waste is not expected to result in handling problems caused by a temperature rise as can occur with LIMB waste.
- Three techniques (thermogravimetric analysis, Fourier-transform infrared spectroscopy, and lime index measurement) were used to characterize changes in the chemical component composition of the waste before and after curing. The concentration of $\text{Ca}(\text{OH})_2$ was observed to decrease with increasing curing time (and thus with increasing compressive strength), indicating that pozzolanic reactions proceeded during curing. One cured sample was analyzed by X-ray diffraction (XRD) and found to contain ettringite. Though the only sample analyzed by XRD was not produced at simulated Edgewater conditions, the presence of ettringite indicates that pozzolanic reactions do indeed occur as Coolside waste cures.

RESULTS AND DISCUSSION

Moisture-Density Relationship

During the process demonstration at the Edgewater station, Coolside waste will be transported from the plant to the landfill disposal site by truck. If it is desired to dispose of the waste in a moist condition, sufficient amounts of water may be added and the waste/water mixture may be processed by a pug mill at the plant to improve handling and to reduce fugitive dust emissions during transportation. Since water may not be available at the landfill site, enough water may have to be added

at the plant to achieve the optimum physical stability of the waste at the disposal site. The total amount of water required to produce the maximum dry density (i.e., the optimum moisture) of the Coolside waste can be estimated using ASTM method D-698. This method determines the moisture-density relationship and has commonly been used for wastes of other flue gas desulfurization processes (1,5,6). In this study, the optimum moisture was estimated by adding water in increasing amounts from 20 to 32 w/w % to a series of five specimens, compacting the waste/water mixtures in a 4-inch mold using a 5.5 lb rammer with a 12-inch drop, then determining the dry densities of the molded specimens. The waste used in this study was produced while using the sodium hydroxide additive in the pilot plant.

The molded waste showed no cohesion when the added water was below 20 w/w %. Surface moisture was visible after compaction when the added water was above 32 w/w %. Therefore, these added-moisture values were used as the lower and upper limits for this test. At the highest moisture content studied here (32 wt % added), the Coolside waste had the appearance of moist sand, i.e., it in no way resembled a slurry.

In ASTM D-698, moisture contents are typically expressed on a dry basis. An illustration follows that demonstrates how to convert added water content to moisture content on a dry basis. In the illustration, 32 lbs of water are added to 100 lbs of Coolside waste (produced with the NaOH additive). The 100 lbs of this particular sample of waste includes 1.7 lbs of water and 98.3 lbs of dry solids (see Table 7). Therefore, the total moisture content of the mixture is 32 lbs plus 1.7 lbs (33.7 lbs) and the dry solids content is 98.3 lbs. The moisture content expressed on a dry basis is $33.7/98.3$ which is 34.3 wt %. Similarly, it can be calculated that when 28.27 lbs of water are added to 100 lbs of this Coolside waste, the total moisture content is 30 wt % (dry basis).

Figure 2 presents the moisture-density relationship of Coolside waste and shows that the optimum moisture content is 30 wt % (based on dry solids). At 30 wt % moisture (dry basis), the dry bulk density of the waste is 66.8 lb/ft³.

In addition to using ASTM D-698 (dry bulk density), other bulk density data were obtained using the Coolside waste (produced with the sodium hydroxide additive) containing the optimum moisture. These data may be useful in waste transportation. Loose bulk density was obtained by weighing 500 mL of the waste in a graduated cylinder. Tapped bulk density was obtained similarly except that the graduated cylinder was tapped 250 times. Tapped bulk density was calculated based on the measured weight and volume after tapping. Loose and tapped bulk densities of the waste containing the optimum moisture were 30.5 lb/ft³ and 39.4 lb/ft³, respectively.

Compressive Strength

Waste disposed at a landfill site may be subject to numerous passes of earth-moving equipment and trucks. Because of this, the structural integrity of the waste is very important for landfill disposal. Measurements of unconfined compressive strength (ASTM Method D-1633) were used to predict the structural integrity in the Coolside waste. This method has been commonly employed for wastes of other dry flue gas desulfurization processes (2,5). The waste samples were cured in a humidity chamber by ASTM method D-559. Table 1 lists the compressive strengths of Coolside wastes containing the optimum moisture at various curing times (0, 7, 14 and 28 days). The samples tested included Coolside wastes generated from pilot plant runs both with and without the sodium hydroxide additive. The compressive strength of Coolside waste generated with the sodium hydroxide additive increased with curing time from 32 psi (uncured) to 251 psi at 28 days. The compressive strength of the Coolside waste generated without the sodium hydroxide additive increased with curing time from 51 psi

(uncured) to 200 psi at 28 days. These strengths appear adequate to permit landfill disposal (2,5,7). For example, the compressive strength of clay is about 20 psi. The fact that compressive strength increased with curing time indicates that pozzolanic reactions had taken place during curing (1,2,7).

In addition to curing time, moisture content can affect the compressive strength of the waste. The effects of moisture content on compressive strength of the waste generated with the sodium hydroxide additive were examined using waste samples cured for 7 and 28 days. Results are listed in Table 2. These data show that the compressive strength of Coolside waste increases with increasing moisture content over the range of 21 to 30 wt % (dry basis). The increase in compressive strength with time observed in Table 2 is consistent with the data in Table 1. As points of reference for compressive strength values, the following data are useful. A person walking exerts pressure of about 5 psi (2). Bulldozers typically exert pressures ranging from about 11.6 psi to about 19.0 psi.

Leachate Toxicity

The Resource Conservation and Recovery Act (RCRA) and the State of Ohio may require the leachate toxicities of Coolside wastes to be determined. RCRA requires that eight trace elements (As, Ba, Cd, Cr, Pb, Hg, Se and Ag) in the waste leachate be less than one hundred times the corresponding EPA primary drinking water standards in order for the waste to be classified as non-hazardous (unless the waste is already classified non-hazardous by definition). The State of Ohio requires that the concentrations of the above trace elements and other trace and major elements (F, Cl, Fe, N, sulfate, Zn, Mn, Cu) and total dissolved solids (TDS) be less than thirty times the corresponding EPA primary and secondary drinking water standards for the Coolside waste to be classified as non-toxic (8). The allowable limits according to RCRA and the State of Ohio are listed in Table 3.

According to a policy issued by Ohio EPA in 1983 (8), the leachate in the toxicity test may be prepared by either of two procedures: 1) the EP toxicity test procedure as defined in RCRA (9), which uses acetic acid as the extraction medium, and 2) the EP procedure except that deionized water is used in place of the acetic acid solution. The second option is acceptable if waste is not disposed in a sanitary landfill. The first procedure is the EPA accepted method for the determination of toxic metals in the leachates of solid wastes (9). The second procedure has been used to examine leachate toxicities of other lime-enriched wastes such as lime spray dryer (2) and LIMB (10) wastes. In this study, the effects of the sodium additive and curing on leachate toxicities of Coolside wastes were examined with both procedures. In this report, the term "EP leachate" is used to represent the leachate from the EP test and the term "aqueous leachate" is used to represent the leachate from the same test except with only deionized water extraction.

The effect of sodium additive was studied by comparing leachate compositions of Coolside wastes generated from Consol pilot plant tests with and without the sodium hydroxide additive. The effect of the sodium hydroxide additive on leachate properties may be a major concern for Coolside waste disposal. The effect of curing was studied by comparing the leachate compositions of Coolside waste (produced with the NaOH additive) as collected and after curing for 28 days. The cured waste (containing the optimum moisture) was prepared according to ASTM method D-698 and cured in the humidity chamber as in the compressive strength tests discussed previously.

Table 3 lists leachate compositions of Coolside wastes generated with and without the sodium hydroxide additive. In all waste leachates, the trace element concentrations measured are below the allowable limits by RCRA and the concentrations of trace elements and sulfate, and of total dissolved solids (TDS) are below the allowable limits of the State of Ohio. Concentrations of nitrate, fluoride and chloride were determined

in the aqueous leachates but were not determined in the EP leachates due to interference of acetate ion in the analytical procedure which uses ion chromatography. Since concentrations of these trace elements in the aqueous leachates were well below the allowable limits, it appears highly unlikely that these concentrations would exceed the allowable limits in the EP leachates. Also, both procedures are acceptable by Ohio EPA. These results show that Coolside waste can be classified as non-hazardous by RCRA. In addition, all leachate parameters are within the Ohio EPA guidelines known by the authors.

Comparing the leachate compositions obtained with the two procedures for either waste sample (Table 3), TDS and calcium concentrations were higher in the EP leachate than in the aqueous leachate. The difference is undoubtedly caused by the reaction of $\text{Ca}(\text{OH})_2$ in the waste with the acetic acid used in the EP test to form soluble calcium acetate. Both TDS and calcium concentrations increased due to dissolved calcium acetate.

As expected, low sodium concentrations were observed in the leachates using the waste generated without the sodium hydroxide additive (Table 3). The leachate of this waste also contained higher calcium and lower sulfate concentrations than the leachate of the waste generated with the sodium hydroxide additive.

As shown in Table 4, good material balances (based on measured and calculated TDS) and charge balances (based on concentrations of anions and cations) were obtained in both the EP and aqueous leachates, when the dissolved calcium acetate concentrations in the EP leachates were taken into consideration. This confirms the influence of added acetic acid on leachability in the EP test.

Table 5 lists leachate compositions of Coolside wastes (produced with the sodium hydroxide additive) as collected and after 28 days curing using both procedures. Since the cured waste is a solid mass, the

cured sample was ground to -200 mesh (-75 μm) to permit the leaching medium to access the material. As with the leachates of the as collected waste, the concentrations of measured trace elements and sulfate, and TDS in the leachates of cured waste samples were below the RCRA and Ohio limits shown. As before, nitrate, fluoride and chloride were not determined in the EP leachates. As shown in Table 5, TDS, calcium, sodium and sulfate concentrations in the leachates decreased, though only slightly, after curing. This indicates that curing did not reduce the leachability significantly. However, it should be recognized that the cured sample used in this comparison was finely ground before leaching. Curing may reduce the leachability if a coarser particle size were used for comparison as demonstrated for spray dryer FGD wastes (2). Good material balances (based on measured and calculated TDS) and charge balances (based on concentrations of anions and cations) were also obtained in these leachates (Table 4). Since curing had only minor effects on leachate compositions for the waste produced with the NaOH additive, no cured sample produced without the additive was tested.

In the EP test for solids, the material is slurried with water and the pH is measured. If the pH is above 5.0, 0.5N acetic acid is added until the pH decreases to 5.0 or until 400 mL of acid are added. The mixture is allowed to stir for 24 hours before final analysis. Though not required by the EP test, we also measured the pH after the 24-hour period. These values are shown below.

<u>Standard EP Test</u>	<u>pH</u>	
	<u>Initial*</u>	<u>After 24 Hours</u>
Waste with the NaOH additive	12.6	12.3
Waste without the NaOH additive	12.6	12.3
Cured Waste	12.5	12.2
*Before acetic acid addition		
<u>Water-Only Test</u>	<u>Initial</u>	<u>After 24 Hours</u>
Waste with the NaOH additive	12.6	12.5
Waste without the NaOH additive	12.6	12.4
Cured Waste	12.5	12.4

For comparison, in standard EP tests with LIMB waste (1), the initial pH was reported to be 12.4 and the pH immediately after acetic acid addition was reported to be 12.2. If the run-off water from landfilled Coolside or LIMB waste has a pH value in this range, and if it is required to meet the Ohio discharge water standard of $9.0 \geq \text{pH} \geq 6.5$ (11), it is possible that it will need to be partially neutralized before discharge. However, dilution effects or partial neutralization from other materials in the landfill may make this unnecessary. Task 7, which is reported in Part 2 of this report, addresses run-off water quality.

Permeability

Leachate quantity is a major concern in landfill disposal. The amount of rainwater that percolates through landfilled waste significantly affects the quantity of leachate. The percolation rate can be estimated using laboratory permeability measurements (12). Permeability coefficients ranging from 10^{-4} to 10^{-7} cm/sec have been reported using lime-enriched wastes from other dry FGD processes (1,2,5,7). Materials with permeability coefficients in this range and lower are considered to have poor drainage characteristics (2). In this study, Coolside waste samples (produced using the sodium hydroxide additive) were prepared using ASTM method D-698 (standard Proctor method) as commonly used for lime spray dryer (5) and limestone FGD wastes (6,13). Permeability coefficients were measured using Earth Method 1110-02-1906 as commonly used for other FGD waste landfill disposal studies (1,2,5).

As shown in Table 6, the permeability coefficient of Coolside waste containing the optimum moisture decreased from 1.2×10^{-5} cm/sec (uncured) to 1.4×10^{-6} cm/sec after 7 days curing. The samples cured for 28 and 32 days had permeability coefficients of 2.2×10^{-6} cm/sec and 1.8×10^{-6} cm/sec, respectively, which are about the same as that of the sample cured for 7 days.

These coefficients are similar to those reported for wastes prepared according to ASTM D-698 from the spray dryer FGD process (2,5) and the Joy/Niro SO₂/NO_x process (14). Spray dryer FGD, which involves the injection of hydrated lime to remove SO₂ from flue gas, has been commercialized since early 1980. The wastes are disposed in landfill sites routinely (5). The major components of the spent sorbent from the spray dryer process are Ca(OH)₂, CaSO₃ and CaSO₄. The Joy/Niro SO₂/NO_x process, like the Coolside process, involves the injection of a sodium hydroxide additive in conjunction with hydrated lime. As in Coolside waste, the major components of the spent sorbent in the waste of the Joy/Niro SO₂/NO_x process are Ca(OH)₂, CaSO₃ and CaSO₄. The Joy/Niro SO₂/NO_x process has been demonstrated in pilot and full scale tests (14). Since spray dryer wastes, which have similar permeability coefficients to Coolside waste, are commercially landfilled, the permeability coefficient of Coolside waste appears to be suitable for landfill disposal.

In addition to ASTM method D-698, Coolside waste was also prepared using ASTM method C-192 which has been used for permeability measurements of LIMB waste (1). The major difference of these two methods is the compaction procedure. With ASTM method D-698, the waste (after mixing with water) was compacted in a 4-inch ID cylinder mold using a 5.5 lb rammer (2-inch ID) with 12-inch drop. With ASTM C-192, the waste (after mixing with water) was compacted in a 2 1/2-inch ID cylinder using a steel rod (3/8 x 12-inch length) for mild compaction. In both methods, three layers of waste sample were used. Each layer was struck uniformly twenty-five times by the rammer (ASTM method D-198) or the rod (ASTM method C-192). Waste samples prepared with ASTM method D-698 were more compact and dense than those prepared with ASTM method C-192. Since waste disposed at a landfill site is subject to earth moving equipment and trucks, samples prepared with ASTM method D-698 appear to be more realistic than those prepared with ASTM method C-192. For example, the permeability coefficient (2.6×10^{-6} cm/sec) of a sprayer dryer FGD waste

prepared in the laboratory using ASTM method D-698 was reported to be similar to that (3.9×10^{-6} cm/sec) obtained in a landfill core sample (5). Table 6 includes permeability coefficients of Coolside wastes using ASTM method C-192 determined by Consol R&D and by Southern Research Institute (15). These values are lower than those reported by Southern Research Institute (1) for LIMB waste (5.8×10^{-6} cm/sec for a 28-day cured sample). This may indicate that the Coolside waste has less pozzolanic activity than the LIMB waste. However, both wastes appear to have permeabilities suitable for landfill disposal when compared with spray dryer wastes.

Reactivity

During the Coolside and LIMB process demonstration at the Edgewater station, waste wetting is required to minimize fugitive dust emissions during transportation. Additional water may also be added to assist landfilling. It is known that LIMB waste reacts exothermally with water to produce a substantial temperature rise (1,16). This temperature rise may cause minor problems in transporting LIMB waste by truck from the plant to the landfill site (16). The reactivity of Coolside waste was tested to determine if it also will increase in temperature upon wetting. The reactivities of Coolside and LIMB wastes were compared by adding water to three pounds of each waste to formulate mixtures containing 10, 20 and 30 w/w % added water. The LIMB waste, which contains about 30 wt % lime (CaO), was from the Consol Martinsville LIMB field trial. The Coolside waste used was produced with the sodium hydroxide additive.

At all three moisture levels, the temperature of the Coolside waste rose 10°F or less. In contrast, the LIMB waste exhibited substantial temperature rises when mixed with water. The maximum temperature rise for the LIMB waste (from room temperature to 226°F) was observed at the 10 w/w % moisture level, equivalent to a water-to-lime mol ratio of 1.0. This result is similar to those reported by Southern Research

Institute (1) on other LIMB wastes. The Coolside waste also gave its highest temperature rise at 10% water addition, though it was a very small rise. The temperature profile of Coolside and LIMB wastes after water addition are compared in Figure 3, using the 10 w/w % added moisture samples. This result indicates that wetting Coolside waste will not cause a substantial temperature rise. The lack of reactivity can be attributed to the composition of the Coolside waste. In LIMB waste, the unused sorbent is in the form of lime (CaO), which reacts exothermally with water to form Ca(OH)₂. In Coolside waste, the unused sorbent is already in the form of hydrated lime (Ca(OH)₂).

