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Environmental Protection Technology Series

# EVALUATION OF LINER MATERIALS EXPOSED TO LEACHATE
## Second Interim Report

Municipal Environmental Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

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# EVALUATION OF LINER MATERIALS EXPOSED TO LEACHATE

Second Interim Report

by

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Contract 68-03-2134

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## FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

Although the information contained herein is preliminary, it will provide a guide and insight to the effects that happen after limited exposure. This information and data could be useful for design purposes if not taken out of context.

Francis T. Mayo, Director
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Laboratory

ABSTRACT

This report presents available information covering the first year's exposure of liner materials to sanitary landfill leachate. Included in the report are descriptions of the monitoring and dissassembly of the generators to recover the liner specimens, the results of the testing of the exposed liners, and a discussion of the results.

The year's exposure did not result in losses of impermeability in any of the liners. There were losses, however, in the compressive strength of the admix liner materials. There were some losses in the physical properties of some of the polymeric membranes and swelling of most of these membranes. The seams of several lost strength, with the heat-sealed seams holding up best as a group.

Among the polymeric membranes, the crystalline types of polyethylene, polypropylene, and polybutylene sustained the least change during the year's exposure. However, these liners, or films, are prone to puncture and tear and are generally difficult to handle in the field. The thermoplastic membranes, chlorinated polyethylene, chlorosulfonated polyethylene (Hypalon), and polyvinyl chloride, tended to swell the most. The vulcanized rubbery liner materials, e.g. butyl and EPDM, changed little during the exposure period but had the lowest initial seam strength.

The data presented must be considered as preliminary in an ongoing project; it is premature at this point to make estimates of the service life of the various materials or to make relative comparisons among them for use in a given installation without consideration to costs and to the specifics of the installation.

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## ABBREVIATIONS AND SYMBOLS

### ABBREVIATIONS

| | |
|---|---|
| ppi | -- pounds per inch |
| psi | -- pounds per square inch |
| ipm | -- inches per minute |
| PVC | -- Polyvinyl chloride |
| PE | -- Polyethylene |
| CPE | -- Chlorinated polyethylene |
| EPDM | -- Ethylene propylene rubber |
| THF | -- Tetrahydrofuran |
| TVA | -- Total volatile acids |
| COD | -- Chemical oxygen demand |
| SERL | -- Sanitary Engineering Research Laboratory, University of California, Berkeley, CA |
| TCE | -- Trichlorethylene |

### NOMENCLATURE FOR LOCUS OF FAILURE IN ADHESIVE TESTING

| | |
|---|---|
| AD | -- Failure within the adhesive |
| AD-AD | -- Failure between two coats of adhesive |
| AD-LS | -- Failure between adhesive and liner surface |
| BRK | -- Break of liner material outside of the seam |
| DEL | -- Delamination of the liner material |
| LS | -- Failure at liner surface |
| NT | -- No test (too weak to test) |
| OR | -- Failure of the reinforcing fabric |

### FACTORS FOR CONVERTING DATA IN U.S. CUSTOMARY UNITS TO SI METRIC UNITS

| | Factor |
|---|---|
| Mils to millimetres (mm) | $x2.54x10^{-2}$ |
| Pounds per square inch (psi) to megapascals (MPa) | $x6.895x10^{-3}$ |
| Pound per inch (ppi) to kilo Newtons per metre (kN/m) | $x1.751x10^{-1}$ |
| Pound (force) to Newtons | x4.448 |

# ACKNOWLEDGMENTS

The authors wish to thank Robert E. Landreth for his support and guidance in this project. They also wish to acknowledge the guidance of Dr. Clarence Golueke and Stephen Klein of the Sanitary Engineering Research Laboratory, University of California, Berkeley, California, who were responsible for the analyses and characterization of the leachate.

# SECTION I

## INTRODUCTION AND OBJECTIVES

The use of impervious materials to line sanitary landfills appears to be a promising method for intercepting and controlling leachate generated in a fill to prevent it from polluting surface and ground water. Although there is a wide range of materials (Ref. 1-3) that appear to be potentially useful for this purpose, information available regarding the effects of leachate on them is very limited, even for relatively short periods of exposure.

In an effort to learn about and to assess the status of technology regarding liners as it might be applied to the lining of landfills, this project was undertaken with the following objectives:

1. To determine the effects of exposure to leachate from compacted municipal refuse on the physical properties of lining materials (excluding soils and clays) that are believed to be potentially useful for the lining of sanitary landfills.

2. To estimate the effective life of liner materials when exposed to prolonged contact with leachate under conditions comparable to those encountered in a sanitary landfill.

3. To determine the effects of exposure for 12 and 24 months to sanitary landfill leachate on the physical properties of the 12 liner materials mounted in the bases of the simulated sanitary

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1. Haxo, H.E., and R.M. White. First Interim Report - EPA Contract 68-03-2134, "Evaluation of Liner Materials Exposed to Leachate," November 27, 1974.

2. Haxo, H.E. "Assessing Synthetic and Admix Materials for Lining Landfills," Proceedings of Research Symposium: Gas and Leachate from Landfills - Formulation, Collection, and Treatment - Rutgers University, March 25 and 26, 1975. US-EPA Office of Research and Development, Cincinnati, OH 45268 EPA-600/9-76-004, pp 130-158, March 1976.

3. Geswein, A.J. "Liners for Land Disposal Sites - An Assessment." U.S. Environmental Protection Agency Report SPA/530/SW-137, March 1975.

landfills and on the 42 smaller specimens buried in the sand placed above the mounted liners.

4. To analyze the costs of these materials for lining sanitary landfills. This analysis will include liner costs, installation costs, and the benefits from longer durability.

The First Interim Report (Ref. 1) described the overall technical approach that was taken, the construction of the simulated sanitary landfills, the selection of liner materials, the loading of the cells with ground refuse, characterization of the refuse, and bringing the cells to field capacity. In that report the various liner materials were discussed individually and the bases for selecting the twelve primary materials being tested were presented. Results of tests of properties of the various materials before exposure to leachate were presented, and they form the basis for assessing the effects of leachate over the exposure period. Also presented were data on the costs of various materials used in the lining of ponds, lagoons, pits, etc.

In this, the Second Interim Report, the results of a 1 year exposure of liner materials to leachate are presented. The monitoring of the generators is described, and the analyses of leachate generated in the simulated sanitary landfills over the 1 year period are reported. Also described is the overall operation of the simulated landfills and the performance of the materials that were employed in fabricating the apparatus used in this project. Permeability of the various materials to water and leachate is discussed.

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1. Haxo, H.E., and R.M. White. First Interim Report - EPA Contract 68-03-2134, "Evaluation of Liner Materials Exposed to Leachate," November 27, 1974.

## SECTION II

## SUMMARY OF WORK

Specimens of 12 liner materials that had been mounted as barriers at the base of simulated landfills were removed and tested after a 1 year exposure to the leachate generated in these cells. These materials consist of:

Six Polymeric Liner Membranes -

- Butyl rubber
- Chlorinated polyethylene (CPE)
- Chlorosulfonated polyethylene (Hypalon)
- Ethylene propylene rubber (EPDM)
- Polyethylene (PE)
- Polyvinyl chloride (PVC)

Four Admix Materials -

- Hydraulic asphalt concrete
- Paving asphalt concrete
- Soil asphalt
- Soil cement

Two Asphaltic Membranes -

- A blown asphalt (canal lining asphalt)
- Emulsified asphalt on fabric

The polymeric materials, all commercial products, were mounted with seams either made by the supplier or made in accordance with the recommended practice of the respective supplier.

The four admix materials and the blown asphalt membrane were formed-in-place in accordance with recommended practice. The membrane of emulsified asphalt was supplied by the manufacturer in sheet form, and a test specimen was cut from that sheet. Normally, it too would be formed-in-place.