Chemical Compositions

The chemical components in Coolside waste were determined to provide characterization data unavailable by elemental analyses. Coolside waste properties may be directly related to the chemical component compositions of the waste. For instance, characterization of the waste for molecular compositions before and after curing can provide a better understanding of property changes during curing, as discussed previously. Three techniques (thermogravimetric analysis, Fourier-transform infrared spectroscopy, and lime index measurement by ASTM method C-25) were used to characterize the effects of curing on component compositions of Coolside waste.

Thermogravimetric analysis (TGA) was used to determine Ca(OH)₂ and CaCO₃ in Coolside waste produced with the sodium hydroxide additive. Figures 4 to 6 show TGA curves of Coolside waste containing the optimum moisture that were cured for 0, 14 and 28 days, respectively. These waste samples were obtained from pellets used in compressive strength measurements. The following table summarizes the results of the TGA analyses and the corresponding compressive strengths of these samples.

Curing Time (Days)	TGA Analyses			Compressive Strength (psi)
	Moisture Content (wt % as received)	wt %, Dry Basis		
		Ca(OH) ₂	CaCO ₃	
0	22.4	26.2	16.9	32
14	15.8	22.5	15.0	159
28	11.7	20.5	11.5	251

The moisture content and the concentrations of Ca(OH)₂ and CaCO₃ decreased with increasing curing time and increasing compressive strength, indicating that pozzolanic reactions occurred during curing (17). Ettringite (3CaO · Al₂O₃ · 3CaSO₄ · 3H₂O) was identified by X-ray diffraction (18) in another Coolside waste sample (obtained from Consol pilot plant tests not run under Edgewater-simulated conditions) after 28 days curing. This sample was cured at 100°F in a humidity chamber instead of 70°F as in ASTM Method D-559. Ettringite, a product of pozzolanic reactions, was also identified in a synthetic aggregate product of LIMB waste (19).

The effects of curing on waste composition were also examined by Fourier-transform infrared (FTIR) spectroscopy. Figure 7 shows the spectra of uncured and 28 days cured Coolside wastes produced with the sodium hydroxide additive. These two samples were the same as used in the TGA analyses. FTIR spectral bands can be associated with component functional groups contained in the waste as indicated in Figure 7. Hydroxide, carbonate, SO₄⁻² and SO₃⁻² are mostly in the forms of the respective calcium compounds. The band intensities in FTIR spectra relate to the amount of the respective functional group. It is evident from Figure 7 that the amount of OH⁻ (from Ca(OH)₂) decreases after curing, which is consistent with TGA results. These two spectra were obtained by scaling to equal sample weights for quantitative comparison.

The concentration of Ca(OH)₂ in Coolside waste was also examined by lime index measurements using ASTM method C-25. Only Ca(OH)₂

concentration can be determined by this titration method. $\text{Ca}(\text{OH})_2$ concentrations of 25.8 wt % and 19.7 wt % (dry basis) were obtained in the uncured and 28 days cured waste samples, respectively. The decrease in $\text{Ca}(\text{OH})_2$ concentration after curing is consistent with TGA and FTIR analyses. This method has the advantage of simplicity, and it can be readily used in the field. These three techniques are being used to evaluate the component composition changes in Coolside waste piles under natural weathering conditions (run-off simulation test, Task 7 of the test program).

EXPERIMENTAL

Source of Material

Coolside wastes used in this study were obtained from Consol pilot-plant tests which used hydrated lime from the Mississippi Lime Co. The test runs were made under simulated Edgewater process demonstration conditions with a 25°F approach to adiabatic saturation, Ca/S mol ratio of 2.0 and 1,900 ppm SO_2 (dry basis) in the flue gas. Coolside tests were made both with and without the NaOH additive. Run PR-3 was made with the additive on March 26, 27 and 30, 1987. The weight ratio of injected NaOH to $\text{Ca}(\text{OH})_2$ was 0.1. Runs ST-1 to ST-3 were made without the additive on March 17-19, 1987. The waste from these three runs were blended. Analyses of Coolside waste samples used in this study are listed in Table 7. The LIMB waste used in the reactivity study was obtained from the Consol Martinsville field tests (Run 31L) with a Ca/S mol ratio of 2.5 and a 55°F approach to adiabatic saturation in the humidifier.

Test Procedure

The moisture-density relationship of the Coolside waste was measured using ASTM method D-698. The compressive strengths of Coolside wastes were measured using ASTM Method D-1633. The cured wastes

were made by ASTM Method D-559. Leachates for toxicity tests were prepared using the EP toxicity test procedure (9) and also by using the EP procedure except with deionized water as the only extraction medium. Permeability coefficients of Coolside wastes were measured using Earth Method 1110-02-1906 with a Gilson E-216 combination permeameter (Gilson Company, Inc.) in the falling-head mode. Samples used in the permeability study were prepared according to both ASTM methods D-698 and C-192 and cured by ASTM method D-559. The reactivities of Coolside and LIMB wastes were measured by adding and mixing various amounts of water to three pounds of each waste in an insulated one-gallon container. The temperature rise was monitored as a function of time by using a thermocouple inserted immediately after mixing.

Analyses

Total dissolved and suspended solids, hydroxide, carbonate, chloride, fluoride, nitrate and sulfate in the leachates from toxicity studies were measured using Consol R&D's Analytical Laboratory according to standard procedures. The trace elements (Ba, Ca, Cu, Fe, Mg, Mn, Na, Ag, Zn) in the leachates were measured using the Inductivity Coupled Plasma/Atomic Emission Spectrometer (ICP/AES). Other trace elements (As, Cd, Cr, Pb, Se) were measured using the Inductively Coupled Plasma-Mass Spectrometer (ICP-MS). TGA spectra of waste samples were collected using a Perkin-Elmer TGA7 thermogravimetric analyzer. Helium gas was used as a carrier gas. The heating rate was 30°C/min. FTIR spectra of waste samples were collected using a Nicolet Model 7199 FTIR spectrometer in the transmittance mode on KBr pellets produced from Coolside wastes.

REFERENCES

1. Dahlin, R. S., Lishawa, R. S. and Kaplan, N., "Analysis of LIMB Waste Management Options", 1986 Joint Symposium on Dry SO₂ and Simultaneous SO₂/NO_x Control Technologies, Raleigh, North Carolina, June 2-6, 1986.
2. Eklund, A. G., Meserole, F. B., Heinrich, D. L., Owens, J. B., Wells, R. E. and Williams, K. R., "Characterization of Waste Products from Dry Scrubbing Systems", EPRI Final Report, CS-2766, December 1982.
3. Eklund, A. G., Wellington, T. M., "Composition and Leaching of FBC Wastes at the Alliance Test Facility", EPRI Final Report, CS-3715, November 1984.
4. Wu, M. M., "Test Program for Coolside Waste Management", Issued to Babcock and Wilcox, June 2, 1987.
5. Donnelly, J. R., Ellis, R. P. and Webster, W. C., "Dry Flue Gas Desulfurization End-Product Disposal Riverside Demonstration Facility Experience", EPA/EPRI FGD Symposium, Hollywood, Florida, May 1982.
6. Coltharp, W. M., Meserole, N. P., Jones, B. F., Schwitzgebel, K., Merrill, R. S., Seliman, G. L., Thompson C. M. and Malish, D. A., "Chemical/Physical Stability of Flue Gas Cleaning Wastes", EPRI Final Report, FP-671, January 1979.
7. Stearns, Conrad and Schmidt Consulting Engineers, Inc., "Recovery, Utilization and Disposal of Solid By-Products Generated by Dry Flue Gas Desulfurization Systems: State-of-the-Art and Research Needs", EPRI Final Report, CS-1765, March 1981.
8. Harris, D., Ohio EPA, personal communication with authors, April 27, 1988.
9. Federal Register, 45 (98), 33127, May 19, 1980.
10. Dahlin, R. S. (SoRI), personal communication with authors, June 18, 1987.
11. State of Ohio Water Quality Standards, Chapter 3745-1 of the Administrative Code, effective April 30, 1987.
12. Laboratory Soils Testing, Engineering Manual, Earth Method 1110-02-1906, Appendix VII, Department of the Army, Office of the Chief of Engineers, 1976.
13. Sevichky, W. (NYSEG), personal communication with D. C. McCoy (Consol R&D), July 1987.

REFERENCES (Continued)

14. Felsvang, K., Morsing, P. and Veltman, P., "Acid Rain Prevention Through New SO_x/NO_x Dry Scrubbing Process", EPA/EPRI FGD Symposium, New Orleans, Louisiana, November 1983.
15. Clark, C. C. (SoRI), Personal communication with author, July 14 and September 9, 1987.
16. Dahlin, R. S., "SoRI's Laboratory Characterization of LIMB Ash and Handling and Disposal of Ontario Hydro LIMB Ash", LIMB Waste Disposal Meeting at Ohio EPA, Columbus, Ohio, January 21, 1987.
17. Lea, F. M., "The Chemistry of Cement and Concrete", Chemical Publishing Co., New York, 1971.
18. Dickinson, G. (Conoco Research Services Division), Personal communication with author, March 18, 1987.
19. Dahlin, R. S., Lishawa, C. L., Clark, C. C., Nolan, P. S. and Kaplan, N., "Disposal, Recycle and Utilization of Modified Fly Ash from Hydrated Lime Injection into Coal-Fired Utility Boilers", 80th APCA Annual Meeting, New York, New York, June 21-26, 1987.

TABLE 1
 COMPRESSIVE STRENGTH OF COOLSIDE WASTE
 CONTAINING THE OPTIMUM MOISTURE CONTENT AS A
 FUNCTION OF CURING TIME

<u>Curing Time (Days)</u>	<u>Unconfined Compressive Strength (psi)</u>	
	<u>Waste Generated With NaOH Additive</u>	<u>Waste Generated Without NaOH Additive</u>
0	32	51
7	88	87
14	159	111
28	251	200

/1s

TABLE 2
 COMPRESSIVE STRENGTH OF COOLSIDE WASTE
 PRODUCED WITH THE SODIUM HYDROXIDE ADDITIVE AS A
 FUNCTION OF MOISTURE CONTENT

Moisture Content (wt %, dry basis)	Unconfined Compressive Strength (psi)	
	<u>7 Days Curing</u>	<u>28 Days Curing</u>
21	5.1	40
24	52	191
30	88	251

/ls

TABLE 3

LEACHATE COMPOSITIONS OF COOLSIDE WASTES GENERATED WITH AND WITHOUT THE NaOH ADDITIVE

Analysis	Allowable Limit by RCRA (a)	Allowable Limit by the State of Ohio (b)	Leachate Concentration, mg/L			
			Waste Generated With the Sodium Hydroxide Additive		Waste Generated Without the Sodium Hydroxide Additive	
			Acetic Acid Extraction	Deionized Water Extraction	Acetic Acid Extraction	Deionized Water Extraction
Hydroxide as CaCO ₃	-	-	1,267	2,817	1,680	2,035
Carbonate as CaCO ₃	-	-	<20	126	<20	212
Total Suspended Solids	-	-	17	3	15	3
Total Dissolved Solids	-	15,000	12,598	5,478	9,868	2,688
Calcium	-	-	2,676	895	2,961	1,155
Sodium	-	-	1,245	1,320	48.8	43.3
Arsenic	5	1.5	0.003	0.001	<0.005	0.001
Barium	100	30	<0.4	0.35	0.52	0.51
Cadmium	1	0.3	0.0006	0.0007	0.0009	0.0008
Chromium	5	1.5	0.13	0.099	0.10	0.082
Lead	5	1.5	0.0031	0.0019	0.0029	0.0015
Mercury	0.2	0.06	0.0001	0.0002	<0.0001	<0.0002
Silver	5	1.5	<0.025	<0.025	<0.025	<0.025
Selenium	1	0.3	<0.03	<0.05	<0.015	<0.008
Nitrate (as N)	-	300	(c)	1.0	(c)	2.0
Fluoride	-	42 to 72	(c)	0.01	(c)	<0.01
Chloride	-	7,500	(c)	6.0	(c)	8.0
Sulfate	-	7,500	1,437	2,032	557	944
Iron	-	9	<0.2	<0.2	<0.2	<0.2
Zinc	-	150	0.059	<0.02	<0.02	<0.02
Manganese	-	1.5	<0.02	<0.02	<0.02	<0.02
Copper	-	30	0.068	0.020	0.029	0.023

(a) 100 times the EPA primary drinking water standards.

(b) 30 times the EPA primary and secondary drinking water standards, as communicated in Reference 8.

(c) Not determined due to interferences in analytical procedure.

/1s

TABLE 4

MATERIAL AND CHARGE BALANCES OF LEACHATE COMPONENTS IN COOLSIDE WASTE SAMPLES

	Waste Generated With the Sodium Hydroxide Additive		Waste Generated Without the Sodium Hydroxide Additive		Cured Waste (a)	
	Acetic Acid Extraction	Deionized Water Extraction	Acetic Acid Extraction	Deionized Water Extraction	Acetic Acid Extraction	Deionized Water Extraction
<u>Leachate Compositions (mg/L)</u>						
Total Dissolved Solids (measured)	12598	5478	9868	2688	10266	4848
Ca ²⁺	2676	895	2961	1155	2201	870
Na ⁺	1245	1320	488	43	1097	1265
CH ₃ COO ⁻	5900	0	5900	0	5900	0
SO ₄ ²⁻	1437	2032	557	944	1391	1790
OH ⁻	431	958	571	692	497	840
CO ₃ ²⁻	0	76	0	127	0	127
Total Dissolved Solids (calculated) (b)	11689	5281	10037	2961	11086	4892
<u>Balance (%)</u>						
Material (c)	92.8	96.4	101.7	110.1	92.6	100.9
Charge (d)	82.7	99.2	96.7	92.6	99.7	108.6

(a) Cured waste sample as in Table 5.

(b) Calculated by adding concentrations of dissolved ions.

(c) Calculated by TDS (calculated)/TDS (measured) x 100%.

(d) Calculated by

$$\frac{2[\text{Ca}^{2+}] + [\text{Na}^+]}{2[\text{SO}_4^{2-}] + [\text{OH}^-] + [\text{CH}_3\text{COO}^-] + 2[\text{CO}_3^{2-}]} \times 100\%$$

/1s

TABLE 5
THE EFFECT OF CURING ON COOLSIDE WASTE LEACHATE COMPOSITION

Analysis	Leachate Concentration, mg/L							
	Allowable Limit by the State of Ohio (b)		Waste as Collected (c)		Cured Waste (d)		Cured Waste (d)	
	by RCRA (a)	State of Ohio (b)	Acetic Acid Extraction	Deionized Water Extraction	Acetic Acid Extraction	Deionized Water Extraction	Acetic Acid Extraction	Deionized Water Extraction
Hydroxide as CaCO ₃	-	-	1,267	2,817	1,463	2,470	1,463	2,470
Carbonate as CaCO ₃	-	-	<20	126	<20	211	<20	211
Total Suspended Solids	-	-	17	3	17	6	17	6
Total Dissolved Solids	-	15,000	12,598	5,478	10,266	4,848	10,266	4,848
Calcium	-	-	2,676	895	2,201	870.3	2,201	870.3
Sodium	-	-	1,245	1,320	1,097	1,265	1,097	1,265
Arsenic	5	1.5	0.003	0.001	<0.005	0.001	<0.005	0.001
Barium	100	30	<0.4	0.35	1.0	0.35	1.0	0.35
Cadmium	1	0.3	0.0006	0.0007	0.0008	0.001	0.0008	0.001
Chromium	5	1.5	0.13	0.099	0.076	0.07	0.076	0.07
Lead	5	1.5	0.0031	0.0019	0.0062	0.006	0.0062	0.006
Mercury	0.2	0.06	0.0001	0.0002	0.0001	0.0002	0.0001	0.0002
Silver	5	1.5	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Selenium	1	0.3	<0.03	<0.050	<0.01	<0.0015	<0.01	<0.0015
Nitrate (as N)	-	300	(e)	1.0	(e)	2.0	(e)	2.0
Fluoride	-	42 to 72	(e)	0.01	(e)	0.01	(e)	0.01
Chloride	-	7,500	(e)	6.0	(e)	4.0	(e)	4.0
Sulfate	-	7,500	1,437	2,032	1,391	1,790	1,391	1,790
Iron	-	9	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Zinc	-	150	0.059	<0.02	0.093	<0.02	0.093	<0.02
Manganese	-	1.5	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Copper	-	30	0.068	0.020	0.098	<0.02	0.098	<0.02

(a) 100 times the EPA primary drinking water standards.

(b) 30 times the EPA primary and secondary drinking water standards, as communicated in Reference 8.

(c) Waste generated with the NaOH additive.

(d) The same waste as in (c), mixed with the optimum moisture, compacted (ASTM Method D-698) and cured in a humidity chamber for 28 days.

(e) Not determined due to interferences in analytical procedure.

TABLE 6
PERMEABILITY COEFFICIENTS OF COOLSIDE WASTES

Curing Time (Days)	Permeability Coefficient (cm/sec)		
	ASTM Method D-698 (a)	ASTM Method C-192	
	Waste Generated with the NaOH Additive	Waste Generated with the NaOH Additive	Waste Generated without the NaOH Additive
0	1.2×10^{-5}	-	-
7	1.4×10^{-6}	-	-
28	2.2×10^{-6}	9.7×10^{-4}	-
30	-	5.4×10^{-4} (b)	2.7×10^{-4} (b)
32	1.8×10^{-6}	-	-

(a) Dry bulk density was 66.8 lb/ft³.

(b) Value determined by Southern Research Institute (SoRI), all others by Conso1 R&D.

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TABLE 7
ANALYSES OF COOLSIDE WASTE SAMPLES

<u>Analysis, wt % as received</u>	<u>Waste Generated With the NaOH Additive</u>	<u>Waste Generated Without the NaOH Additive</u>
Moisture	1.7	2.9
Ash	83.5	80.3
Carbon	5.8	7.6
Hydrogen	1.2	1.4
Nitrogen	0.1	0.1
Sulfur (Total)	7.7	4.8
Sulfate Sulfur	2.2	1.0
Sulfite Sulfur	5.6	4.2
Carbonate (CO ₃ ²⁻)	7.6	5.1
 <u>Elemental Analysis, wt % of Ash</u>		
Na ₂ O	4.9	0.5
K ₂ O	0.7	1.1
CaO	44.5	44.6
MgO	0.6	0.8
Fe ₂ O ₃	3.5	5.5
TiO ₂	0.3	0.4
P ₂ O ₅	0.1	0.2
SiO ₂	14.0	22.2
Al ₂ O ₃	5.9	9.4
SO ₃	23.4	14.5
Unaccounted	2.1	0.8

/1s

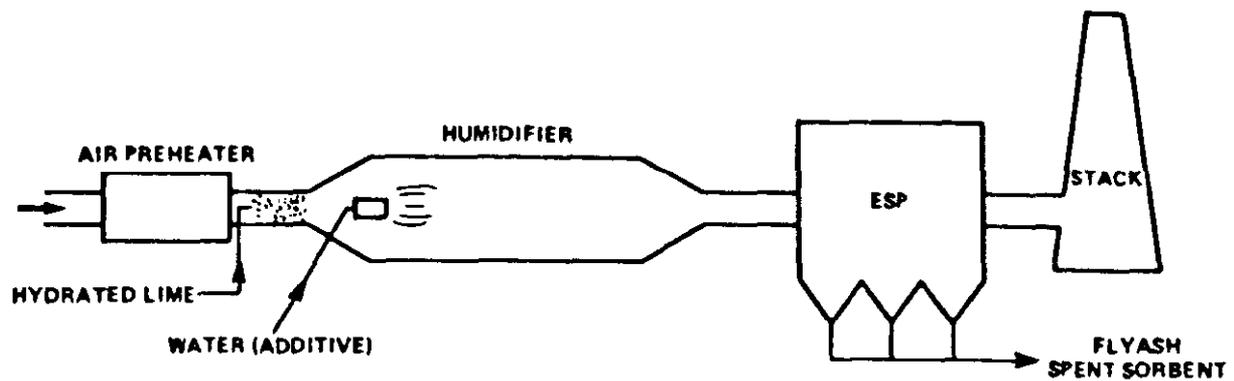


Figure 1. Coolside Process.

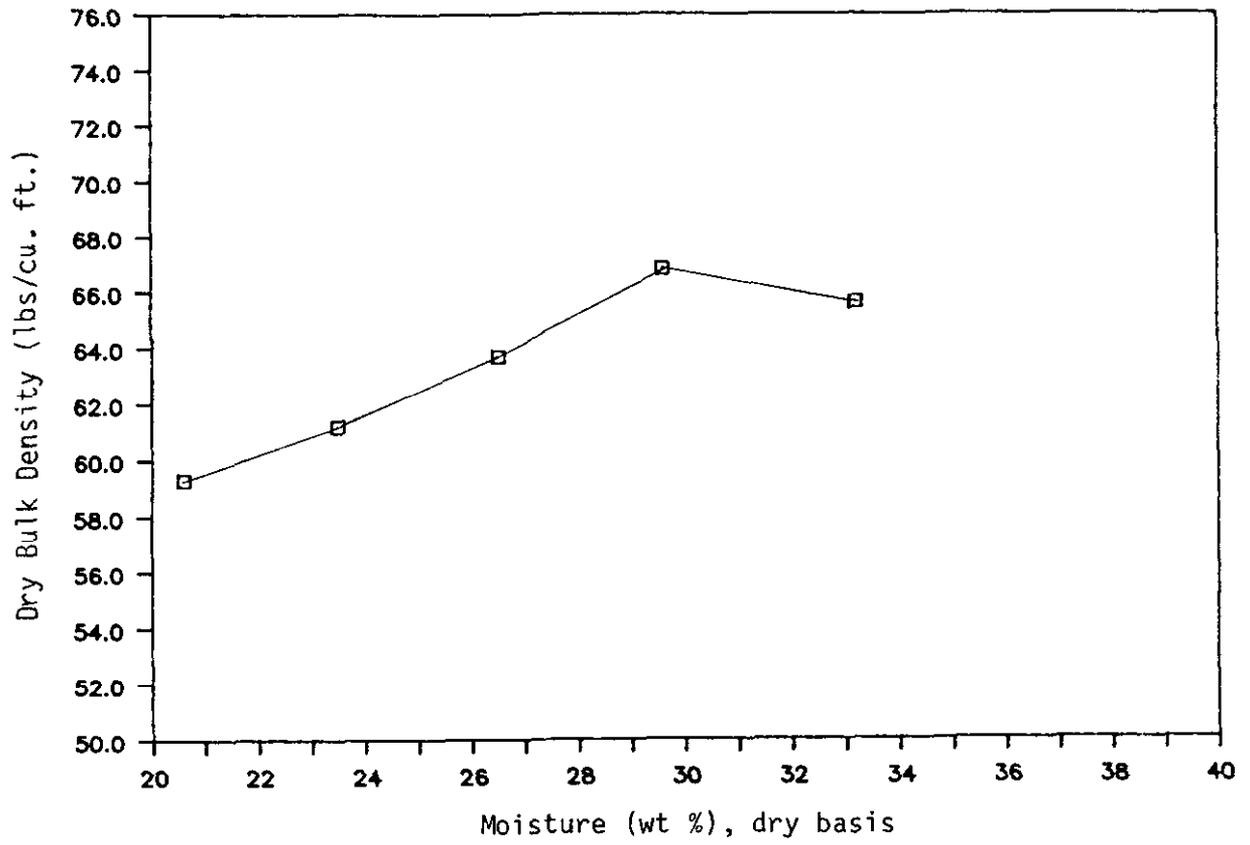


Figure 2. Moisture-Density Relationship of Coolside Waste.

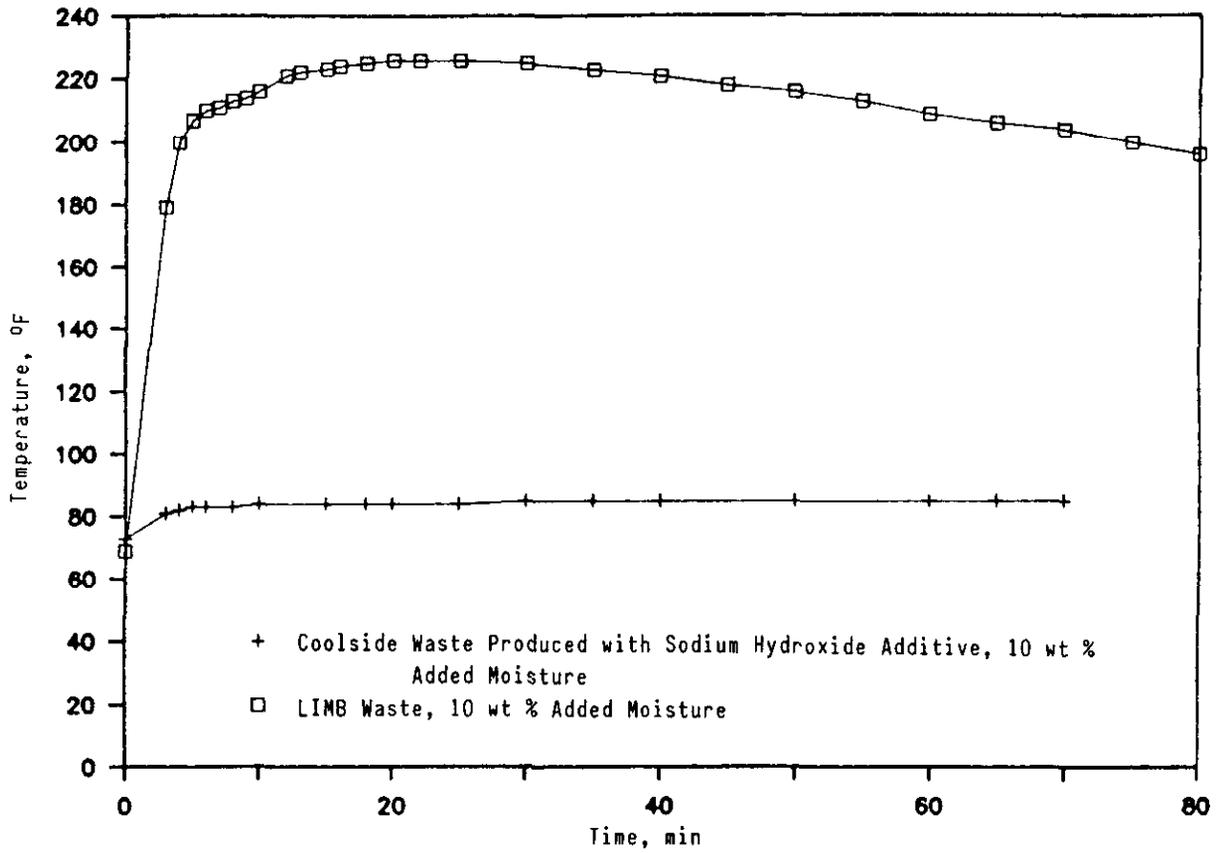


Figure 3. Temperature Rise of Coolside and LIMB Wastes as a Function of Time.

TGA File Name: g382
 Sample Weight: 36.603 mg
 Thu Dec 17 11:13:36 1987
 pp w/e

PERKIN-ELMER
 7 Series Thermal Analysis System

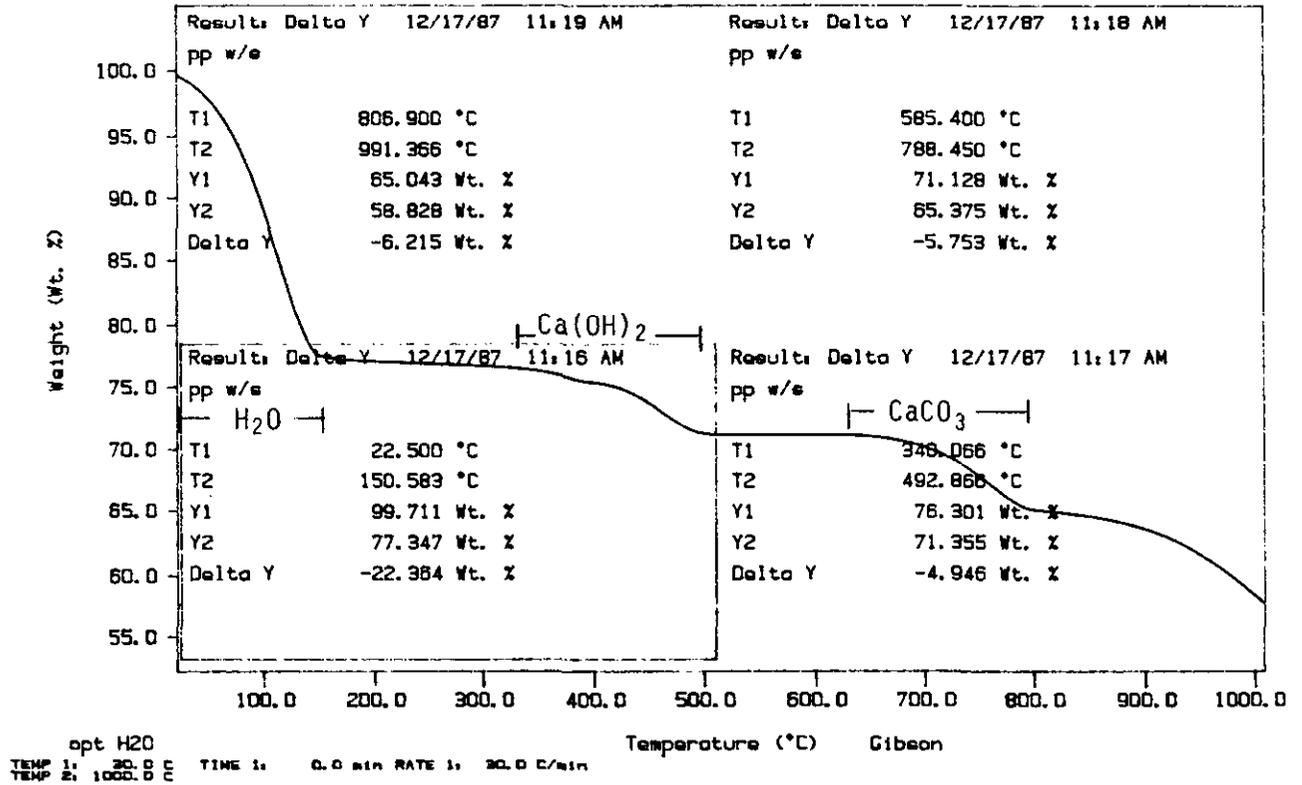


Figure 4. Thermogram of Uncured Coolside Waste Sample Produced With the Sodium Hydroxide Additive.

TGA File Name: w213
 Sample Weight: 9.201 mg
 Thu Jun 25 15:07:15 1987
 1362-pp-we 14 days

PERKIN-ELMER
 7 Series Thermal Analysis System

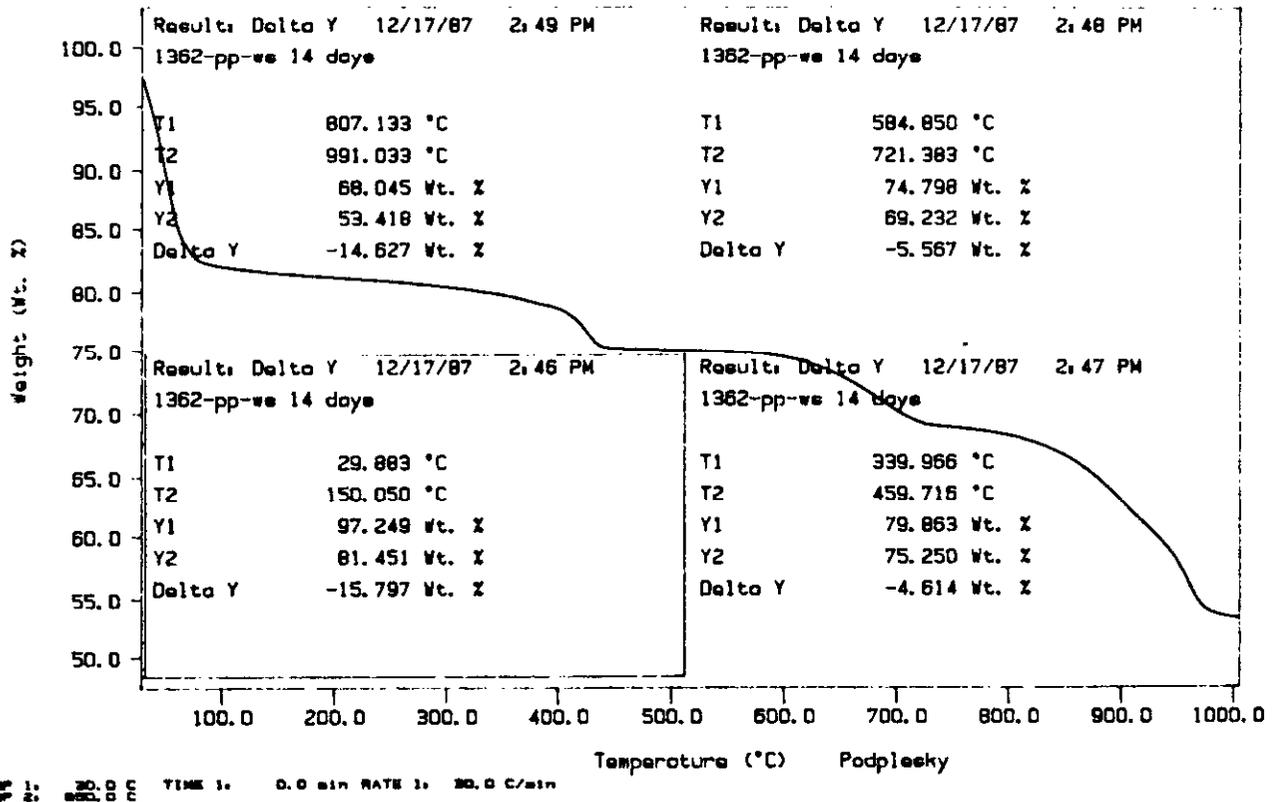


Figure 5. Thermogram of 14 Days Cured Coolside Waste Sample Produced With the Sodium Hydroxide Additive.