In addition, the 42 secondary specimens of membrane liners, many of which incorporated splices, were recovered and tested after a 1 year exposure to leachate. These had been buried in the sand above the primary liners in the bases of the cells and thus had both faces exposed to leachate.

The monitoring of the generators during the first year consisted of:

1. Adding 2 gallons of tap water and collecting the leachate produced. Each addition was equal to 1 inch of water entering the landfill. The amount of water and leachate were recorded.

2. Every 4 weeks the leachate from each of the generators was subjected to the following tests: hydrogen ion concentration (pH), chemical oxygen demand (COD), total solids, and volatile solids. Total volatile acids were measured twice, and then this test was dropped.

3. Chromatographic analyses were made 5 times during the year for individual acids: acetic, propionic, isobutyric, and butyric acid.

4. Attempts were made to maintain a hydraulic head of 1 foot on the liners.

5. Measurements were made of the temperature and the consolidation of the refuse in each of the generators.

After about 8 to 9 months of operation, "U" tubes were placed in the lines to maintain a head of 1 foot on each of the liners and a continuous collection of leachate was set up. This was made possible by fabricating the collection bags of polybutylene replacing the bags of polyethylene that failed at the seams in relatively short times.

## SECTION III

## OBSERVATIONS AFTER A 1 YEAR EXPOSURE OF LINERS TO LEACHATE

1. The admix liners containing asphalt, although losing drastically in their compressive strength, maintain their impermeability to leachate. The asphalt itself became softer, indicating possible absorption of organic components from the leachate.

2. During the year's monitoring of the cells, in only three of the cells did the leachate enter the base below the liners. Two of these liners, soil asphalt and paving asphalt concrete, leaked whereas the leakage in the third was caused by a failure of the epoxy sealing compound around the periphery of the specimen.

3. The soil cement lost some of its compressive strength; however, it hardened considerably during the exposure period and cored like a Portland cement concrete. Its permeability decreased somewhat.

4. Inhomogeneities in the admix materials, which probably caused the leakage in the paving asphalt and soil asphalt liners, indicate the need for considerably thicker materials in practice.

   Note: 2 to 4-inch-thick liners were selected for this experiment to give an accelerated test and were designed with an appropriately sized aggregate.

5. The asphaltic membranes withstood the leachate for 1 year, although they did swell slightly. There was no indication of disintegration or dissolving of the asphalt.

6. All of the polymeric liner materials withstood a 1 year exposure to the leachate, although several, e.g. chlorinated polyethylene and Hypalon, swelled appreciably. Swollen liners softened but did not lose tensile, tear, or puncture resistance. Preliminary tests of the exposed liners now in progress indicate some increase in permeability, probably because of swelling. The values will be reported when completed.

7. Variation among polymeric membrane liners based upon a given polymer occurred which may reflect variations in polymer source, compound composition, and possibly methods of manufacture.

8. The seams of the polyvinyl chloride, Hypalon and chlorinated polyethylene liners deteriorated in strength. The polyethylene retained its strength best.

9. The quality of the leachate in all 24 of the cells was similar, indicating that the initial composition of the refuse was controlled and that the comparison among the liner materials would be valid. These leachates had relatively high COD values, i.e. 40,000 to 50,000 ppm, and high organic acids, i.e. approximately 20,000 ppm, at the time the twelve simulated landfills were dismantled.

10. The design of the simulated landfills was effective, giving anaerobic conditions in the generators to yield satisfactory leachate and means of exposing and retrieving liner test specimens. The use of polybutylene bags and "U" tubes allowed continual drainage of the generators, yet retained a 1-foot head of leachate above the liner surface.

11. All of the materials of construction, except the epoxy resin used for sealing the liners in the bases, showed no significant deterioration. The epoxy resin had been selected on the basis of its rapid cure and its past use in engineering construction. However, this resin was not specifically designed for chemical resistance. More chemically resistant materials have now been developed.

12. The epoxies used to coat the concrete bases showed no signs of softening or other deterioration.

## SECTION IV

## RECOMMENDATIONS

1. Extend the exposure period for at least 1 additional year for a total exposure period of 3 years.

2. Determine the basic composition features of polymeric liner materials before and after exposure to leachate. The compound formulation, particularly the polymer, filler, and plasticizer contents of a liner, is an important factor in the long-term performance of a given liner.

3. Investigate the permeability of various materials under highly swollen conditions, such as may be encountered in long-term exposure to leachate.

4. Develop simpler tests for assessing the effectiveness of potential liner materials for sanitary landfills; explore the effectiveness of immersion tests of liner materials in leachate.

5. Collect information on plastic and rubbery materials which may have been exposed to leachate in sanitary landfills.

## SECTION V

## EXPERIMENTAL WORK

### MONITORING THE GENERATORS DURING THE FIRST YEAR

The 24 simulated sanitary landfills in which the liner material specimens were being exposed were erected in an unheated wooden frame building (No. 165) at the Richmond Field Station of the University of California, Berkeley. The windows of the building remained open. This Station is on the eastern shore of San Francisco Bay in Richmond, California. The temperature in this building is relatively cool and uniform, ranging from 10 to 20°C (50 to 68°F), a temperature likely to be encountered at the base of landfills. The design and construction of these simulated landfills are described fully in Figures 1 and 2. The arrangement of the generators in the building is shown in Figure 3.

During the first year of exposure of the liner materials to leachate (November 1974 - November 1975), the following measures were taken in monitoring the generators:

a. Two gallons of tap water were added on a biweekly basis (equals 1 inch of water per 2 weeks or 26 inches per year).

b. The leachate was collected on a biweekly basis.

c. Ambient and temperatures in the refuse of 4 of the generators were measured biweekly.

d. On a 4-week basis, the leachate was analyzed for the following:

Chemical oxygen demand (COD)
pH
Total solids
Volatile solids
Total volatile acids as acetic acid (this was discontinued after 2 months as individual acids were analyzed.)

e. Five sets of analyses were made of the individual volatile acids.

All analyses of the leachate were made by personnel of the Sanitary Engineering Research Laboratory of the University of California.