TGA File Name: w207
 Sample Weight: 15.933 mg
 Wed Jun 24 14:11:18 1987
 1362-pp-we 28days

PERKIN-ELMER
 7 Series Thermal Analysis System

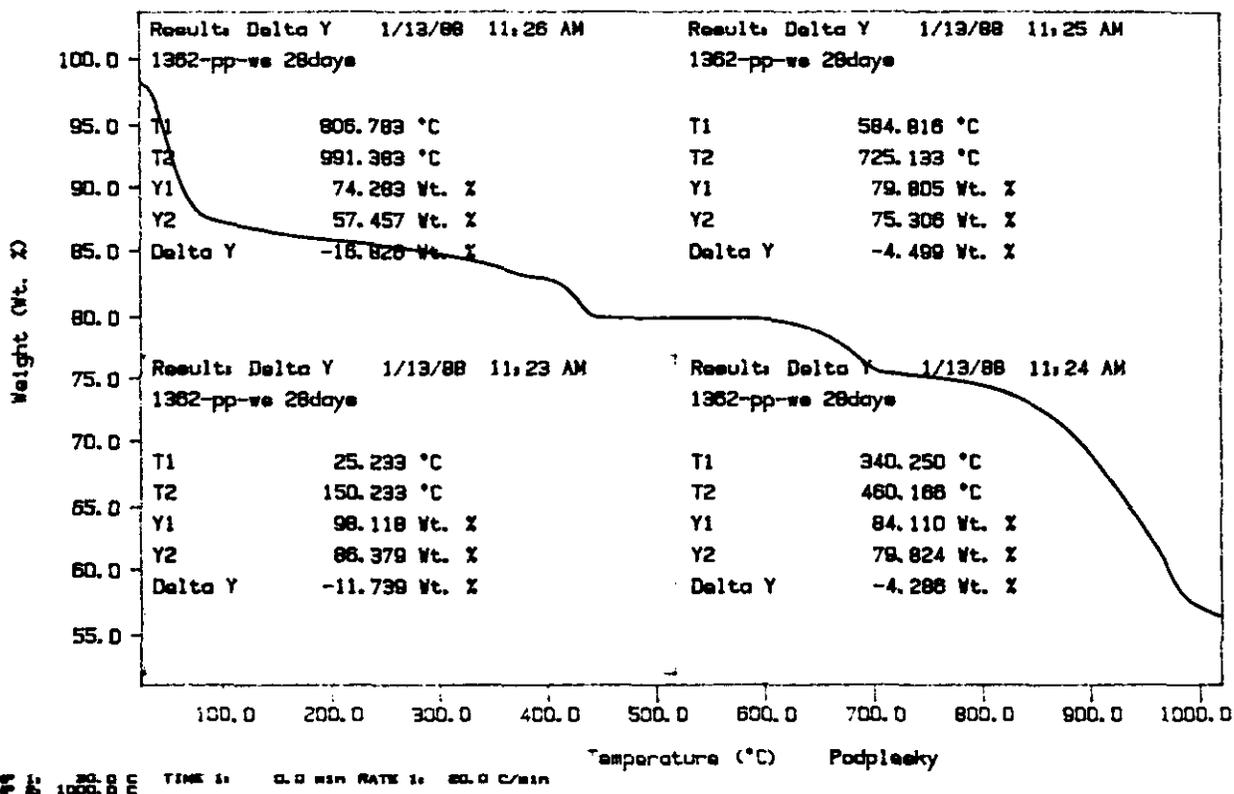


Figure 6. Thermogram of 28 Days Cured Coolside Waste Sample Produced With the Sodium Hydroxide Additive.

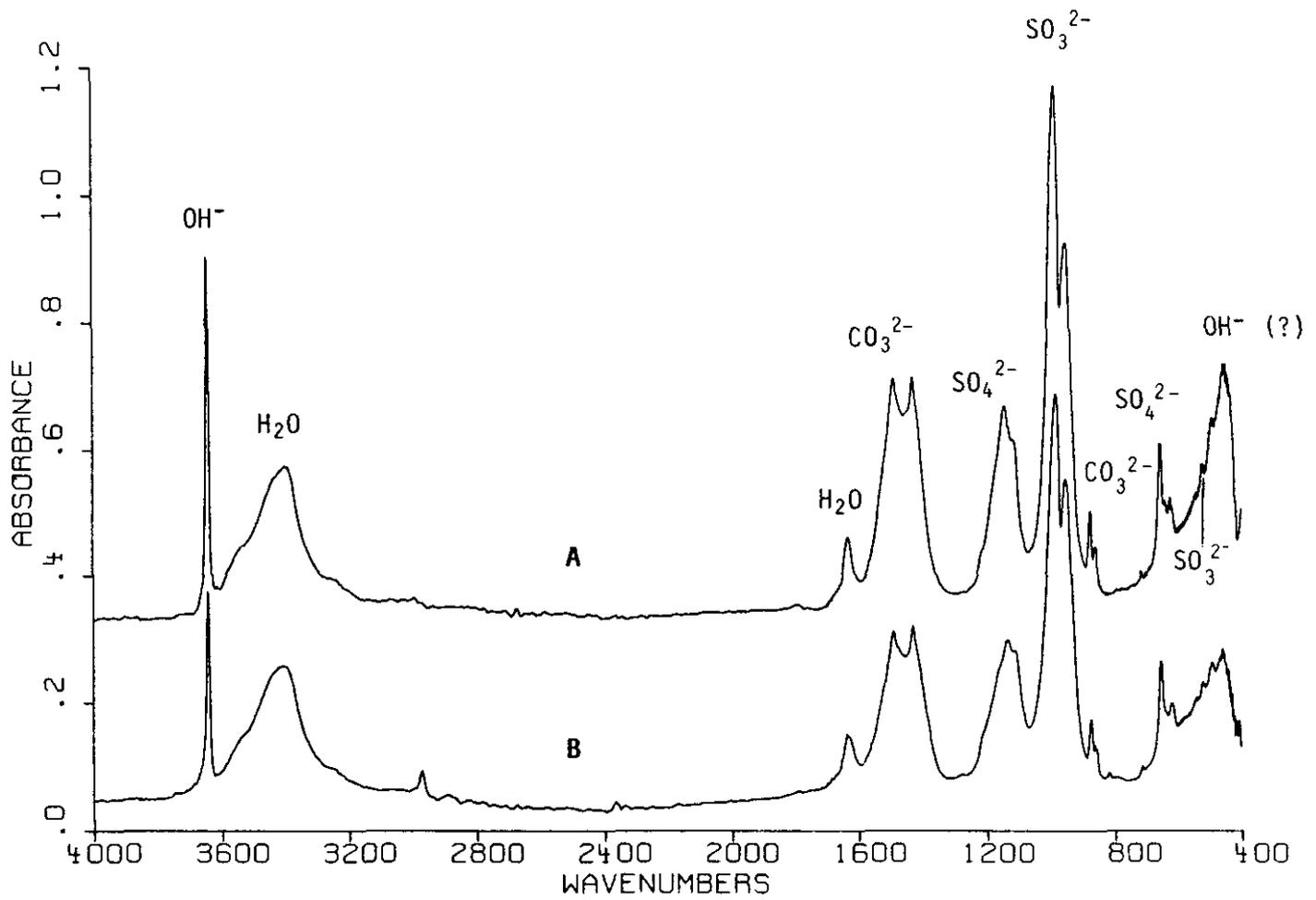


Figure 7. FTIR Spectra of Uncured and 28 Days Cured Coolside Waste Samples Produced with the Sodium Hydroxide Additive.
 A. Uncured Coolside Waste
 B. 28 Days Cured Waste

PART 2

COOLSIDE WASTE MANAGEMENT
STUDIES - FINAL REPORT ON THE
RUN-OFF SIMULATION TEST

INTRODUCTION

The Coolside waste management program (1) consisted of seven tasks. The final report on the first six tasks appears in Part 1 of this report. This is the final report on task 7, the run-off simulation test. The run-off simulation test was designed to address the effects of weathering on Coolside solid waste. For present purposes, weathering is defined as the exposure of the waste to natural weather (atmosphere, rain, snow, wind and sunshine).

Two tests were performed in which Coolside solid waste (generated with the NaOH additive) was mixed with either 20% or 33.3% added water, lightly compacted and exposed outside for 5 1/2 or 6 1/2 months, respectively, in plastic containment vessels. The moisture contents of the two piles, expressed on a dry basis, were 22.1% and 35.6%, respectively. The containment vessels were placed in a slightly sloped area and equipped with a drain at their lowest level. When enough precipitation water entered the containment vessels, it drained into receiving containers. The receiving containers were routinely checked following precipitation on normal working days and sampled for analysis when they contained water. The containers were also usually sampled on those week-end days and holidays when significant precipitation occurred. The drainage water samples were analyzed to determine various water quality parameters. About 40 drainage samples from each test were analyzed. Solid samples were taken periodically from the piles to determine changes during weathering. At completion of the test, solid samples were taken for permeability tests and each pile was blended and sampled for analysis.

Several important conclusions were drawn from this work regarding the behavior of Coolside waste during landfill disposal. However, in many respects the waste piles were not good models of commercially landfilled Coolside waste. The waste piles were formed with a minimum of compaction. Waste disposed in a commercial landfill would be much more

greatly compacted. As a result of the light compaction, 1) the waste piles never formed into a solid cohesive mass, 2), the waste piles remained relatively highly permeable throughout the test, and 3) precipitation percolated through the waste rather than simply running off its surface.

Therefore, we believe that the permeabilities and the drainage water quality parameters measured in this work are not representative of commercially landfilled Coolside waste. Regardless of this, these data are still valuable in that they would appear to represent upper limits for commercially disposed Coolside waste.

CONCLUSIONS

To a great extent, the results of this test appear to have been controlled by one factor - the mild initial compaction of the waste piles. The waste piles remained soft and loose, and therefore permeable, for the entire six-month test. The earlier laboratory tests showed that moist Coolside waste does indeed form a strong, relatively impermeable mass upon curing. However, the laboratory tests are performed on well-compacted material (waste disposed in a landfill is usually well compacted by earth-moving equipment). Waste pile 1 (made with 33.3% added water) was compacted with an estimated 5 psig pressure. Waste pile 2 (made with 20% added water) was compacted with even less pressure. Because of the high permeability of the waste, at least some of the precipitation water percolated through the piles as opposed to simply running off the surface.

Specific conclusions from this work follow.

- $\text{Ca}(\text{OH})_2$ disappeared from the pile surface early in the tests. The major cause appears to be its reaction with atmospheric CO_2 to form CaCO_3 , though dissolution may have contributed to its disappearance on the surface. Even after completion of the tests,

$\text{Ca}(\text{OH})_2$ was present in the pile interiors. On the pile surface, CaSO_3 was oxidized to CaSO_4 which then dissolved during precipitation (rainfall or snow melt).

- The concentrations of trace elements in the drainage water generally decreased with time. In all cases, trace element concentrations were below thirty times the EPA primary and secondary drinking water standards.
- The pH of the drainage water varied widely. It was associated with the amount of precipitation and it appears that it was affected by the relative amounts of percolation and true runoff as well as by atmospheric CO_2 absorption by the drainage water.
- Because of the experimental design, essentially all the drainage water analyzed made intimate contact with the waste. Dilution from precipitation not falling on the waste was minimal. Therefore, it would appear that the water quality measurements reported here are worst case values.
- Core samples taken at the end of the test had relatively high permeability coefficients (5.3×10^{-3} cm/sec for pile 1 and 9.8×10^{-3} cm/sec for pile 2). The high permeability coefficients, which appear to be caused by the mild compaction used to form the waste piles, allowed some of the precipitation to percolate through, rather than run off the piles. Apparently, Coolside waste must be sufficiently compacted to produce a material with low permeability.
- Sodium concentrations in the two bulk waste piles were reduced by 87 to 95% during the duration of the tests. This confirms that much of the precipitation percolated through the piles.
- Because of the different histories of the two waste piles, few definitive conclusions can be drawn concerning the effects of initial

moisture content on the results. However, during preparation of the piles, the waste with the greater moisture content (33.3% added, pile 1) was much easier to pack. Pile 2 had less water added (20%) and was fairly dry and powdery, making it very difficult to compress.

EXPERIMENTAL

RUN-OFF SIMULATION TESTS

The run-off simulation tests were performed from June 17 through December 31, 1987. Two waste piles were constructed from the Coolside waste produced with the NaOH additive. The source and analysis of this material are included in Part 1 of this report. The two tests differed primarily in the amount of water added to the as-received waste prior to starting the test, though there were several other differences. Waste pile 1 was formed from 90 lbs of as-received waste and 30 lbs of water and was packed with a hand held tamper. Pile 1 began weathering on June 17, 1987. Run-off was collected in a 7-gallon container. Waste pile 2 was formed from 50 lbs as-received waste and 10 lbs water and was packed by hand pressure. Pile 2 began weathering on July 17, 1987. Run-off was collected in a 5-gallon container.

The tests were performed as follows. A 6-inch deep trench, one foot wide was dug around a 6 x 6 foot site located at the south end of the Library facility. A 36 x 8 inch plastic circular containment vessel (a child's wading pool) was purchased and lined with polyethylene sheeting. The vessel was sloped 5° from horizontal to assure run-off and to facilitate collection of the run-off water. A hole was cut into the containment vessel at its lowest point to permit drainage through a funnel into a collection container. Since no filter was used, all entrained solids also entered the collection vessel.

For the first pile, 90 lbs of waste was mixed with 30 lbs of water in a cement mixer. The water did not mix evenly with the waste, but rather, the waste agglomerated into spheres of approximately 1/4 inch to 1 inch in diameter. The mixture was sealed in a polyethylene bag overnight. The next morning, the spheres were pressed through an 8 mesh screen, then mixed to ensure a uniform water content throughout the pile. A cone-shaped pile, 36 inches in diameter and 5 inches high, was constructed from 112.6 lbs of the prepared waste. The pile was packed using a 50 lb, 8 x 8-inch hand held tamper. We estimate that the tamper generated about 300 lbs of force, which gives about 5 psi pressure. Weathering of the first pile started June 17, 1987. Drainage was collected in a 7-gallon polyolefin carboy. After the pile had weathered for 21 days, a large crack formed in the pile. Since the containment vessel was originally placed on ground that was not perfectly level, it was able to bend slightly from the weight of its contents. The crack appeared to form as a result of bending of the containment vessel. A 4 ft² x 1/2 inch sheet of plywood was placed under the vessel to support the pile to prevent further crack formation.

A second, similar pile was made on July 17, 1987, and located directly beside the original. The waste for the second pile was mixed by hand with 20% added water (50 lbs of waste was mixed with 10 lbs of water). Less material was used for this test because of limited quantities. No agglomeration problems were encountered; however, the material was again passed through an 8 mesh screen. This pile was packed by hand pressure only, for when it was compacted with the tamper, large cracks developed through out the pile. A cone-shaped pile, 32 inches in diameter and 5 inches high, was made from 59.6 lbs of the prepared waste. The second pile began weathering July 17, 1987. Drainage was collected in a 5-gallon polyolefin bucket equipped with a lid with a bung hole. The containment vessel was set on a shipping pallet for support.

Most precipitation occurred as rain, though several snowfalls occurred in November and December. On several occasions, drainage water was

collected that appeared to arise from collected dew or melted frost. The collection containers were routinely checked following precipitation on normal working days, and usually on those week-end days and holidays when there was significant precipitation. Samples were taken when any water was available. In those cases when there was non-stop precipitation lasting several days, drainage samples were only collected after precipitation ceased. The container was emptied and rinsed with deionized water before reuse. Upon collection, pH was immediately determined on all collected drainage samples. Periodic samples were more thoroughly analyzed. In several cases, the drainage volume exceeded the capacity of the container. This is indicated in Tables 1 and 2 as collection volumes of 26.5L and 18.9L, respectively.

WATER ANALYSIS

pH was determined on all drainage samples. Periodic samples were more thoroughly analyzed. In those cases, the collected run-off water was split into two aliquots. One sample was analyzed, as collected, for pH, total dissolved solids, total suspended solids, hydroxide, carbonate, turbidity, chloride, fluoride, nitrate and sulfate by R&D's Analytical Laboratory according to standard procedures. The second aliquot was filtered and treated with dilute nitric acid (1%), according to EPA guidelines (2) This aliquot was analyzed for the major and trace elements (As, Ba, Ca, Cr, Pb, Hg, Se, Ag, Fe, Cu, Mn, Zn, Na, Ca) as reported in Part 1 of this report.

SOLIDS ANALYSIS

TGA analyses of solid waste samples were obtained with a Perkin-Elmer TGA7 Thermogravimetric Analyzer as reported in Part 1 of this report. DTG analyses were obtained with Perkin-Elmer software. FTIR spectra of the solid wastes were collected with a Nicolet Model 7199 FTIR Spectrometer in the transmittance mode on KBr pellets produced from solid waste samples.

RESULTS AND DISCUSSION

OBSERVATIONS

As the waste piles weathered, the physical appearances of the piles changed. Pile 1, which was initially mixed to a higher water content than pile 2, developed a tough crust (ca. 1/4" thick) after several days. The pile interior slumped away from the crust leaving a gap between the crust and the bulk of the pile. Pile 2 also developed a slight crust, but it was not nearly as thick or tough as the crust on pile 1. The crusts persisted for about one month. They eventually settled onto the pile and disappeared. Early in the tests, a white powder was observed on the pile surfaces during periods in which there were several days without precipitation. The white powder appeared to arise from efflorescence. It was identified as sodium sulfate by FTIR. The white powder disappeared after heavy precipitation, but returned as the pile dried. After about the first month of the test, the white powder did not reappear.