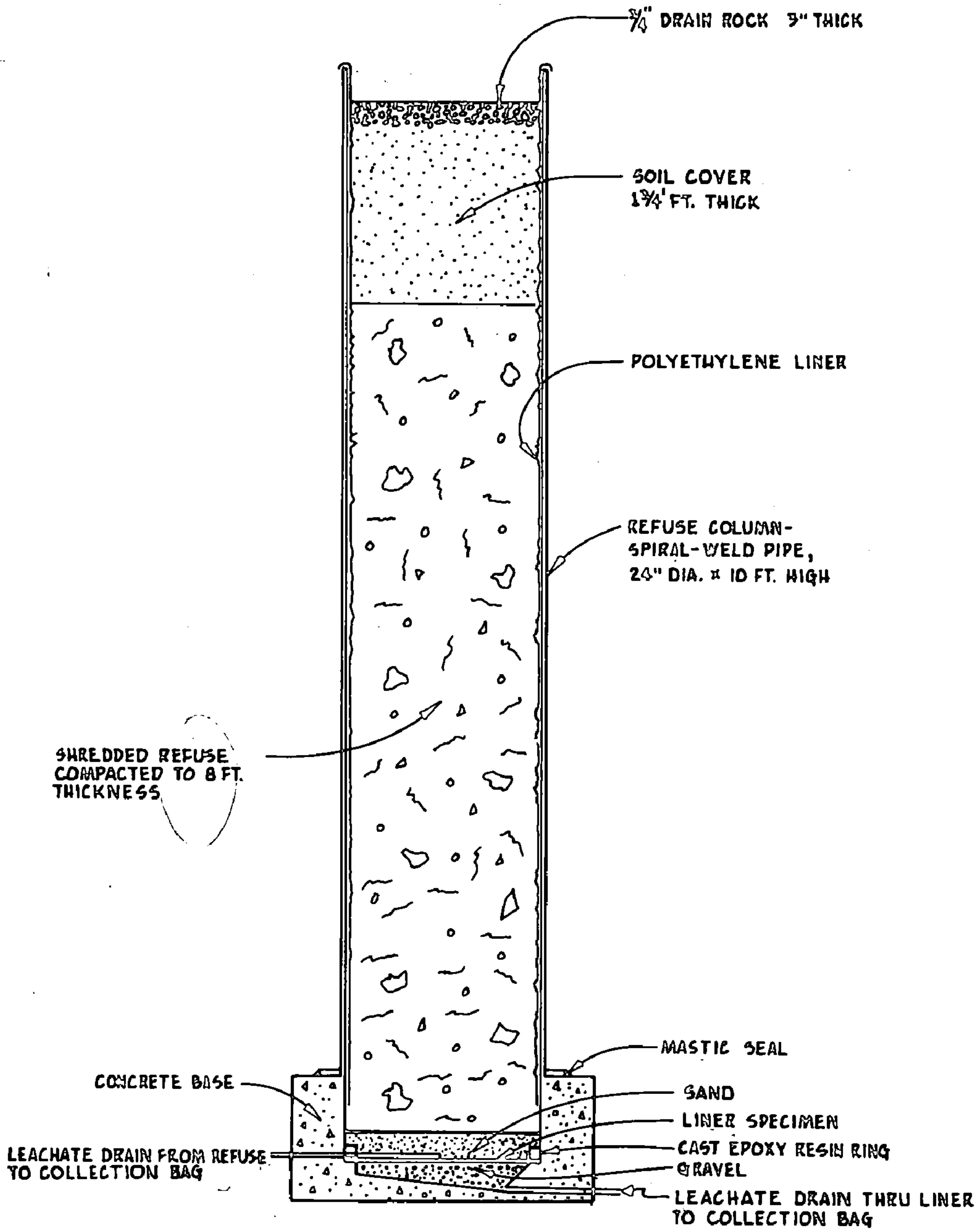


Figure 1 - Schematic drawing of leachate generator and cell in which the liner materials are being exposed to leachate under conditions simulating sanitary landfills.

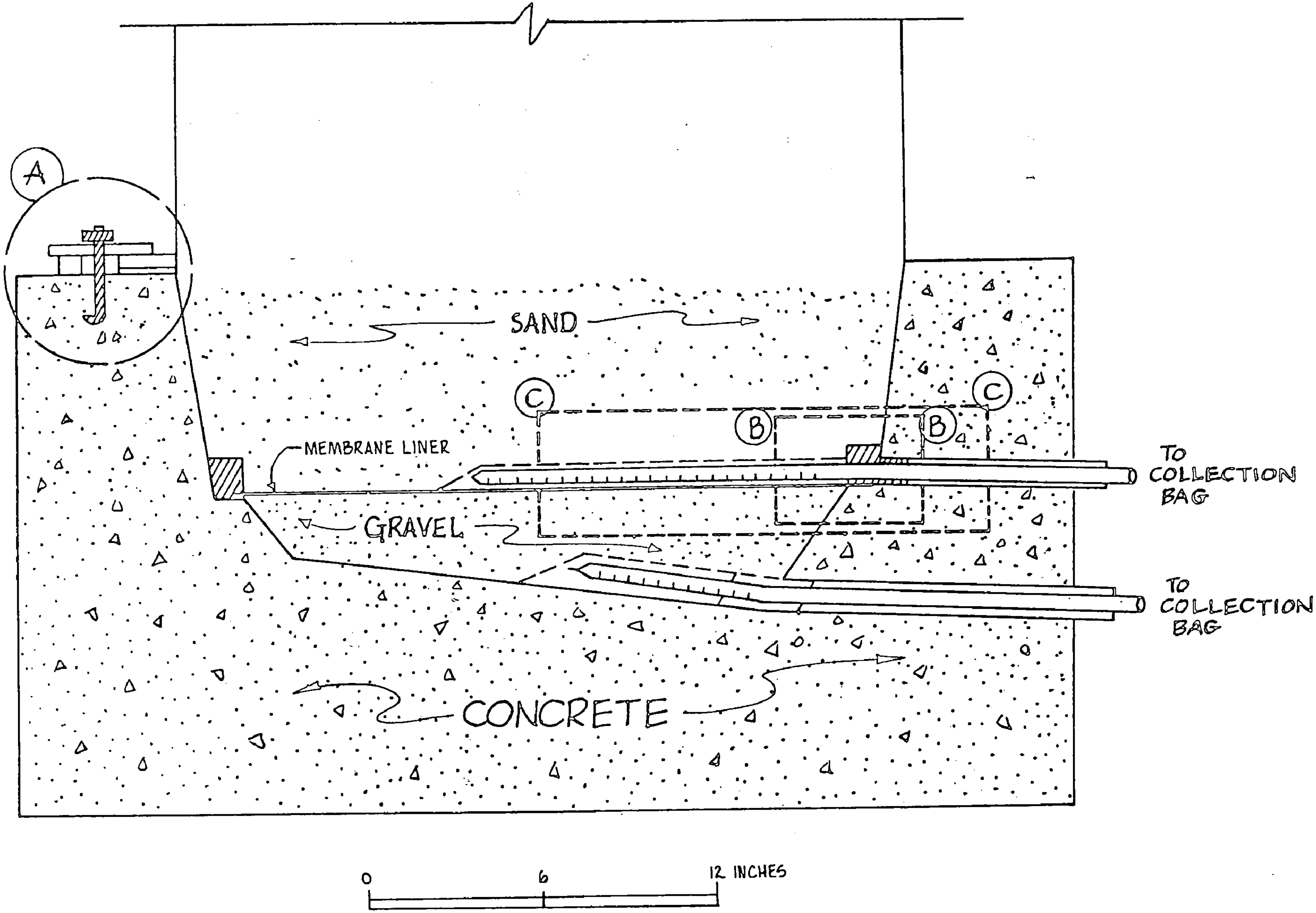


Figure 2 - Base of leachate generator with membrane barrier.

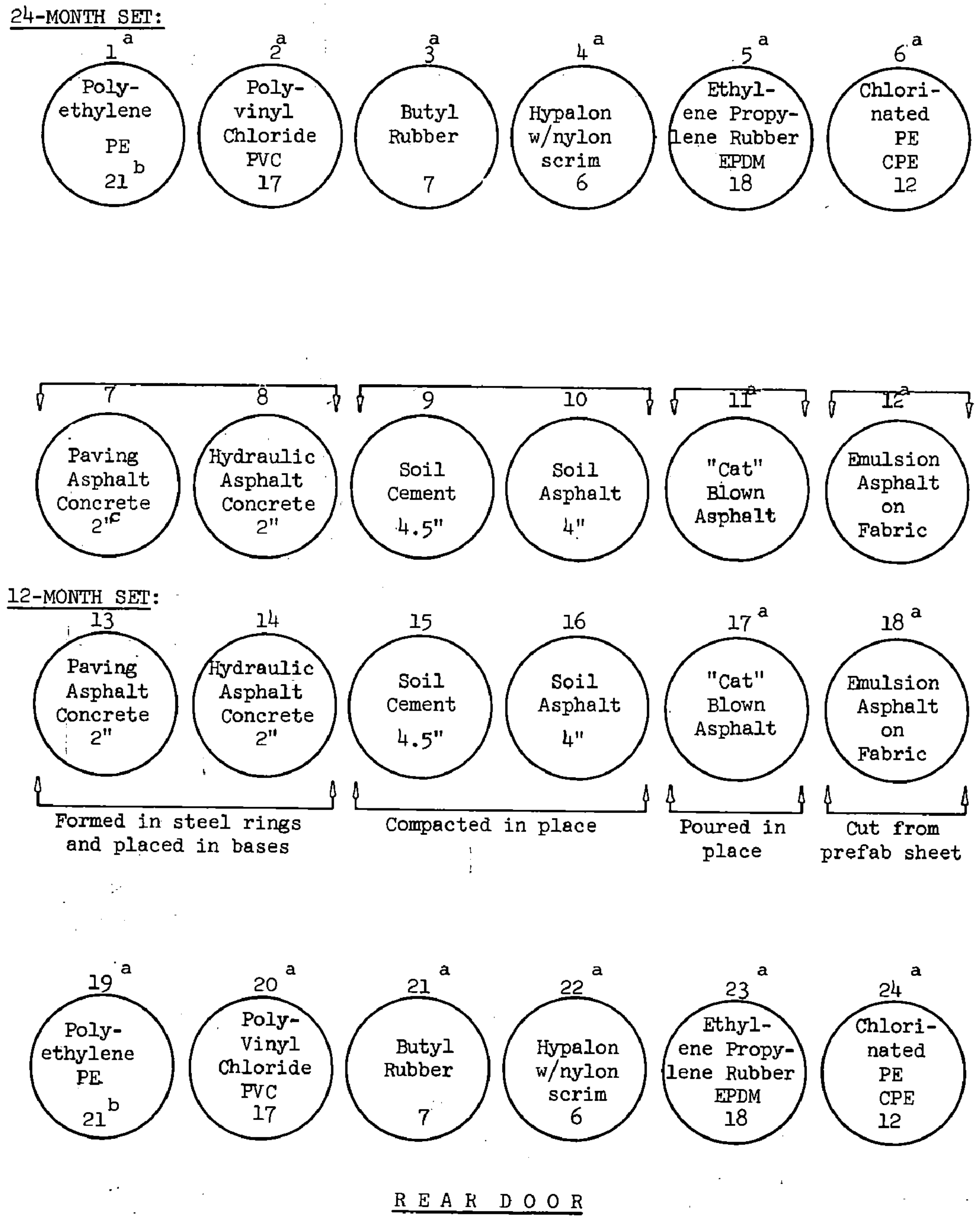


Figure 3 - Placement of the liner materials in the leachate generation and exposure cells in Building 165, Richmond Field Station. Cell numbers shown above the circles. Cells containing strip specimens are indicated by a. Matrecon serial numbers for membrane liners are indicated in appropriate circles. Thickness of concrete and modified soil liner also shown in appropriate circles.

Average values of the data obtained during the first year of monitoring the 24 generators are reported in Table 1. Typical of the data obtained for the leachate from individual generators is that shown in Table 2 for Generators 13 through 24 just prior to their being dismantled to recover the liners.

The temperature observed in the refuse of the 4 generators very closely equalled ambient temperature (10 to 20°C). Temperatures in the refuse exceeding ambient were only observed during the first few days after the cells were loaded with refuse. By the time the thermocouples had been placed in the cells, the temperatures had already fallen to ambient.

During the year the height of the refuse decreased due to consolidation. Measurements were made which indicated an approximate 7% consolidation during the first year.

During the course of the year the method of collecting the leachate was changed. Initially, the leachate was allowed to accumulate in the cells and to pond on the liners at various heights, although efforts were made to keep the height between 1 and 2 feet. Later, "U" tubes were installed at a height of 1 foot and the leachate was drained continually, leaving a head of 1 foot on the liners at all times. In making this change the collection bags were changed from polyethylene to polybutylene because of the superior seams which could be obtained by heat-sealing polybutylene. The polyethylene bags failed at the heat-sealing seams when kept under constant stress and continuous draining could not be performed with these bags.

It was recognized early that a large amount of organic acids was being generated in the anaerobic decomposition of the refuse. Several of these organic acids can interact with organic compositions such as the membrane and asphaltic liners in the study; butyric acids, in particular have adverse effects on many rubbery and plastic materials. Consequently, analyses were made for individual organic acids.

DISASSEMBLY OF GENERATORS AND RECOVERY OF LINERS

Twelve of the 24 leachate generators and exposure cells containing the test liner specimens were dismantled in November 1975 and the liner specimens recovered for laboratory testing. This was done 52 weeks after the refuse in the columns had been brought to field capacity and leachate began ponding on the liners.

The major problem faced in dismantling and recovering the exposed liners was to perform the operations without damaging the liner specimens. The individual filled columns weighed approximately 3000 pounds, broken down as follows:

| | Pounds |
|---|---|
| Steel pipe ---------------------- | 400 |
| Refuse + water ------------------ | 1690 |
| Soil cover - 1 2/3 ft. ---------- | 800 |
| Rock, 1/3 foot ------------------ | 150 |
| Total ---------------- | 3040 |

TABLE 1. MONITORING OF SIMULATED LANDFILLS AND LEACHATE QUALITY[a]

| Item | Date | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1974 | 1975 | | | | | | | | | | | |
| | 12-10 | 1-6 | 2-3 | 3-3 | 3-31 | 4-29 | 5-27 | 6-23 | 7-21 | 8-18 | 10-15 | 11-10 | 12-8 |
| Week of leachate generation | 2 | 5 | 10 | 14 | 18 | 22 | 26 | 30 | 34 | 38 | 46 | 50 | 54 |
| Ambient temp, °C | 9.5 | 10.5 | -- | 15.5 | 12.0 | 19 | 18 | 15 | 18 | 16 | 19 | 14 | 17 |
| Total Solids, % | 3.49 | 3.38 | 3.58 | 3.54 | 3.43 | 3.66 | 3.35 | 3.20 | 3.27 | 3.20 | - | 3.31 | 3.34 |
| Volatile, % | -- | -- | -- | -- | -- | -- | 1.99 | 1.90 | 1.91 | 1.82 | - | 1.95 | 1.84 |
| Nonvolatile, % | -- | -- | -- | -- | -- | -- | 1.36 | 1.30 | 1.36 | 1.38 | - | 1.36 | 1.50 |
| COD, g/liter | 46.1 | 58.4 | 45.1 | 43.5 | 46.0 | 45.4 | 47.5 | 48.7 | 49.0 | 43.8 | 46.6 | 45.9 | 45.8 |
| pH | 5.51 | 5.50 | 5.30 | 5.21 | 5.24 | 5.16 | 5.16 | 5.13 | 5.07 | 5.03 | 5.06 | 5.05 | 5.14 |
| TVA as acetic acid, g/l | 10.5 | 10.6 | -- | -- | -- | -- | -- | -- | 15.7 | -- | 24.33 | -- | -- |
| Individual Acids: | | | | | | | | | | | | | |
| Acetic, g/l | 1.45 | -- | -- | 2.00 | -- | -- | -- | -- | 3.32 | -- | 6.18 | 11.25 | -- |
| Propionic, g/l | 1.58 | -- | -- | 1.55 | -- | -- | -- | -- | 3.38 | -- | 2.42 | 2.87 | -- |
| Isobutyric, g/l | 0.33 | -- | -- | 0.50 | -- | -- | -- | -- | 1.17 | -- | 0.59 | 0.81 | -- |
| Butyric, g/l | 2.39 | -- | -- | 2.52 | -- | -- | -- | -- | 7.79 | -- | 6.20 | 6.93 | -- |
| Consolidation of refuse, cm. | -- | -- | -- | -- | -- | -- | 5.0 | -- | 7.3 | 9.9 | 10.6 | 12.5 | 16.0 |