On July 8, 1987, the first pile developed a large crack in the middle of the pile. We believe that this crack developed as the pile became heavier as it absorbed rain water, causing the containment vessel to bend. A plywood support, added after the crack developed, prevented further crack formation. The containment vessel for pile 2 was placed on a shipping pallet for better support. Pile 2 did not crack. Both pile surfaces were soft (except when the crust was present). After precipitation, the surfaces could be penetrated readily with finger pressure. Waste pile 1 was relatively firmer than waste pile 2. This is consistent with the fact that pile 1 was more strongly compacted during its formation. The cone-shaped waste piles became flatter over time. Both slumping and erosion may have contributed to this, though any eroded waste was mostly confined in the containment vessel. Only minor amounts of solids were observed in the water collection container, and then only occasionally.

As these observations attest, neither pile ever formed into a strong cohesive mass. As discussed later, we believe this resulted from the very slight compaction used during formation of the piles.

SOLID WASTE CHARACTERIZATION

Three techniques, thermogravimetric analysis (TGA), Fourier-transform infrared spectroscopy (FTIR), and lime index measurement (ASTM Method C-25) were used to characterize the changes in molecular composition of samples taken from different points of the waste piles as the test progressed. The results of this work showed that Ca(OH)_2 was rapidly lost from the pile surface, mostly by reaction with atmospheric CO_2 to form CaCO_3 . Calcium hydroxide was present in the pile interior, even at the end of the six month weathering test. On the pile surface, CaSO_3 oxidized to CaSO_4 , which was then leached away with rain. The oxidation of CaSO_3 did not occur as rapidly as the carbonation of Ca(OH)_2 .

Figure 1 shows FTIR spectra of three surface samples taken from waste pile 1 on 6/24, 6/29 and 7/7/87 after 7, 12 and 21 days weathering, respectively. FTIR spectral bands can be associated with various functional groups in the wastes. The band intensities relate to the amount of the respective functional group present in the sample. Note that samples analyzed by FTIR were dried. Therefore, moisture contents are not representative. Carbonate, SO_4^{2-} and SO_3^{2-} , shown in Figure 1, are mostly in the forms of their respective calcium compounds. It is evident from Figures 1A and 1B that the amount of SO_3^{2-} in the waste decreased and the amount of SO_4^{2-} increased between June 24 and 29, 1987. This demonstrates that CaSO_3 was being oxidized to CaSO_4 on the pile surface. There was no rain between June 24 and 29, 1987 (see Table 1). Three days of rain followed. Only a slight amount of SO_4^{2-} was presented in the surface sample (Figure 1C) taken on July 7, 1987. This shows that much of the surface CaSO_4 was leached from the pile surface by rainfall. No

OH⁻ (from Ca(OH)₂) was detected in these samples by FTIR. The absence of Ca(OH)₂ in these samples was confirmed by TGA. Figure 2 shows the TGA and differential thermogravimetric (DTG) traces of the sample taken from the surface of pile 1 after only seven days weathering (6/24/87). Ca(OH)₂ would show a signal between about 350 and 450°C if it were present. Though Ca(OH)₂ was absent in these surface samples, CaCO₃ was a major component. Evidently, the disappearance of Ca(OH)₂ in the surface samples was caused by its reaction with atmospheric CO₂ to form Ca(OH)₂, though dissolution may have also contributed to its disappearance.

For comparison, a sample was taken with a microspatula on July 9, 1987, from within a crack that formed in waste pile 1. Both FTIR (Figure 3) and TGA (Figure 4) show the presence of OH⁻ (from Ca(OH)₂) in the sample from the fissure. This indicates that the disappearance of Ca(OH)₂ by conversion to CaCO₃ or dissolution was slower in the pile interior than on the surface. The moisture, Ca(OH)₂ and CaCO₃ contents of these pile 1 samples are summarized in the table below, as determined by TGA and DTG. The table also includes data for a sample taken near the drain of waste pile 1.

Pile 1					
<u>Date Taken,</u> <u>1987</u>	<u>Weathering</u> <u>Time, Days</u>	<u>Sample Type</u>	<u>Moisture Content,</u> <u>wt % As Received</u>	<u>wt %, Dry Basis</u>	
				<u>Ca(OH)₂</u>	<u>CaCO₃</u>
6/24	7	Surface	31.9	0	39.5
6/29	12	Surface	14.9	0	33.0
7/7	22	Surface	24.2	0	49.1
7/9	24	Near Drain	6.09	6.53	34.2
7/9	24	In Fissure	21.6	18.0	17.2

Ca(OH)₂ was not detected in any of the surface samples; however, it was present in the samples taken from the fissure and near the drain. The differences in CaCO₃ contents of the surface samples may represent the heterogeneity of the small samples (about 20 mg) used for TGA analyses.

Similar observations were made concerning surface samples taken from waste pile 2. TGA data of surface samples from pile 2 are summarized below.

Pile 2					
Date Taken, 1987	Weathering Time, Days	Sample Type	Moisture Content, wt % As Received	wt %, Dry Basis	
				Ca(OH) ₂	CaCO ₃
7/17	0	Surface	17.3	18.3	23.1
7/20	3	Surface	4.60	6.28	37.6
8/4	8	Surface	40.7	0	39.8

As with pile 1, Ca(OH)₂ decreased and CaCO₃ increased upon weathering. The sample dated 8/4 was collected from pile 2 after the first rainfall.

After the test was completed, a core sample was collected from each pile by pressing an 11/16-inch ID stainless steel pipe through the pile at a point near the center. Small samples taken from the top, middle and bottom of these two core samples were characterized by TGA. The remainder of each pile was broken up, passed through a 1/8-inch screen, thoroughly mixed and sampled for TGA analysis. These composite samples are discussed in more detail later. The following table summarizes the Ca(OH)₂ contents of these samples, as determined by TGA.

Waste Pile	Ca(OH) ₂ , wt %, Dry Basis			
	Core Sample			Composite Sample
	Top	Middle	Bottom	
1	0	10.31	7.93	5.52
2	0	8.61	9.40	5.03

These data show that though Ca(OH)₂ was not present on the pile surface, it was present in the interior of each pile even at the completion of the run-off test. FTIR confirmed the presence of OH⁻ (from Ca(OH)₂) in the composite samples from pile 1 (Figure 5) and pile 2 (Figure 6). Lime index measurements (ASTM method C-25)

agreed well with the TGA results, giving 5.30 wt % and 4.71 wt % Ca(OH)₂ (dry basis) in pile 1 and pile 2, respectively. Since Ca(OH)₂ was present in the interior of waste pile but not on its surface, percolated water would have a higher pH than water which simply ran off the surface. This will be discussed next.

DRAINAGE WATER CHARACTERIZATION

Analyses of rain water run-off from Coolside waste piles 1 and 2 are listed in Tables 1 and 2, respectively. These tables include the sampling date, the collected volume of rain water, and the determined pH, total dissolved solids (TDS), total suspended solids, turbidity, and major and trace elements. Forty-one run-off samples were collected from pile 1 and forty were collected from pile 2.

The pH values of the drainages varied widely, ranging from 7.4 to 12.8 for pile 1 and from 8.0 to 12.4 for pile 2. The drainage pH did not depend strictly on sampling date. Instead, it is apparent that there is a correlation between pH and the volume of the collected drainage. Heavy precipitation produced large volume samples which tended to have higher pHs than the small volume samples produced by light precipitation. This is illustrated below for all samples taken after July 2, 1987. The earlier samples from pile 1 are omitted from this comparison because their volumes were not recorded.

	Drainage pH, Range	
	<u>Sample Volume Less than 1L</u>	<u>Sample Volume 1L or Greater</u>
Pile 1	7.4 - 9.9*	10.6 - 12.4
Pile 2	8.0 - 9.7**	9.9 - 12.3

*One sample had pH of 12.0

**One sample each had pH of 11.6, 12.1, 12.2 and 12.4

We speculate on two causes of the observed correlation between sample volume and pH. First and probably most importantly, during heavy

and prolonged precipitation, the piles became saturated with water. Once the piles were saturated, much of the collected water may have derived from percolation rather than simple run-off. Percolated water would make intimate contact with the $\text{Ca}(\text{OH})_2$ inside the piles and dissolve some of it, thus giving it high pH. During light precipitation, most of the collected water probably was true run-off. As noted previously, some $\text{Ca}(\text{OH})_2$ was present in the interior of both piles even at the end of the test, whereas on the pile surface it was completely converted to CaCO_3 or leached early in the tests.

A second factor contributing to the correlation of sample volume and pH appears to be the differential absorption of atmospheric CO_2 , depending on sample volume. Though all pH measurements were made immediately upon collection and almost always within one day after precipitation, 24 hours is enough time for atmospheric CO_2 absorption to decrease the pH of the alkaline drainage. This was illustrated by the results of a test in which a 200 mL sample of run-off water was placed in a 1000 mL beaker and exposed to air at the pile site for 43 hours. The pH decreased from 12.1 to 10.2 after 24 hours and to 9.6 after 43 hours. In any cylindrical container, large volume samples have smaller surface area to volume ratios than small volume samples and, thus, would be less rapidly neutralized by atmospheric CO_2 absorption. As noted earlier, all pH measurements were made immediately upon collection (usually within 1 day after precipitation).

Thus, we hypothesize that the high drainage pH values observed after heavy precipitation (even late in the test) resulted in part from water percolating through the pile. This hypothesis is consistent with the existence of $\text{Ca}(\text{OH})_2$ in the pile interior and its absence on the surface of the aged pile, and with the relatively high permeabilities of the piles. Permeability will be discussed later in this report.

It would appear from these results that the run-off water from landfilled Coolside waste may need to be partially neutralized before

discharge. It is possible that this can be achieved by neutralization with atmospheric CO₂ through aeration of the run-off water. However, dilution effects or partial neutralization from other materials in the landfill may make this unnecessary.

The State of Ohio requires that the concentrations of 15 trace elements (As, Ba, Cd, Cr, Pb, Hg, Se, Ag, nitrate (as N), F, Cl, Fe, Cu, Mn and Zn), sulfate and total dissolved solids (TDS) be less than thirty times the corresponding EPA primary and secondary drinking water standards for a waste to be classified as non-toxic. The allowable limits of the Ohio regulations, which are listed in Table 3, were communicated to us by Mr. Dan Harris of Ohio Environmental Protection Agency (3). Mr. Harris indicated that these regulations are applicable to run-off water from landfilled waste.

In all cases where the 15 trace elements were determined, their concentrations were lower than the Ohio regulations. However, in several cases, total dissolved solids (TDS) and sulfate exceeded the regulations listed in Table 3. In the case of the drainages from pile 1, TDS and sulfate exceeded the regulations only for the two earliest samples analyzed (6/21 and 7/2/87). In the case of the drainages from pile 2, TDS exceeded the regulation only for one early sample (8/37/87) and sulfate exceeded the regulation for two early (8/27 and 9/1/87) and two middle (10/7 and 10/12/87) samples. The two latter samples represented very small collection volumes (less than 250 mL). Those samples that had high TDS and sulfate concentrations also had high sodium concentrations indicating that Na₂SO₄ is a major component of the early drainage samples.

Similar to pH, the other measured drainage parameters varied widely and not as simple functions of weathering time. Presumably, a significant portion of this variation is also related to the relative amounts of drainage derived from percolation and from simple run-off. Though weathering time was not the only factor affecting drainage

water quality, it clearly had a large effect. This is illustrated below by comparing the earliest and latest high-volume drainage from each pile that was analyzed for a variety of parameters.

Date, 1987	Pile 1		Pile 2	
	8/22	12/21	8/24	11/29
pH	12.2	11.9	11.9	11.9
TDS, mg/L	4540	1425	9564	4302
Na, mg/L	656	93	1746	1012
sulfate, mg/L	2307	563	5818	2826
nitrate (as N), mg/L	8	<1	57	1
F, mg/L	16	<1	8	<1
Cl, mg/L	33	2	56	7
Ca, mg/L	263	638	198	193
hydroxide (reported as CaCO ₃ equivalent), mg/L	1100	1193	100	103
carbonate (reported as CaCO ₃ equivalent), mg/L	600	106	600	356

In general, higher sulfate concentrations and TDS were observed in corresponding drainage samples from pile 2 than those from pile 1, as shown in Tables 1 and 2. This may relate to the relative ages of the piles at any point (the test with pile 1 was started one month earlier) or to permeability differences which are discussed later.

Several of the TDS and sulfate concentrations observed in the drainages exceeded Ohio regulations. As noted earlier for pH, dilution from precipitation in other areas of the landfill may reduce these concentrations to acceptable levels. The experimental design was such that essentially all the water analyzed made intimate contact with the Coolside waste. Dilution from precipitation not falling on the waste was minimized. Therefore, it would appear that the water quality measurements reported here are worst case values.

High TDS and SO₄⁻² concentrations were also reported in leachates from Dual Alkali FGD wastes (4,5) and from western coal fly ash (6). Dual Alkali FGD wastes and western coal fly ash are disposed routinely by landfilling. TDS and sulfate concentrations in the leachates from both wastes decreased with time in the landfill (4,6).

PERMEABILITY COEFFICIENTS OF COOLSIDE WASTE PILES

At the completion of the weathering tests, a square prism-shaped sample was cut from the center of each waste pile for permeability measurements. Permeability coefficients were measured according to Earth Method 1110-02-1906 (7) with the apparatus described in Part 1 of this report. Permeability coefficients were determined to be 5.3×10^{-3} cm/sec and 9.8×10^{-3} cm/sec for the samples from pile 1 and pile 2, respectively. These values are considerably higher than the permeability coefficients obtained for Coolside waste in the laboratory tests, which are reported in Part 1 of this report.

In the laboratory tests, permeability coefficients were also measured according to EM 1110-02-1906, but two different compaction procedures (ASTM D-698 and C-192) were used to prepare the Coolside waste samples. Compaction is more intense in ASTM D-698 than in ASTM C-192, and permeability coefficients were lower with the former method. For example, with ASTM D-698, coefficients were 1.2×10^{-5} cm/sec (uncured) and 1.8×10^{-6} cm/sec (after 32 days curing) with the Coolside waste produced with the NaOH additive that contained 30 wt % moisture (dry basis). The milder compaction method (ASTM C-192) resulted in higher permeability coefficients (ca. 8×10^{-4} for cured samples).

It was estimated that about 5 psig was used to prepare waste pile 1 and even less pressure was used to prepare pile 2. Compared with pile 1, pile 2 had a higher permeability coefficient and generally higher leachate concentrations in the run-off water.

Thus, it appears that the high permeability coefficients observed for the final samples from the waste piles resulted largely from the very mild compaction procedures used on the piles (see Experimental section). The resulting high permeabilities permitted precipitation to thoroughly percolate through the piles instead of running off the pile surfaces.

It appears that sufficient compaction is essential to produce low permeability coefficients for Coolside waste. Waste disposed in landfills is typically subjected to numerous passes of earth-moving equipment. Since bulldozers typically exert pressures ranging from about 11.6 psi to about 19.0 psi, it appears likely that in a real landfill, Coolside waste would be compacted better and would have lower permeability coefficients than in this test.

COMPOSITION OF COOLSIDE WASTE AFTER WEATHERING

After the weathering tests were completed and the permeability samples were taken, each waste pile was broken up, passed through a 1/8-inch screen, mixed and sampled for analysis. The final masses of the two piles, including all losses from weathering, sampling and handling were 90.6 lbs for pile 1 and 47.6 lbs for pile 2. The analyses of the feed and blended final sample from both piles are shown in Table 4. The Ca(OH)_2 content of these samples was discussed earlier. The analyses show that the net results of weathering on the composition of each total pile were increases in carbonate and sulfate sulfur contents and decreases in the sulfite sulfur, total sulfur, calcium and, particularly, sodium contents. The extremely low sodium contents of the final samples lend strong support to the hypothesis that at least some of the precipitation thoroughly percolated through the piles; i.e., at least some of the drainage water was not simple run-off. The analyses shown in Table 4 are consistent with the conclusions drawn earlier that as the pile weathered, the hydroxides reacted with atmospheric CO_2 to form carbonates, the sulfites oxidized to sulfates and much of the sulfate and sodium were leached. Sodium concentrations in the bulk waste piles were reduced by 94.8% (pile 1) and 87.8% (pile 2) over the duration of the tests.

REFERENCES

1. Wu, M. M., "Test Program for Coolside Waste Management", issued to Babcock and Wilcox, June 2, 1987.
2. U.S. Environmental Protection Agency, "Method for Chemical Analyses of Water and Wastes" EPA-600/4-79-020, March 1979.
3. Harris, D. (Ohio EPA), Personal communication with author, April 27, 1988.
4. Fox, L. K., Gibson, E. D., Pierson, J. F. and Brown, D. M., "Landfill Disposal of Limestone Dual Alkali Flue Gas Desulfurization Waste", EPRI Final Report CS-2559, September 1982.
5. Knight, R. G., Rothfuss, E. H. and Yard, K. D., "FGD Sludge Disposal Manual Second Edition", EPRI Final Report CS-1515, September 1980.
6. Groenewold, G. H., Hassett, D. J., Koov, R. D. and Manz, O. E., "Disposal of Western Fly Ash in the Northern Great Plains", Nat. Res. Soc. Symp. Proc., Material Research Society, 43, 191-204, 1985.
7. Laboratory Soil Testing, Engineering Manual, Earth Method 1110-02-1906, Appendix VII, Department of the Army, Office of the Chief of Engineers, 1976.