[a]Data are averages over 24 cells

TABLE 2. MONITORING DATA FOR GENERATORS 13-24 JUST PRIOR TO DISMANTLING[a]

| Gen. no. | Liner material | Ash, % | | pH | COD g/l | Volatile acids, g/l | | | | Rock level cm. | Leachate collection, Kg. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Total | Volatile | | | Acetic | Propionic | Isobutyric | Butyric | | Nov. 10 | Nov.11-17 | Total |
| 13 | Paving asphalt concrete | 3.6 | 2.1 | 5.05 | 49.5 | 18.6 | 9.2 | 1.1 | 9.7 | -16.0 | 6.36 | 8.30 | 15.84[b] |
| 14 | Hydraulic asphalt concrete | 2.7 | 1.7 | 5.05 | 42.3 | 12.0 | 2.7 | 0.6 | 6.8 | -12.0 | 6.82 | 15.19 | 22.46[b] |
| 15 | Soil cement | 3.4 | 2.1 | 5.00 | 43.5 | 14.6 | 3.3 | 0.9 | 8.6 | -13.0 | 6.36 | 11.06 | 17.42 |
| 16 | Soil asphalt | 4.4 | 1.7 | 5.05 | 43.1 | 12.2 | 3.6 | 1.1 | 7.4 | -17.0 | 6.36 | 21.05 | 27.36[b] |
| 17 | "Cat" blown asphalt | 3.4 | 2.3 | 5.07 | 45.2 | 10.8 | 3.0 | 1.4 | 7.5 | -14.0 | 6.27 | 17.01 | 23.28 |
| 18 | Emulsified asphalt, on fabric | 3.5 | 2.1 | 5.05 | 56.8 | 10.6 | 3.5 | 0.9 | 7.0 | -17.5 | 5.55 | 18.62 | 27.69 |
| | Averages | 3.5 | 2.0 | 5.04 | 46.7 | 13.13 | 3.38 | 1.01 | 7.84 | -14.9 | --- | --- | 22.43 |
| 19 | Polyethylene | 3.3 | 2.0 | 5.05 | 33.6 | 13.2 | 3.2 | 0.7 | 7.3 | - 3.0 | 6.82 | 17.91 | 24.73 |
| 20 | Polyvinyl chloride | 3.0 | 1.9 | 5.05 | 48.9 | 8.1 | 1.6 | 0.2 | 5.2 | - 3.0 | 5.91 | 18.41 | 24.32 |
| 21 | Butyl rubber | 2.9 | 1.8 | 5.05 | 45.3 | 8.8 | 2.6 | 0.6 | 5.5 | - 3.0 | 6.82 | 13.83 | 20.65 |
| 22 | Chlorosulfonated PE | 3.2 | 1.9 | 5.05 | 52.6 | 12.1 | 3.1 | 1.1 | 7.1 | - 2.5 | 6.36 | 20.47 | 26.83 |
| 23 | Ethylene propylene rubber (EPDM) | 3.1 | 1.9 | 5.05 | 49.3 | 7.3 | 2.0 | 0.8 | 5.3 | - 7.5 | 6.82 | 17.24 | 24.06 |
| 24 | Chlorinated PE (CPE) | 3.2 | 2.0 | 5.10 | 39.8 | 6.7 | 1.6 | 0.3 | 5.6 | - 5.5 | 6.36 | 21.77 | 28.13 |
| | Averages | 3.12 | 1.9 | 5.06 | 44.9 | 9.37 | 2.35 | 0.60 | 6.02 | - 4.1 | --- | --- | 24.79 |
| | Leachate collected below liners: | | | | | | | | | | | | |
| 13 | Paving asphalt concrete | 3.5 | 2.1 | 5.10 | 49.9 | 6.5 | 1.7 | 0.3 | 5.7 | - | 0.91 | 0.27 | 1.18 |
| 14 | Hydraulic asphalt concrete | 2.7 | 1.7 | 5.77 | 31.1 | 4.6 | 0.6 | 0.2 | 4.4 | - | 0.45 | - | 0.45 |
| 16 | Soil asphalt | 2.9 | 1.6 | 5.05 | 27.1 | 6.9 | 1.1 | 0.8 | 4.5 | - | 0.45 | - | 0.45 |

[a]Ambient temperature 10 Nov. = 14°C.

[b]Total includes the leachate collected below the liner.

Equipment to raise the columns of waste, etc., was not available at the Richmond Field Station, so it was necessary to use a private rigging firm. They fabricated a split collar with horizontal pins which could be bolted to the steel pipe containing the refuse somewhat above the center of gravity. Using a 4-ton forklift truck an individual column was lifted at the pins, tilted after it had cleared the base, a steel cover placed over the opening of the column to prevent refuse from falling out, and then removed from the building.

Both the columns and the bases were removed from the building without problem. The bases had been cast on butyl rubber sheeting which had been placed on the floor of the building and, thus, they could be lifted off the floor and moved away.

To prepare for dismantling, we did the following:

1. Stopped the addition of water 2 weeks prior to dismantling.

2. Allowed the leachate to drain thoroughly from the refuse.

3. Removed the soil and rock cover from the columns.

4. Detached all bolts, bags, tubing, etc.

The dismantling proceeded without incident except where the entire contents of one of the steel columns slipped out of the pipe in the polyethylene casing. This gave us the opportunity to inspect the full depth of the refuse in the generator (see below).

After removing the sand and buried specimens by hand and washing out with a hose, the polymeric membranes were photographed and cut out of the bases, as were the blown asphalt and emulsified asphalt membranes. The admix liner specimens were tested for air leaks by flooding the liner with water and pressurizing the space below the liner and observing the bubbles. Six 2-inch cores (2 near the center and 4 in the periphery) were then cut with a diamond core drill from each of the liners except the soil asphalt. The top part of the soil asphalt had become almost a soft mud which disintegrated within the drill. No full length intact cores could be obtained of this material, but as the lower portion was firmer than the top, partial cores were obtained for testing.

REFUSE AFTER 1 YEAR OF OPERATION OF THE GENERATORS

A shredded municipal refuse from Palo Alto, California, was used in filling the generators. It was loaded and compacted into the generators in 20-pound aliquots in a manner to minimize variation among the generators to approximately 1500 pounds per cubic yard at a water content of 30%. Details regarding the loading of the generators and the refuse are given in the First Interim Report (Ref. 1). During the year the level of the refuse in

1. Haxo, H.E., and R.M. White. First Interim Report - EPA Contract 68-03-2134, "Evaluation of Liner Materials Exposed to Leachate," November 27, 1974.

the column fell. It was found that during this period of time the refuse consolidated ca 7%.

When being loaded, 1 row of generators could not be compacted as much as the other 3 rows because of interference of a rafter. The refuse in this row of generators did not consolidate as greatly as that in the other generators. However, with time the rate of consolidation increased in this row of generators.

When the generators were dismantled, the refuse was inspected and a photographic record made. The appearance of the refuse showed that it had deteriorated very little during the course of the year. Pieces of newspaper could be read and colors were retained in both paper and pieces of fabric. Organic material, leaves, twigs, etc., also showed little damage. Pieces of plastic and metal (aluminum, tin cans, pennies, etc.) were little changed. However, pieces of rubber, such as rubber bands, were highly swollen and some pieces of what appeared to be polyvinyl chloride, such as used in wallets, had become extremely hard. The moisture content of the refuse taken from the generators was found to be about 60%.

Facts regarding the refuse in the generators are given in Table 3.

MEASURING THE EFFECTS ON LINER MATERIALS OF EXPOSURE TO LEACHATE

The effect of landfill leachate upon liner materials is being assessed in 2 ways:

1. Measuring the amount of leachate which passes through a liner as a function of exposure time.

2. Measuring the changes in physical properties of the liner on components of the liner as a function of exposure time.

The exposure cells which simulate landfills were designed to act as large permeameters with the liners sealed at the bases so that any leachate which passes through the liners can be collected and measured. The purpose of the liner is to prevent passage of the leachate, so leakage through the liner is an indication of failure.

Exposure to leachate can result in property changes with exposure, due to swelling, dissolving, or deteriorations of the liner material. The physical properties of the liner specimens, after 1 year exposure to leachate, were measured using the following tests:

POLYMERIC MEMBRANE LINERS:

Hardness, ASTM D2240
Puncture resistance, Fed. Test Method Std. No. 101B, Method 2065
Seam strength, in peel, ASTM D413, and in shear (1" x 2" lap seam)
Tear strength, ASTM D624, Die C
Tensile strength and elongation at break, ASTM D412
Thickness

TABLE 3. INFORMATION ON THE REFUSE IN GENERATORS: ESTIMATED REFUSE CONTENT OF A SINGLE GENERATOR (Average Values)

| | Total | Moisture |
|---|---|---|
| Amount of shredded refuse as received[a], lb | 950 | 118 |
| Water added to aid compaction, lb | 440 | 440 |
| Water added to bring refuse to field capacity, lb | 312 | 312 |
| Total, lb | 1692 | 820 |
| Calculated moisture content of refuse at field capacity, % | 48.5 | --- |
| Initial volume of refuse in a generator, cu ft | 25.1 | --- |
| Density at time refuse reached field capacity, lb/cu yd | 1820 | --- |
| Density at time refuse reached field capacity, lb/cu ft | 67.4 | --- |
| Moisture content of refuse taken from generator 17 after 1 year of operation, % | 59.5 | --- |

[a]Shredded refuse received containing about 12.1% moisture was added in lifts of 20 pounds each. The first few lifts of 30 pounds could not be compacted; therefore, size of lifts was reduced to 20 pounds and about 1 gallon of water added to each.

Water absorption or extraction at RT and 70°C, ASTM D570
Water vapor permeability, ASTM E96-66, Procedure BW

ADMIX LINERS:

Coefficient of permeability: Back-pressure permeameter (Ref. 2)
Compressive strength: ASTM D1074
Density and voids content: ASTM D1184 and D2041
Viscosity of asphalt: California Division of Highways 348
Water swell: California Division of Highways 305

The results are presented in the Appendix. The original properties of all of the liner materials are given in the First Interim Report (Ref. 1).

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1. Haxo, H.E., and R.M. White. First Interim Report - EPA Contract 68-03-2134, "Evaluation of Liner Materials Exposed to Leachate," November 27, 1974.

2. Vallerga, B.A., and R.G. Hicks. J. Materials 3 (1) 73-86, "Water Permeability of Asphalt Concrete Specimens Using Back-Pressure Saturation," 1968.

## SECTION VI

## DISCUSSION

### LINER MATERIALS EXPOSED TO LEACHATE FOR 1 YEAR

One year's exposure to leachate resulted in no significant change in the water permeability of any of the liners. The changes in physical properties which were observed were small except for some losses in seam strength. The following general observations can be made about the types of liner materials:

1. The admix liner materials generally lost substantially in compressive strength, particularly the soil asphalt (See Appendix B).

2. The asphalt membranes absorbed leachate slightly, but otherwise changed little during exposure.

3. The polymeric membranes swelled to varying degrees and lost slightly in tensile and hardness but generally retained puncture and tear strengths.

4. Seam strengths were significantly lower in almost all cases except the heat-sealed seams.

#### Admix Liners

This group of materials includes the following 4 liners:

1. Paving asphalt, 2 inches thick
2. Hydraulic asphalt concrete, 2 inches thick
3. Soil cement, 4.5 inches thick
4. Soil asphalt, 4 inches thick.

The 2 asphalt concrete specimens were compacted in molds as circular discs, 22 inches in diameter, and sealed in the bases with an epoxy resin. The soil cement and soil asphalt specimens were compacted in place in the bases and sealed with epoxies. The placement and composition of these materials are described in the First Interim Report (Ref. 1)

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1. Haxo, H.E., and R.M. White. First Interim Report - EPA Contract 68-03-2134, "Evaluation of Liner Materials Exposed to Leachate," November 27, 1974.

During the year the paving asphalt concrete and the soil asphalt liners leaked (see Table 2). Neither the hydraulic nor the soil cement liners actually leaked through the liners; however, there was leakage through the epoxy sealant around the hydraulic asphalt. Permeability measurements made of cores of the admix liners (see Appendix B) had low water permeability, in some cases lower than had been measured for unexposed specimens. This may reflect absorption of leachate by the admix material which would tend to reduce voids. When the sand was removed, both of the asphalt concretes looked undeteriorated with no gumminess or solutioning of the surface, as did the asphaltic membranes.

Paving Asphalt Concrete - The voids content of the exposed concrete was slightly less than measured before exposure, possibly indicating swelling of the binder. It seems unlikely that enough leachate could have passed through the liner for fines filtering out to account for the decrease in voids. The permeabilities measured on the cores bracket the range found earlier; permeability of some of the cores was very low. Compressive strength was much lower than the original. Only 15% of original compressive strength was retained after 12 months exposure to leachate *vs*. 80% retained after 24 hours in water at 60°C (see Appendix B). The extracted binder was softer than before exposure, as shown by the decrease in viscosity which may account for part of the loss of compressive strength.

Hydraulic Asphalt Concrete - The voids content of the exposed material was slightly less than measured before exposure, possibly indicating some swelling of the binder. Permeability was very low, one core giving the same permeability as obtained on the unexposed concrete, and another being even lower. As with the asphalt concrete liner, only 13% of original compressive strength was retained after 12 months exposure to leachate *vs*. 86% retained after 24 hours in water at 60°C. The extracted binder softened even more than in the asphalt concrete, as shown by decrease of viscosity.

Soil Asphalt - The soil asphalt had almost completely disintegrated structurally and great difficulty was encountered in obtaining core samples for tests. It was not possible to recover intact cores, so the test results obtained may not be typical for the entire liner. The voids content was high, ranging from 18 to 32 on the 3 cores measured, compared to 10.3 to 10.5 on the cores tested before exposure. In spite of the high voids, the permeability was much lower than for unexposed cores. Compressive strength was very low on the exposed material and must have been near zero in the portions of the liner where cores could not be obtained. The viscosity of the extracted binder was higher than before exposure, but was still very low, possibly reflecting loss of the low molecular fraction used to cut-back the asphalt.

Soil Cement - Excellent core samples were cut from the exposed soil cement liner showing continuation of cure during the year's exposure to leachate. Satisfactory cores could not be cut from the original unexposed soil cement; it was necessary to use molded test specimens for permeability and compressive strength measurements.

The compressive strength of the soil cement was 62% of the original value. In the preliminary testing of the soil cement, molded test specimens retained 69% on 24 hour immersion in water at 60°C.

The soil cement liner did not leak in the exposure cell during the year. In laboratory testing water permeability of the cores of the exposed liner was lower than that of an unexposed molded specimen, $1.5 \times 10^{-8}$ and $4.0 \times 10^{-7}$ cm/sec vs. $1.5 \times 10^{-6}$ cm/sec.

Asphalt Membranes

Two types of asphalt membranes were tested. One was a blown asphalt similar to that used in canal linings and the second was an emulsified asphalt placed on a non-woven fabric. The preparation and composition of these liner materials are described in the First Interim Report (Ref. 1). Both of these materials showed no deterioration during the course of 1 year's exposure. They absorbed a small amount of leachate, the blown asphalt 2.9% and the emulsified asphalt 4.8%.

Bituminous Seal - The catalytically oxidized canal lining asphalt had the same softening point after 12 months exposure to leachate as before exposure. The viscosity at 25°C was slightly higher at 0.05 $sec^{-1}$ shear rate but was much higher at the slow shear rate, 0.001 $sec^{-1}$, indicating a high shear susceptibility.