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TABLE 1

ANALYSES OF RAIN WATER RUN-OFF FROM COOLSIDE WASTE PILE 1

Sample No. ROW	1-1	1-2	1-3	1-4	1-5	-	1-6
Date, 1987	6/21	6/23	6/30	7/1	7/2	8/3(a)	8/5
H ₂ O Volume, L	-	-	-	-	-	-	3.6
pH	12.6	12.6	12.7	12.7	12.8	-	12.4
Hydroxide as CaCO ₃ , mg/L	4775	-	-	-	6405	-	3390
Carbonate as CaCO ₃ , mg/L	610	-	-	-	1630	-	680
Bicarbonate as CaCO ₃ , mg/L	-	-	-	-	-	-	-
Total Suspended Solids, mg/L	95	-	-	-	357	-	33
Total Dissolved Solids, mg/L	35478	-	-	-	42130	-	11820
Turbidity, Ntu	3.2	-	-	-	130	-	2.5
Calcium, mg/L	765	-	-	-	360	-	235.31
Sodium, mg/L	9750	-	-	-	11450	-	3540
Arsenic, mg/L	0.0116	-	-	-	0.0342	-	0.0058
Barium, mg/L	0.186	-	-	-	0.103	-	0.086
Cadmium, mg/L	0.0025	-	-	-	0.0136	-	0.0032
Chromium, mg/L	0.611	-	-	-	0.399	-	0.107
Lead, mg/L	0.00938	-	-	-	0.0153	-	0.00238
Mercury, mg/L	0.0041	-	-	-	0.0008	-	<0.0005
Silver, mg/L	0.0924	-	-	-	0.120	-	0.025
Selenium, mg/L	<0.700	-	-	-	<1.0	-	0.0787
Nitrate (as N), mg/L	10.00	-	-	-	6.00	-	40.0
Fluoride, mg/L	<0.01	-	-	-	-	-	8.00
Chloride, mg/L	52.0	-	-	-	24.0	-	142
Sulfate, mg/L	18140	-	-	-	26279	-	6343
Iron, mg/L	0.118	-	-	-	0.0253	-	0.0268
Zinc, mg/L	0.366	-	-	-	0.0538	-	<0.020
Manganese, mg/L	<0.020	-	-	-	0.020	-	0.00433
Copper, mg/L	0.0362	-	-	-	0.0431	-	0.0284
Magnesium, mg/L	0.281	-	-	-	0.0499	-	0.0414
Nitrite (as N), mg/L	29.00	-	-	-	<1.0	-	6.0

(a) Carboy tipped over in high winds; no sample collected.

TABLE 1 (Continued)

ANALYSES OF RAIN WATER RUN-OFF FROM COOLSIDE WASTE PILE 1

Sample No. ROW	1-7	1-8	1-9	1-10	1-11	1-12	1-13
Date, 1987	8/10	8/18	8/24(c)	8/27	8/28	8/31	9/1
H ₂ O Volume, L	16.0	0.45	26.5(b)	6.0	9.0	6.0	2.0
pH	11.8	9.9	12.2	12.1	12.2	12.2	12.2
Hydroxide as CaCO ₃ , mg/L	580	0	1100	1356	-	-	1610
Carbonate as CaCO ₃ , mg/L	200.0	2450	600.0	170.0	-	-	126.0
Bicarbonate as CaCO ₃ , mg/L	-	1223	-	-	-	-	-
Total Suspended Solids, mg/L	44	104	45	63	-	-	16
Total Dissolved Solids, mg/L	3332	12040	4540	4790	-	-	4046
Turbidity, Ntu	34	46	10	2.0	-	-	0.5
Calcium, mg/L	210.20	7.62	262.6	252	-	-	296
Sodium, mg/L	640	2242	656	1240	-	-	981
Arsenic, mg/L	0.00353	0.0118	<0.010	-	-	-	<0.001
Barium, mg/L	0.0318	<0.025	0.0699	-	-	-	0.109
Cadmium, mg/L	<0.001	0.00196	<0.001	-	-	-	<0.001
Chromium, mg/L	0.0234	0.163	0.030	-	-	-	0.0379
Lead, mg/L	0.00313	0.00325	0.00131	-	-	-	0.00238
Mercury, mg/L	<0.0001	<0.0005	<0.0001	-	-	-	<0.0005
Silver, mg/L	0.0356	0.0665	0.0492	-	-	-	<0.025
Selenium, mg/L	0.0318	<0.250	<0.100	-	-	-	0.017
Nitrate (as N), mg/L	6.00	3.00	8.00	11.00	-	-	8.00
Fluoride, mg/L	25.00	8.00	16.00	16.00	-	-	8.00
Chloride, mg/L	40.00	17.00	33.0	18.00	-	-	4.00
Sulfate, mg/L	2209	5157	2307	2081	-	-	1460
Iron, mg/L	0.0485	0.270	0.0304	-	-	-	<0.025
Zinc, mg/L	0.0775	<0.100	<0.020	-	-	-	0.193
Manganese, mg/L	0.00202	0.0145	0.00471	-	-	-	0.00281
Copper, mg/L	0.0523	0.0461	<0.020	-	-	-	0.140
Magnesium, mg/L	0.0378	0.153	<0.002	-	-	-	<0.040
Nitrite (as N), mg/l.	2.00	8.00	3.00	2.00	-	-	1.00

(b) Drainage volume exceeded capacity of container.

(c) Continuous rain from 8/22 to 8/24; sampled only on 8/24.

TABLE 1 (Continued)

ANALYSES OF RAIN WATER RUN-OFF FROM COOLSIDE WASTE PILE 1

Sample No. ROW	1-14	1-15	1-16	1-17	1-18	1-19	1-20
Date, 1987	9/8	9/9	9/18	9/21	9/22	9/30	10/1
H ₂ O Volume, L	26.5(b)	0.60	4.0	0.20	2.0	2.8	0.1
pH	12.0	12.0	12.1	7.8	12.0	12.0	9.4
Hydroxide as CaCO ₃ , mg/L	1159	-	1104	-	1253	1010	-
Carbonate as CaCO ₃ , mg/L	94.00	-	204.0	-	-	150.0	-
Bicarbonate as CaCO ₃ , mg/L	-	-	-	-	-	-	-
Total Suspended Solids, mg/L	28	-	90	-	44	63	-
Total Dissolved Solids, mg/L	2716	-	2784	-	2666	2368	-
Turbidity, Ntu	12	-	46	-	11	30	-
Calcium, mg/L	407.359	-	913	-	891	572.78	-
Sodium, mg/L	475.867	-	257	-	227	224.57	-
Arsenic, mg/L	<0.001	-	-	-	-	<0.001	-
Barium, mg/L	0.130	-	-	-	-	0.164	-
Cadmium, mg/L	<0.001	-	-	-	-	<0.001	-
Chromium, mg/L	<0.005	-	-	-	-	0.0128	-
Lead, mg/L	0.00203	-	-	-	-	0.00320	-
Mercury, mg/L	-	-	-	-	-	-	-
Silver, mg/L	<0.025	-	-	-	-	<0.025	-
Selenium, mg/L	0.0075	-	-	-	-	0.00522	-
Nitrate (as N), mg/L	3.00	-	3.00	-	<1.0	3.00	-
Fluoride, mg/L	18.00	-	<0.10	-	<0.10	<0.10	-
Chloride, mg/L	1.0	-	7.0	-	1.0	2.0	-
Sulfate, mg/L	950	-	964	-	888	839	-
Iron, mg/L	<0.025	-	-	-	-	<0.025	-
Zinc, mg/L	<0.020	-	-	-	-	0.0656	-
Manganese, mg/L	0.022	-	-	-	-	0.0226	-
Copper, mg/L	<0.020	-	-	-	-	0.0229	-
Magnesium, mg/L	0.177	-	-	-	-	0.100	-
Nitrite (as N), mg/L	1.00	-	3.00	-	-	-	-

(b) Drainage volume exceeded capacity of container.

TABLE 1 (Continued)

ANALYSES OF RAIN WATER RUN-OFF FROM COOLSIDE WASTE PILE 1

Sample No. ROW	1-21	1-22	1-23	1-24	1-25	1-26	1-27
Date, 1987	10/5	10/7	10/12	10/20	10-28	11/9	11/10
H ₂ O Volume, l	0.06	0.13	0.14	0.04	0.25	0.017	0.020
pH	7.9	7.8	7.6	7.8	7.9	7.8	7.9
Hydroxide as CaCO ₃ , mg/L	-	0	0	-	0	-	-
Carbonate as CaCO ₃ , mg/L	-	0	51.20	-	0	-	-
Ricarbonate as CaCO ₃ , mg/L	-	85	71	-	71	-	-
Total Suspended Solids, mg/L	-	30	40	-	11	-	-
Total Dissolved Solids, mg/L	-	1192	730	-	246	-	-
Turbidity, Ntu	-	1.5	15	-	3.6	-	-
Calcium, mg/L	-	299	176	-	60.0	-	-
Sodium, mg/L	-	25.6	11.8	-	2.82	-	-
Arsenic, mg/L	-	-	-	-	-	-	-
Barium, mg/L	-	-	-	-	-	-	-
Cadmium, mg/L	-	-	-	-	-	-	-
Chromium, mg/L	-	-	-	-	-	-	-
Lead, mg/L	-	-	-	-	-	-	-
Mercury, mg/L	-	-	-	-	-	-	-
Silver, mg/L	-	-	-	-	-	-	-
Selenium, mg/L	-	-	-	-	-	-	-
Nitrate (as N), mg/L	-	2.00	3.00	-	1.00	-	-
Fluoride, mg/L	-	<0.10	<1.00	-	<1	-	-
Chloride, mg/L	-	1.0	4.0	-	2.0	-	-
Sulfate, mg/L	-	724	413	-	101	-	-
Iron, mg/L	-	-	-	-	-	-	-
Zinc, mg/L	-	-	-	-	-	-	-
Manganese, mg/L	-	-	-	-	-	-	-
Copper, mg/L	-	-	-	-	-	-	-
Magnesium, mg/L	-	-	-	-	-	-	-
Nitrite (as N), mg/L	-	-	-	-	-	-	-

(b) Drainage volume exceeded capacity of container.

TABLE 1 (Continued)

ANALYSES OF RAIN WATER RUN-OFF FROM COOLSIDE WASTE PILE 1

Sample No. ROW	1-28	1-29	1-30	1-31	1-32	1-33	1-34
Date, 1987	11/11	11/12	11/18	11/23	11/24	11/29	12/3
H ₂ O Volume, L	0.012	0.40	0.80	0.80	1.70	26.5(b)	6.0
pH	8.2	8.2	8.0	7.4	10.6	11.6	11.4
Hydroxide as CaCO ₃ , mg/L	-	0	0	-	-	924	-
Carbonate as CaCO ₃ , mg/L	-	0.00	0.00	-	-	72.00	-
Bicarbonate as CaCO ₃ , mg/L	-	60.00	36	-	-	0	-
Total Suspended Solids, mg/L	-	6.00	28	-	-	9	-
Total Dissolved Solids, mg/L	-	158.00	580	-	-	1946	-
Turbidity, Ntu	-	5.00	4.4	-	-	5.0	-
Calcium, mg/L	-	39.1	138.556	-	-	488	-
Sodium, mg/L	-	5.06	6.084	-	-	158	-
Arsenic, mg/L	-	-	0.00147	-	-	-	-
Barium, mg/L	-	-	0.038	-	-	-	-
Cadmium, mg/L	-	-	0.00122	-	-	-	-
Chromium, mg/L	-	-	<0.005	-	-	-	-
Lead, mg/L	-	-	0.00154	-	-	-	-
Mercury, mg/L	-	-	-	-	-	-	-
Silver, mg/L	-	-	<0.025	-	-	-	-
Selenium, mg/L	-	-	<0.001	-	-	-	-
Nitrate (as N), mg/L	-	<1	<1	-	-	2.00	-
Fluoride, mg/L	-	<1	<1	-	-	<1	-
Chloride, mg/L	-	3	2.0	-	-	3.0	-
Sulfate, mg/L	-	51	329	-	-	653	-
Iron, mg/L	-	<0.30	<0.025	-	-	-	-
Zinc, mg/L	-	-	<0.020	-	-	-	-
Manganese, mg/L	-	-	-	-	-	-	-
Copper, mg/L	-	-	<0.020	-	-	-	-
Magnesium, mg/L	-	-	0.887	-	-	-	-
Nitrite (as N), mg/L	-	-	<2	-	-	-	-

(b) Drainage volume exceeded capacity of container.

TABLE 1 (Continued)

ANALYSES OF RAIN WATER RUN-OFF FROM COOLSIDE WASTE PILE 1

Sample No. ROW	1-35	1-36	1-37	1-38	1-39	1-40	1-41
Date, 1987	12/4	12/8	12/10	12/15	12/16	12/21	12/31
H ₂ O Volume, L	13.23	1.0	4.0	4.5	4.0	26.5(b)	26.5(b)
pH	12.1	10.6	11.8	11.7	11.7	11.9	11.9
Hydroxide as CaCO ₃ , mg/L	964	-	569	673	-	1193	-
Carbonate as CaCO ₃ , mg/L	174.0	-	134.0	124.0	-	106.0	-
Bicarbonate as CaCO ₃ , mg/L	0	-	0	0	-	0	-
Total Suspended Solids, mg/L	35	-	69	52	-	12	-
Total Dissolved Solids, mg/L	1926	-	1634	1508	-	1425	-
Turbidity, Ntu	40	-	50	36	-	3.0	-
Calcium, mg/L	542	-	396	404	-	638	-
Sodium, mg/L	145	-	134	97.4	-	93.2	-
Arsenic, mg/L	-	-	-	-	-	-	-
Barium, mg/L	-	-	-	-	-	-	-
Cadmium, mg/L	-	-	-	-	-	-	-
Chromium, mg/L	-	-	-	-	-	-	-
Lead, mg/L	-	-	-	-	-	-	-
Mercury, mg/L	-	-	-	-	-	-	-
Silver, mg/L	-	-	-	-	-	-	-
Selenium, mg/L	-	-	-	-	-	-	-
Nitrate (as N), mg/L	<1	-	2.00	1.00	-	<1	-
Fluoride, mg/L	<1	-	-	<1	-	<1	-
Chloride, mg/L	3.0	-	2.0	1.0	-	2.0	-
Sulfate, mg/L	588	-	619	615	-	563	-
Iron, mg/L	-	-	<0.30	-	-	-	-
Zinc, mg/L	-	-	-	-	-	-	-
Manganese, mg/L	-	-	-	-	-	-	-
Copper, mg/L	-	-	-	-	-	-	-
Magnesium, mg/L	-	-	-	-	-	-	-
Nitrite (as N), mg/L	-	-	-	-	-	-	-

(b) Drainage volume exceeded capacity of container.

TABLE 2

ANALYSES OF RAIN WATER RUN-OFF FROM COOLSIDE WASTE PILE 2

Sample No. ROW Date, 1987	2-1	2-2	2-3	2-4	2-5	2-6
H ₂ O Volume, L	8/3	8/5	8/10	8/18	8/24(c)	8/27
pH	0.95	5.0	4.4	2.5	18.9(b)	4.0
Hydroxide as CaCO ₃ , mg/L	8.6	11.6	12.0	11.5	11.9	12.3
Carbonate as CaCO ₃ , mg/L	0	289	940	0	100	1433
Bicarbonate as CaCO ₃ , mg/L	0.00	156.0	190.0	579.0	600.0	498.0
Total Suspended Solids, mg/L	44	-	-	26	-	-
Turbidity, Ntu	602	41	<1	154	92	64
Calcium, mg/L	1.0	2548	3194	5098	9564	24640
Sodium, mg/L	115.19	48	5.2	120	15	2.5
Arsenic, mg/L	17.70	145.21	376.60	43.94	197.85	176
Barium, mg/L	0.00641	640	652	1860	1746	6116
Cadmium, mg/L	0.00623	0.00237	0.00127	<0.002	<0.010	-
Chromium, mg/L	<0.00105	0.0236	0.0886	0.026	0.0158	-
Lead, mg/L	0.00278	<0.001	0.00163	0.00107	0.00751	-
Mercury, mg/L	0.00502	0.0721	0.0529	0.144	0.0609	-
Lithium, mg/L	<0.0001	0.00146	0.00277	0.00694	0.00119	-
Silver, mg/L	0.0754	<0.0001	<0.0001	<0.0005	<0.0005	-
Selenium, mg/L	0.0125	0.0568	0.0447	0.0543	0.0516	-
Nitrate (as N), mg/L	1.00	0.00881	0.0338	<0.200	<0.200	-
Fluoride, mg/L	8.00	8.00	5.00	33.00	57.00	45.00
Chloride, mg/L	6.0	11.00	14.00	10.00	8.00	7.00
Sulfate, mg/L	346	55.5	44.0	10.0	56.0	104
Iron, mg/L	<0.025	1391	2076	3761	5818	12109
Zinc, mg/L	<0.020	0.0531	0.0529	<0.125	0.0725	-
Manganese, mg/L	0.00315	<0.020	0.0777	<0.100	<0.020	-
Copper, mg/L	0.0256	0.00224	0.00186	0.0109	0.00782	-
Magnesium, mg/L	2.479	0.0313	0.0703	0.0624	<0.020	-
Nitrite (as N), mg/L	2.00	0.0713	0.0540	0.0213	0.0106	-
		1.00	2.00	4.00	2.00	11.00

(c) Continuous rain from 8/22 to 8/24; sampled only on 8/24.