Emulsified Asphalt on Nonwoven Fabric - The asphalt extracted from the fabric plus asphalt emulsion liner, like that extracted from the asphalt concrete and hydraulic asphalt concrete liners, was lower in viscosity after 12 months exposure to leachate than before exposure. The viscosity at the slow rate, 0.001 $sec^{-1}$, was substantially unchanged, indicating a lower shear susceptibility than for the original.

Asphalt Extracted from Liners

Under service conditions where the asphalt composition is exposed to air, the contained asphalt will harden due to oxidation. This is true of paving and roofing asphalts and eventually results in failure of the material. As a component of a buried liner at the bottom of a landfill the asphalt is in an anaerobic environment in contact with leachate which contains dissolved organic constituents. In this situation the asphalt can be expected to remain the same or to soften. The 3 liners made with paving consistency asphalt all softened as shown in Table 4, which may indicate absorption of organic compounds or possibly a degradation by anaerobic bacteria.

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1. Haxo, H.E., and R.M. White. First Interim Report - EPA Contract 68-03-2134, "Evaluation of Liner Materials Exposed to Leachate," November 27, 1974.

TABLE 4. CHANGES IN PROPERTIES OF ASPHALT IN ADMIX MATERIALS AND MEMBRANES DURING 1 YEAR OF EXPOSURE TO LANDFILL LEACHATE

| Material[a] | Asphalt concrete | Hydraulic asphalt concrete | Soil asphalt | Bituminous seal | Fabric and asphalt |
|---|---|---|---|---|---|
| Viscosity at 25°C, Sliding Plate Viscometer, MP | | | | | |
| At shear rate of 0.05 $sec^{-1}$: | | | | | |
| Original | 14.5 | 9.7 | 0.02[b] | 8.5 | 4.5 |
| After 1 year | 8.8 | 3.3 | 0.04 | 10.4 | 2.9 |
| Change | -5.7 | -6.4 | +0.02 | +1.9 | -1.6 |
| % change[c] | -39 | -66 | +100 | +22 | -36 |
| At shear rate of 0.001 $sec^{-1}$: | | | | | |
| Original | 20.0 | 14.5 | 0.14 | 19.3 | 6.0 |
| After 1 year | 15.3 | 4.3 | 0.40 | 117 | 5.9 |
| Change | -4.7 | -10.2 | +0.26 | +97.7 | -0.1 |
| % change | -23 | -70 | +186 | +506 | -2 |
| Penetration at 25°C: | | | | | |
| Original | 29 | 34 | 538 | 36 | 46 |
| After 1 year | 32 | 52 | 390 | 34 | 55 |
| Change | +3 | +18 | -148 | -2 | +9 |
| % change | +10 | +53 | -28 | -6 | +20 |
| Voids Ratio (volume voids/ volume solids x 100): | | | | | |
| Original | 6.4 | 2.9 | 10.4 | -- | -- |
| After 1 year | 4.2 | 1.9 | 26.1 | -- | -- |
| Change | -2.1 | -1.0 | +15.7 | -- | -- |

[a] See Appendix B for details regarding compositions.

[b] Correct value. Viscosity of extracted binder for unexposed soil asphalt reported in error as 0.2 MP in Table III of First Interim Report.

[c] Calculated from viscosity.

Polymeric Membranes

The six polymeric membranes mounted in the bases of the generators were:

Butyl rubber
Chlorinated polyethylene (CPE)
Chlorosulfonated polyethylene (Hypalon)
Ethylene propylene rubber (EPDM)
Polyethylene (PE)
Polyvinyl chloride (PVC).

The changes in the physical properties of these membranes during the first year's exposure to leachate are presented in Table 5. Overall, the change in the physical properties of the membranes was relatively minor. They all tended to soften, probably due to the absorption of leachate. On the other hand, there was a substantial loss in seam strength in the polyvinyl chloride, the Hypalon, and the chlorinated polyethylene liners. The seam strength of the butyl and EPDM liners decreased less but they had lower strength prior to exposure. The polyethylene maintained the highest seam strength reflecting the fact that it was heat-sealed.

Of the 6 polymeric membranes, the polyethylene film best maintained overall properties during the exposure period. It also absorbed the least amount of leachate. However, this liner material has low puncture resistance. The butyl and EPDM liners changed somewhat more in physical properties than did the polyethylene during the exposure period. In particular, they maintained their stress-strain properties and did not soften; they retained their respective seam strengths, but their original values were low. The 3 remaining membranes, PVC, Hypalon, and CPE, were about equal; they all tended to soften and lose in hardness, tensile properties and in seam strength, even though they had good initial values. These latter materials are all thermoplastic and unvulcanized.

In addition to the 6 primary liner specimens, 42 secondary specimens of membrane liners and other polymeric compositions were buried in the sand and exposed to leachate. The membrane specimens were in the form of strips 2 1/8" x 20" which incorporated at one end a lap seam adhesive joint approximately 2" x 2" which could be tested in peel and in shear. Thus, various adhesive systems were tested.

The buried specimens included the following compositions:

1. Samples of all of the primary liner materials which were mounted in the bases of the generators with the same adhesive systems plus additional adhesive systems.

2. Additional liner materials of the same 6 polymers but varying in source, thickness, and fabric reinforcement.

3. Additional polymers which are potentially useful as liners, i.e. neoprene, polybutylene, and polypropylene.

TABLE 5. EFFECT ON THE PROPERTIES[a] OF POLYMERIC MEMBRANE LINERS OF 1 YEAR OF EXPOSURE TO LEACHATE FROM SIMULATED SANITARY LANDFILLS (Date in U.S. Customary Units)

| Item | Exposure Time, Years | Polyethylene | Polyvinyl chloride | Butyl | Chloro-sulfonated polyethylene | Ethylene propylene rubber | Chlorinated polyethylene |
|---|---|---|---|---|---|---|---|
| Liner No. | -- | 21 | 17 | 7 | 6 | 16 | 12 |
| Generator No. | -- | 19 | 20 | 21 | 22 | 23 | 24 |
| Thickness, mils | 0 | 11-12 | 20-21 | 61-65 | 32-36 | 49-53 | 31-32 |
| | 1 | 11 | 21 | 64 | 38 | 51 | 35 |
| Tensile strength, psi | 0 | 2145 | 2580 | 1435 | 1765 | 1475 | 2270 |
| | 1 | 2465 | 2350 | 1395 | 1640 | 1455 | 1810 |
| Elongation at break, % | 0 | 505 | 280 | 395 | 250 | 410 | 410 |
| | 1 | 560 | 330 | 410 | 300 | 435 | 400 |
| Tensile set, % | 0 | 422 | 73 | 17 | 111 | 16 | 429 |
| | 1 | 432 | 57 | 14 | 106 | 12 | 208 |
| S-200[b], psi | 0 | 1260 | 1965 | 690 | 1520 | 760 | 1330 |
| | 1 | 1205 | 1550 | 685 | 1245 | 740 | 1090 |
| Tear strength (Die C), ppi | 0 | 390 | 335 | 180 | 300 | 181 | 255 |
| | 1 | 496 | 450 | 202 | 305 | 195 | 320 |
| Hardness (Duro A - 10 sec.) | 0 | 98 | 76 | 51 | 79 | 54 | 85 |
| | 1 | ---- | 64 | 50.5 | 64 | 51.5 | 65.5 |
| Puncture resistance[c] force, pounds | 0 | 13.9 | 25.8 | 44.8 | 32.9 | 39.4 | 47.0 |
| | 1 | 14.8 | 30.1 | 49.5 | 57.0 | 40.1 | 49.8 |
| Elongation, in. | 0 | 0.76 | 0.69 | 1.22 | 0.60 | 1.44 | 1.04 |
| | 1 | 0.80 | 0.70 | 1.20 | 0.88 | 1.18 | 0.98 |
| Volatiles at 105°C | 1 | 0.02 | 3.55 | 2.02 | 12.76 | 5.54 | 6.84 |
| Seam strength peel, ppi | 0 | 15.6 | 40 | 3.8 | 30.0 | 2.5 | 10.0 |
| | 1 | 10.3[d] | 5.1 | 2.9 | 3.4 | 2.0 | 5.1 |
| Shear, ppi | 0 | 20.2 | 37.2 | 30.0 | 50 | 14.6 | 57 |
| | 1 | 11.4 | 25.6 | 42.0 | 40.2 | 24.3 | 35 |

[a] See page 16 for list of test procedures.
[b] Stress at 200% elongation.
[c] Rate of penetration of probe 20 inches per minute.
[d] Seam in the polyehtylene liner used in the steel column. Tabs in the liner specimens mounted in base were too short.