TABLE 2 (Continued)

ANALYSES OF RAIN WATER RUN-OFF FROM COOLSIDE WASTE PILE 2

Sample No. ROW	2-7	2-8	2-9	2-10	2-11	2-12	2-13
Date, 1987	8/28	8/31	9/1	9/8	9/9	9/18	9/21
H ₂ O Volume, L	8.6	6.0	2.0	18.9(b)	0.5	3.0	0.21
pH	12.2	12.3	12.1	12.2	12.4	11.6	9.4
Hydroxide as CaCO ₃ , mg/L	-	-	739	1632	-	0	-
Carbonate as CaCO ₃ , mg/L	-	-	480.0	180.0	-	174.0	-
Bicarbonate as CaCO ₃ , mg/L	-	-	-	-	-	25	-
Total Suspended Solids, mg/L	-	-	29	72	-	11	-
Total Dissolved Solids, mg/L	-	-	13736	7214	-	4942	-
Turbidity, Ntu	-	-	0.8	20	-	6.0	-
Calcium, mg/L	-	-	86.10	325.929	-	221	-
Sodium, mg/L	-	-	4224	2181	-	1280	-
Arsenic, mg/L	-	-	0.00872	0.00225	-	-	-
Barium, mg/L	-	-	0.0245	0.0753	-	-	-
Cadmium, mg/L	-	-	0.00150	0.00141	-	-	-
Chromium, mg/L	-	-	0.102	0.0516	-	-	-
Lead, mg/L	-	-	0.00231	0.00279	-	-	-
Mercury, mg/L	-	-	<0.0005	-	-	-	-
Lithium, mg/L	-	-	1.876	-	-	-	-
Silver, mg/L	-	-	<0.025	<0.025	-	-	-
Selenium, mg/L	-	-	0.102	0.0334	-	-	-
Nitrate (as N), mg/L	-	-	42.00	12.00	-	12.00	-
Fluoride, mg/L	-	-	8.00	17.00	-	<0.10	-
Chloride, mg/L	-	-	24.0	10.0	-	9.0	-
Sulfate, mg/L	-	-	7810	3662	-	2804	-
Iron, mg/L	-	-	<0.025	<0.025	-	-	-
Zinc, mg/L	-	-	0.167	<0.020	-	-	-
Manganese, mg/L	-	-	0.00716	<0.020	-	-	-
Copper, mg/L	-	-	0.189	<0.020	-	-	-
Magnesium, mg/L	-	-	<0.040	<0.057	-	-	-
Nitrite (as N), mg/L	-	-	7.00	4.00	-	3.00	-

(b) Drainage volume exceeded capacity of container.

TABLE 2 (Continued)

ANALYSES OF RAIN WATER RUN-OFF FROM COOLSIDE WASTE PILE 2

Sample No. ROW	2-14	2-15	2-16	2-17	2-18	2-19	2-20
Date, 1987	9/22	9/25	9/30	10/1	10/5	10/7	10/8
H ₂ O Volume, L	2.0	0.11	2.0	0.075	0.090	0.230	0.028
pH	12.1	8.4	9.9	9.7	12.1	12.2	9.0
Hydroxide as CaCO ₃ , mg/L	1067	-	0	-	-	1084	-
Carbonate as CaCO ₃ , mg/L	-	-	39.00	-	-	394.0	-
Bicarbonate as CaCO ₃ , mg/L	-	-	49	-	-	-	-
Total Suspended Solids, mg/L	171	-	21	-	-	150	-
Total Dissolved Solids, mg/L	8726	-	2654	-	-	13428	-
Turbidity, Ntu	60	-	14	-	-	40	-
Calcium, mg/L	289	-	129.415	-	-	158	-
Sodium, mg/L	2425	-	729.956	-	-	4188	-
Arsenic, mg/L	-	-	0.00289	-	-	-	-
Barium, mg/L	-	-	0.0158	-	-	-	-
Cadmium, mg/L	-	-	<0.001	-	-	-	-
Chromium, mg/L	-	-	0.0057	-	-	-	-
Lead, mg/L	-	-	0.00204	-	-	-	-
Mercury, mg/L	-	-	-	-	-	-	-
Lithium, mg/L	-	-	-	-	-	-	-
Silver, mg/L	-	-	-	-	-	-	-
Selenium, mg/L	-	-	<0.025	-	-	-	-
Nitrate (as N), mg/L	<1	-	0.0123	-	-	-	-
Fluoride, mg/L	<0.10	-	5.00	-	-	24.00	-
Chloride, mg/L	15.0	-	<0.10	-	-	<0.10	-
Sulfate, mg/L	4790	-	3.0	-	-	25.0	-
Iron, mg/L	-	-	1703	-	-	8079	-
Zinc, mg/L	-	-	<0.025	-	-	-	-
Manganese, mg/L	-	-	0.0587	-	-	-	-
Copper, mg/L	-	-	0.022	-	-	-	-
Magnesium, mg/L	-	-	<0.020	-	-	-	-
Nitrite (as N), mg/L	-	-	0.611	-	-	-	-
	-	-	-	-	-	-	-

TABLE 2 (Continued)

ANALYSES OF RAIN WATER RUN-OFF FROM COOLSIDE WASTE PILE 2

Sample No. ROW	2-21	2-22	2-23	2-24	2-25	2-26	2-27
Date, 1987	10/12	10/28	11/9	11/10	11/11	11/12	11/13
H ₂ O Volume, L	0.10	0.03	0.075	0.005	0.017	0.015	0.012
pH	11.6	8.0	8.3	8.1	8.2	8.2	8.0
Hydroxide as CaCO ₃ , mg/L	41	-	-	-	-	-	-
Carbonate as CaCO ₃ , mg/L	1446	-	-	-	-	-	-
Bicarbonate as CaCO ₃ , mg/L	0	-	-	-	-	-	-
Total Suspended Solids, mg/L	NES(d)	-	-	-	-	-	-
Total Dissolved Solids, mg/L	NES(d)	-	-	-	-	-	-
Turbidity, Ntu	35	-	-	-	-	-	-
Calcium, mg/L	31.0	-	-	-	-	-	-
Sodium, mg/L	4420	-	-	-	-	-	-
Arsenic, mg/L	-	-	-	-	-	-	-
Barium, mg/L	-	-	-	-	-	-	-
Cadmium, mg/L	-	-	-	-	-	-	-
Chromium, mg/L	-	-	-	-	-	-	-
Lead, mg/L	-	-	-	-	-	-	-
Mercury, mg/L	-	-	-	-	-	-	-
Lithium, mg/L	-	-	-	-	-	-	-
Silver, mg/L	-	-	-	-	-	-	-
Selenium, mg/L	-	-	-	-	-	-	-
Nitrate (as N), mg/L	15.00	-	-	-	-	-	-
Fluoride, mg/L	<1.0	-	-	-	-	-	-
Chloride, mg/L	25.0	-	-	-	-	-	-
Sulfate, mg/L	8378	-	-	-	-	-	-
Iron, mg/L	-	-	-	-	-	-	-
Zinc, mg/L	-	-	-	-	-	-	-
Manganese, mg/L	-	-	-	-	-	-	-
Copper, mg/L	-	-	-	-	-	-	-
Magnesium, mg/L	-	-	-	-	-	-	-
Nitrite (as N), mg/L	-	-	-	-	-	-	-

(d) Not enough sample.

TABLE 2 (Continued)

ANALYSES OF RAIN WATER RUN-OFF FROM COOLSIDE WASTE PILE 2

Sample No. ROW	2-28	2-29	2-30	2-31	2-32	2-33	2-34
Date, 1987	11/18	11/23	11/24	11/29	12/3	12/4	12/8
H ₂ O Volume, L	1.25	0.090	1.45	18.9(b)	2.0	9.45	2.0
pH	11.6	8.4	10.8	11.9	10.0	11.5	11.2
Hydroxide as CaCO ₃ , mg/L	121	-	156	103	-	116	-
Carbonate as CaCO ₃ , mg/L	178.0	-	128.0	356.0	-	196.0	-
Bicarbonate as CaCO ₃ , mg/L	0	-	0	0	-	0	-
Total Suspended Solids, mg/L	84	-	15	159	-	30	-
Total Dissolved Solids, mg/L	8056	-	1806	4302	-	2328	-
Turbidity, Ntu	6.0	-	6.0	114	-	19	-
Calcium, mg/L	226.329	-	49.9	193	-	68.4	-
Sodium, mg/L	2217.716	-	449	1012	-	750	-
Arsenic, mg/L	0.00217	-	-	-	-	-	-
Barium, mg/L	0.268	-	-	-	-	-	-
Cadmium, mg/L	<0.001	-	-	-	-	-	-
Chromium, mg/L	0.0328	-	-	-	-	-	-
Lead, mg/L	0.00306	-	-	-	-	-	-
Mercury, mg/L	-	-	-	-	-	-	-
Lithium, mg/L	-	-	-	-	-	-	-
Silver, mg/L	0.025	-	-	-	-	-	-
Selenium, mg/L	0.0405	-	-	-	-	-	-
Nitrate (as N), mg/L	52.00	-	1.00	1.00	-	2.00	-
Fluoride, mg/L	<1	-	<1	<1	-	<1	-
Chloride, mg/L	12.0	-	3.0	7.0	-	6.0	-
Sulfate, mg/L	5850	-	733	2826	-	1488	-
Iron, mg/L	0.025	-	-	-	-	-	-
Zinc, mg/L	0.020	-	-	-	-	-	-
Manganese, mg/L	0.020	-	-	-	-	-	-
Copper, mg/L	0.0211	-	-	-	-	-	-
Magnesium, mg/L	0.147	-	-	-	-	-	-
Nitrite (as N), mg/L	4.00	-	-	-	-	-	-

(b) Drainage volume exceeded capacity of container.

TABLE 2 (Continued)

ANALYSES OF RAIN WATER RUN-OFF FROM COOLSIDE WASTE PILE 2

Sample No., ROW	2-35	2-36	2-37	2-38	2-39	2-40
Date, 1987	12/10	12/14	12/15	12/16	12/21	12/31
H ₂ O Volume, L	5.0	0.050	5.0	3.6	18.9(b)	18.9(b)
pH	11.6	8.6	11.7	11.2	11.2	11.6
Hydroxide as CaCO ₃ , mg/L	138	-	333	-	-	-
Carbonate as CaCO ₃ , mg/L	638.0	-	342.0	-	-	-
Bicarbonate as CaCO ₃ , mg/L	0	-	0	-	-	-
Total Suspended Solids, mg/L	170	-	60	-	-	-
Total Dissolved Solids, mg/L	4716	-	3500	-	-	-
Turbidity, Ntu	120	-	40	-	-	-
Calcium, mg/L	27.0	-	43.3	-	-	-
Sodium, mg/L	1500	-	1056	-	-	-
Arsenic, mg/L	-	-	-	-	-	-
Barium, mg/L	-	-	-	-	-	-
Cadmium, mg/L	-	-	-	-	-	-
Chromium, mg/L	-	-	-	-	-	-
Lead, mg/L	-	-	-	-	-	-
Mercury, mg/L	-	-	-	-	-	-
Lithium, mg/L	-	-	-	-	-	-
Silver, mg/L	-	-	-	-	-	-
Selenium, mg/L	-	-	-	-	-	-
Nitrate (as N), mg/L	2.00	-	1.00	-	-	-
Fluoride, mg/L	-	-	<1	-	-	-
Chloride, mg/L	9.0	-	6.0	-	-	-
Sulfate, mg/L	2726	-	1783	-	-	-
Iron, mg/L	-	-	-	-	-	-
Zinc, mg/L	-	-	-	-	-	-
Manganese, mg/L	-	-	-	-	-	-
Copper, mg/L	-	-	-	-	-	-
Magnesium, mg/L	-	-	-	-	-	-
Nitrite (as N), mg/L	-	-	-	-	-	-

(b) Drainage volume exceeded capacity of container.

TABLE 3
DISCHARGE WATER QUALITY LIMITS
STATE OF OHIO

<u>Parameter</u>	<u>Concentration, mg/L</u>
Total Dissolved Solids	15,000
Arsenic	1.5
Barium	30
Cadmium	0.3
Chromium	1.5
Lead	1.5
Mercury	0.06
Silver	1.5
Selenium	0.3
Nitrate (as N)	300
Fluoride	42 to 72
Chloride	7,500
Sulfate	7,500
Iron	9
Zinc	150
Manganese	1.5
Copper	30

/ls

TABLE 4
ANALYSES OF WASTE PILES AT COMPLETION OF TESTS

	Pile 1		Pile 2	
	<u>Feed</u>	<u>Final</u>	<u>Feed</u>	<u>Final</u>
<u>Moisture, wt % as det.</u>	26.3	23.00	18.1	15.82
<u>Analysis, wt % dry basis (a)</u>				
Ash (b)	84.9	79.05	84.9	78.98
Carbon	5.9	9.82	5.9	10.38
Hydrogen	1.2	0.85	1.2	0.90
Nitrogen	0.1	0.06	0.1	0.03
Sulfur, total	7.8	4.60	7.8	4.56
Sulfur, sulfate	2.2	3.18	2.2	2.51
Sulfur, sulfite	5.7	1.43	5.7	2.06
Carbonate	7.7	13.25	7.7	14.56
<u>Elemental Analysis, wt % of ash</u>				
Na ₂ O	4.9	0.26	4.9	0.64
CaO	44.5	40.42	44.5	41.34

(a) These values do not total 100% because: 1) the sulfur in the ash is determined twice, 2) the carbon in the carbonate is determined twice, and 3) non-carbonate oxygen is not included.

(b) Ash was determined at 925°C for complete decomposition of carbonate.

/Is

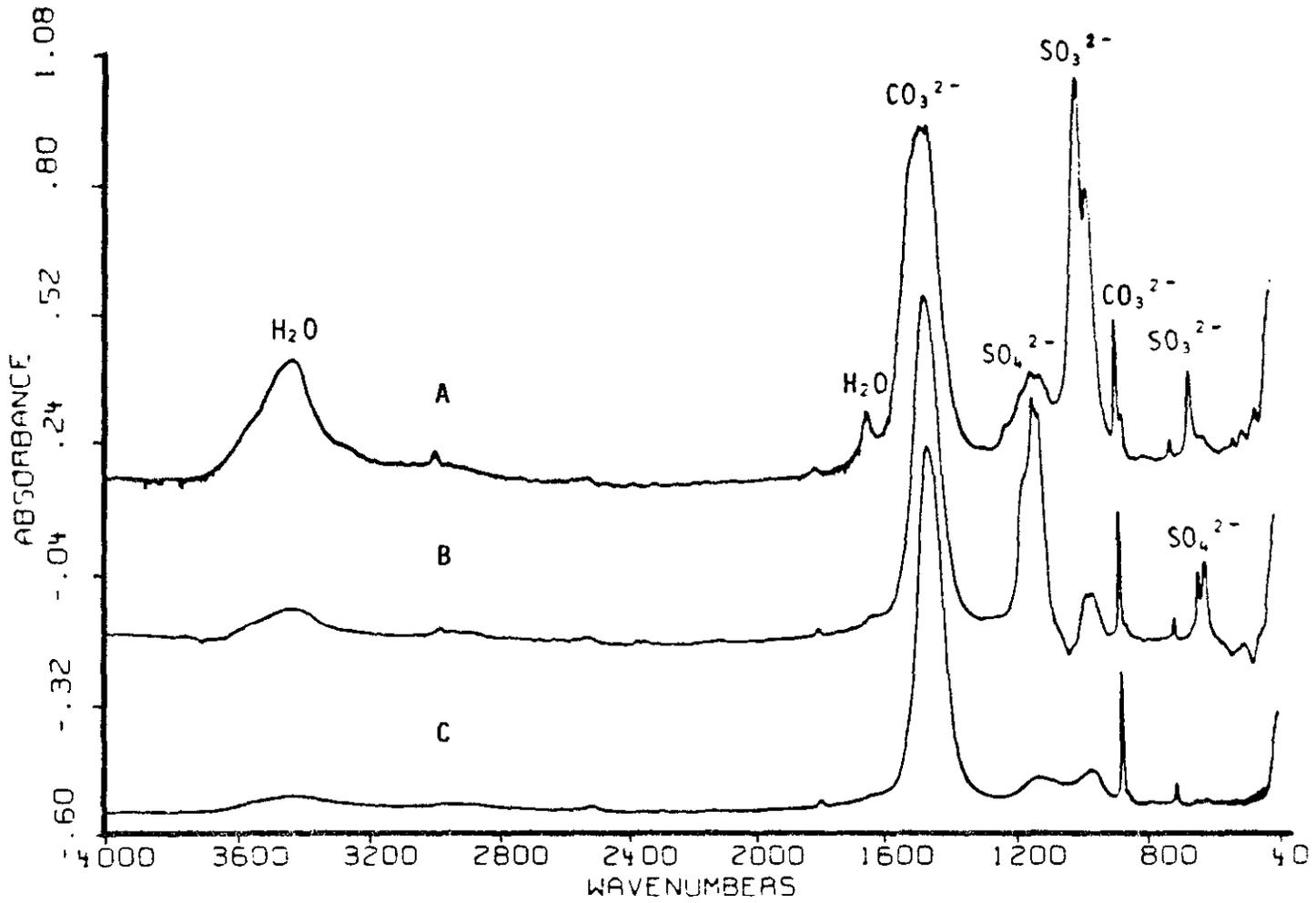


Figure 1. FTIR Spectra of Waste Surface Samples Taken From Pile 1.
 A - on June 24, 1987; B - on June 29, 1987; and
 C - on July 7, 1987.

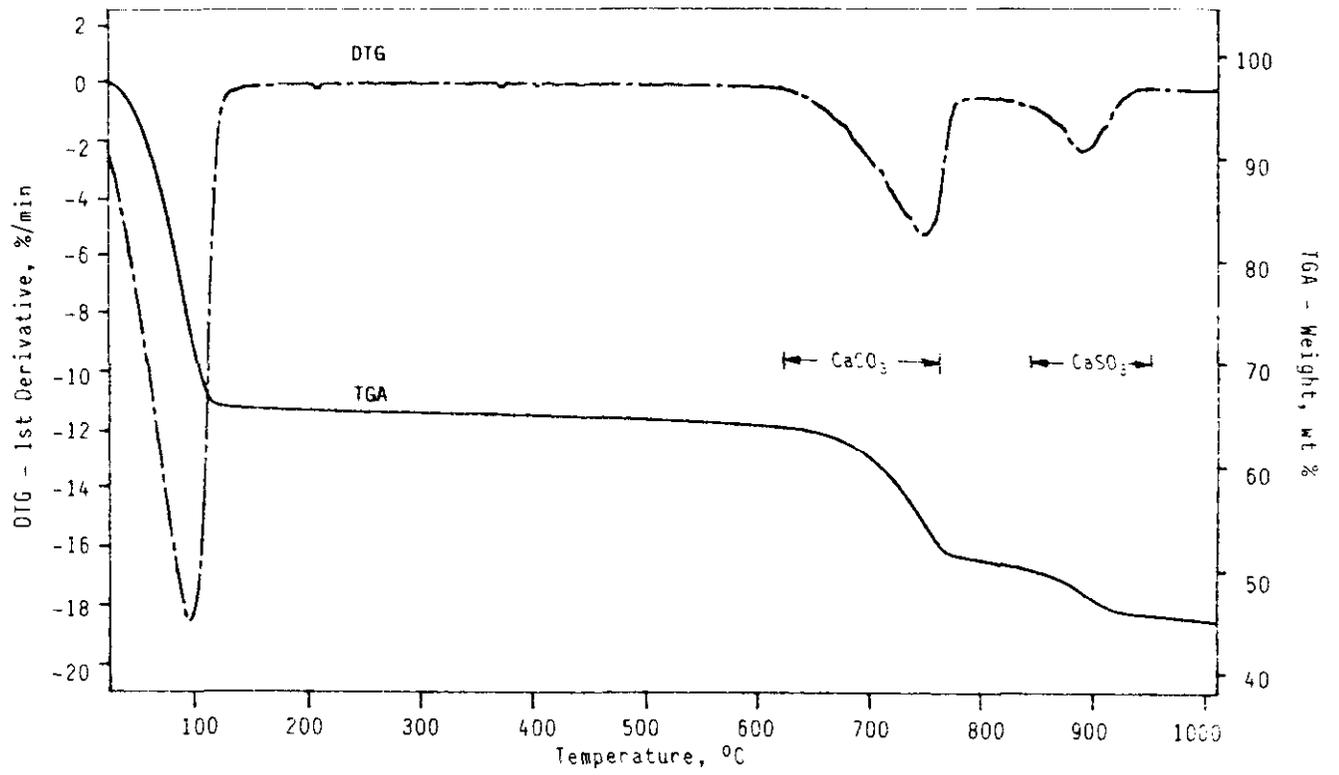


Figure 2. Thermograms of Surface Sample Taken From Waste Pile 1 on June 24, 1987.

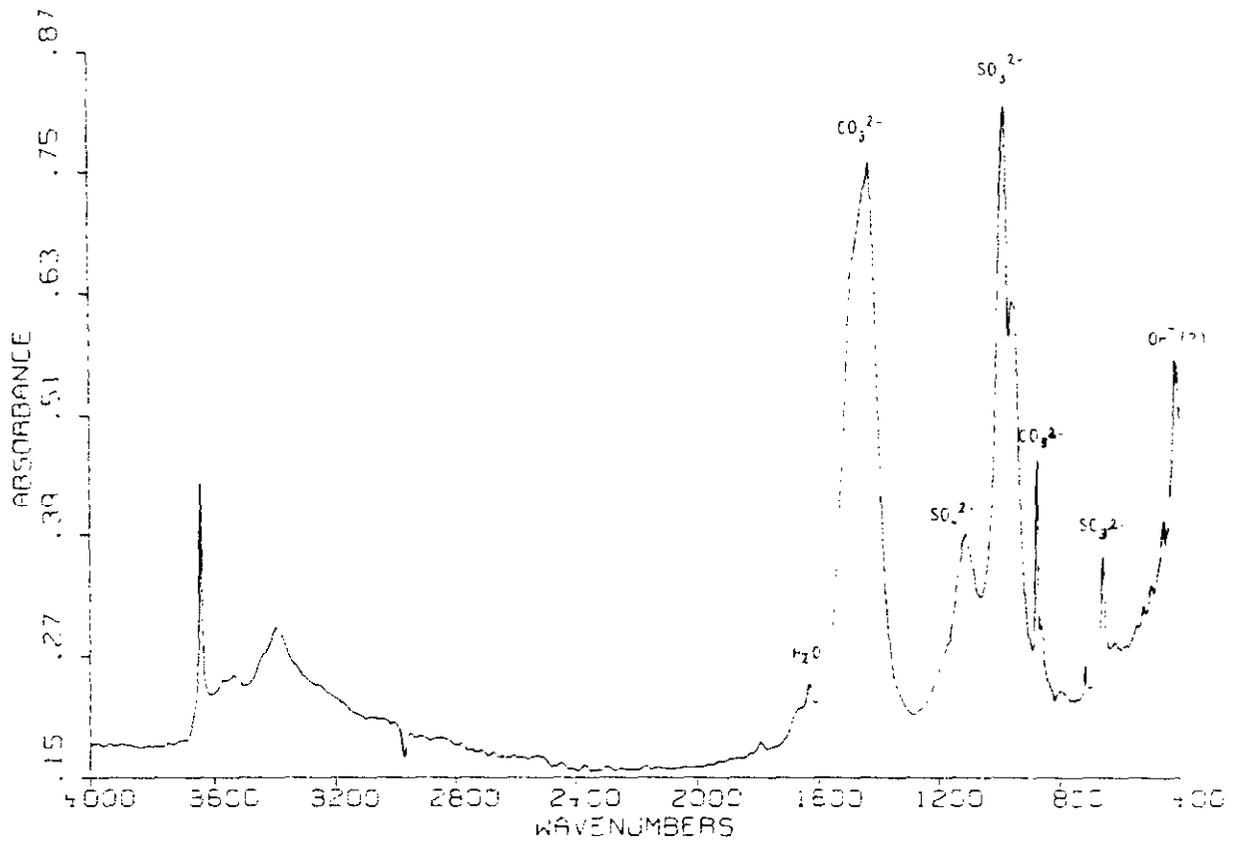


Figure 3. FTIR Spectrum of Waste Pile 1 Sample Taken on July 9, 1987,
From the Fissure.

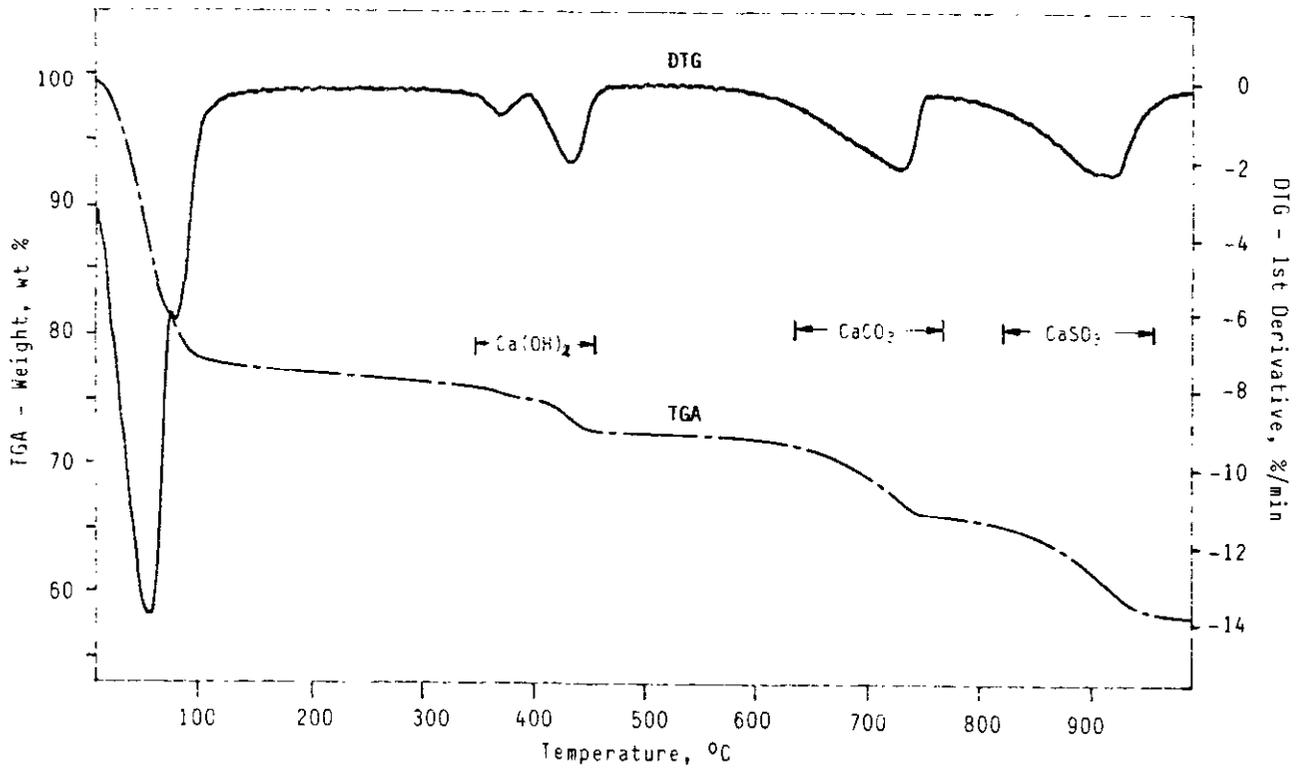


Figure 4. Thermograms of Pile 1 Sample Taken from the Fissure on July 9, 1987.

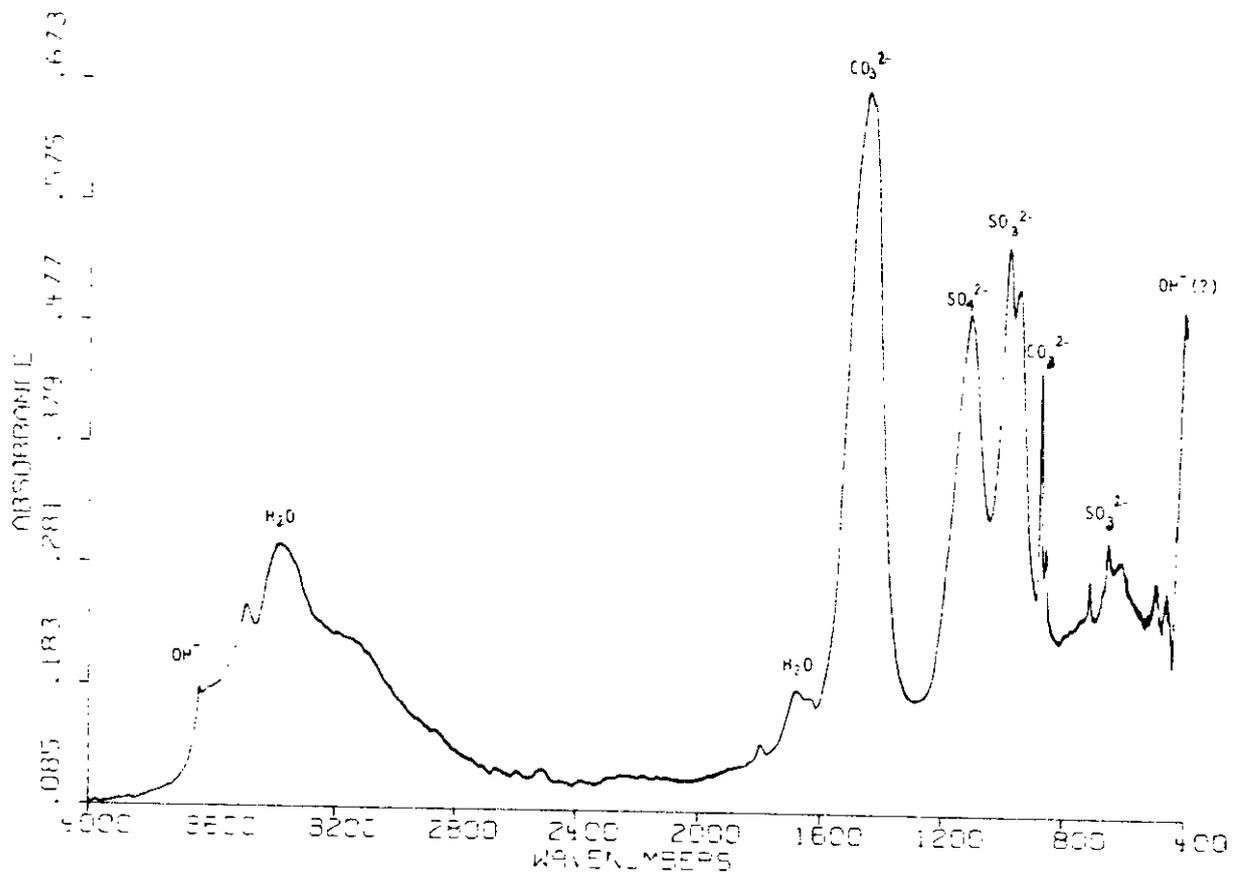


Figure 5. FTIR Spectrum of the Composite Waste Sample From Pile 1.

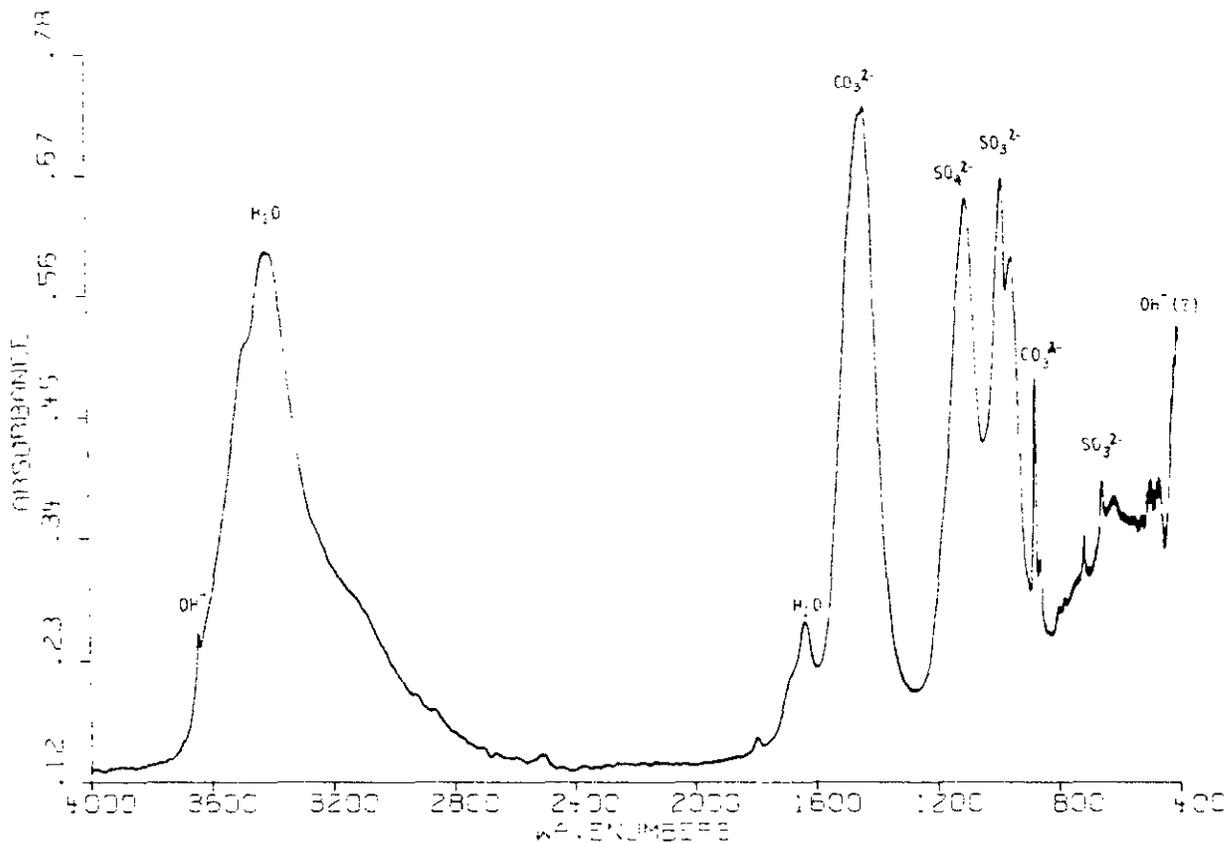


Figure 6. FTIR Spectrum of the Composite Waste Sample From Pile 2.