4. A series of five pieces of gasket sheeting of different rubber compostions and molded slabs of 2 thermoplastic rubbers.

The results of the tests of these specimens are presented in Appendixes C - H, which also include the detailed data on the primary liners. These additional specimens allow us to make comparisons between materials from different sources, different constructions and different thicknesses, as well as exposure to 1 side and both sides of the test specimens. We also can test various adhesive systems which have been suggested by the suppliers.

The overall physical properties of the buried specimens compare with those of the mounted liners. There are variations, however, among the liners based upon a given type of polymer, as can be seen by inspection of the data. Of particular interest are variations in the leachate absorption by different liners of the same polymer. In the case of PVC, the absorption varies from .37% to 6.7%; in the case of the Hypalon, the variations are from 8.7% to 21%. EPDM varies from 5.1% to 9%.

In the case of chlorinated polyethylene membranes from the same supplier, we observe the effect of one-side exposure, thickness and reinforcement, as shown in Table 6.

TABLE 6. ABSORPTION OF LEACHATE BY CHLORINATED POLYETHYLENE LINER

| Thickness, mils | | Reinforced | Exposure | Leachate absorbed in 1 year, % |
|---|---|---|---|---|
| Nominal | Measured | | | |
| 31 | 35 | No | 1 side | 6.84 |
| 31 | 35.7 | No | 2 sides | 9.52 |
| 31 | 40.6 | Yes[a] | 2 sides | 12.37 |
| 16 | 18.2 | No | 2 sides | 10.35 |

[a]Nylon.

The seven miscellaneous polymeric compositions buried in the sand for exposure to the leachate were:

2 Thermoplastic rubbers based on ethylene and propylene

5 Gasket sheeting materials of the following:

Natural rubber
Styrene butadiene rubber (SBR)
Urethane rubber
Neoprene, solid sheeting
Neoprene, sponge

Their properties after 1 year's exposure to leachate are given in Appendix H; properties prior to exposure are presented in the First Interim

Report (Ref. 1), Appendix A.

The 2 thermoplastic rubbers absorbed some leachate, the softer rubber of the 2 absorbed more (3.98%) and dropped in hardness about 15 points, i.e. from 62 to 47, compared with 1.79% absorption and no change in hardness for the harder rubber. Materials of this type may be useful for fabricating liners as they are tough and can be heat-sealed.

The gasket materials absorbed leachate to varying degrees, from 2.0% for the urethane rubber to more than 44% for the neoprene sponge. In spite of the relatively low swell of the urethane it lost substantially in tensile and tensile modulus (S100, S200, and S300). The natural rubber vulcanizate also lost in tensile strength, modulus and hardness as did SBR but to a lesser extent. The solid neoprene gasket material swelled and softened but retained strength and tensile modulus; the sponge became very soft and flabby, indicating the potentially high level to which neoprene might swell. (In the assembled generators only a small area of the neoprene gasket is exposed to leachate as the sponge is collapsed. There was little evidence that the leachate actually entered the seal.)

These data show that absorption of leachate increases when 2 sides of a liner are exposed to leachate, when reinforcement is used, and when a thinner membrane is used. These results are important when developing tests for evaluating various liner materials.

The data on the strengths of the seams in the various strip specimens indicate that there are, in some cases, better adhesive systems than were used in the primary specimens mounted in the bases. In the case of PVC, use of the tetrahydrofuran (THF) with 2 of the PVC strip specimens yielded substantial improvement over the seam made by the manufacturer of the PVC liner. With the Hypalon, the seam made with the supplier's cement in the primary liner was not as good as that made in the strip specimen, which indicates that even in the laboratory major variations can occur in the use of cements. The adhesive system used with the chlorinated polyethylene, i.e. 50-50 toluene-THF gave somewhat lower values than a Fuller cement, SC-1155. The adhesion values for the butyl liner were somewhat less than measured on the strip specimens, although the same cement was used. The factory seam incorporated in the EPDM liner did not give as good values as a cement preparation designed for this type liner by another supplier.

Overall, the heat-sealed seams held up best to exposure to leachate, although some cements and solvent washes have held up. Solvent washes are difficult to handle in the field.

In reviewing the results for both the membrane liners and the strip specimens, it is quite apparent that the crystalline polymers based upon ethylene, propylene, and butylene withstand exposure to leachate best.

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1. Haxo, H.E., and R.M. White. First Interim Report - EPA Contract 68-03-2134, "Evaluation of Liner Materials Exposed to Leachate," November 27, 1974.

Their properties show less change, they absorb only minor amounts of leachate and they maintain good seams when they are heat-sealed. However, they are all hard and would be difficult to handle in the field. Also, they are probably prone to puncture and tear as simple thin films.

PERMEABILITY AND WATER ABSORPTION OF LINERS

The basic purpose of a liner for a landfill is to control the flow of leachate and prevent its entrance into the surface and/or ground water system. Consequently, permeability to water and dissolved ingredients is its most important property.

To assess the permeability of liner materials the test cells were specifically designed and constructed as large permeameters to measure any flow of leachate which might occur through the liner materials. Individual liners were sealed so that leachate could enter the space below the liner only through the liner specimen. In addition, laboratory measurements of water permeability were made of the materials before exposure to the leachate and, in some cases, after exposure to the leachate. (Additional measurements are still underway.)

The water permeability of the admix liners was determined on unexposed and exposed liner materials using a back-pressure permeameter (Ref. 1). Test results are presented in Table 7. During the exposure period, leachate permeated through 2 of the admix materials, the paving asphalt concrete and the soil asphalt. When the generators were dismantled and the liners retrieved, the liners were flooded and the bases pressurized to show the points of leakage. In the case of the paving asphalt concrete, there was a general leakage in the center of the specimen, but none at the periphery. Very little air passed through the soil asphalt, although there were some bubbles on the edges. Tests of cores of these specimens showed that the overall permeability of these materials was equal, if not lower than that of unexposed specimens, indicating possible filling of voids. The tests also showed inhomogeneity in the samples and the need to make thicker liners than were used in the test.

The other 2 admix materials, hydraulic asphalt concrete and soil cement, did not leak during the test and on laboratory testing were somewhat more impermeable than they had been before exposure to leachate (see Table 7).

In the case of the 2 asphalt concretes, there was an apparent reduction in voids contents and a reduction in the asphalt viscosity and an increase in penetration. It would appear that the asphalt may have absorbed organic components from the leachate.

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1. Vallerga, B.A. and R.G. Hicks. J. Materials 3 (1) 73-86, "Water Permeability of Asphalt Concrete Specimens Using Back-Pressure Saturation," 1968.

TABLE 7. PERMEABILITY OF ADMIX LINER MATERIALS

| Admix material[a] | Paving asphalt concrete | Hydraulic asphalt concrete | Soil cement | Soil asphalt |
|---|---|---|---|---|
| Thickness, inches | 2.2 | 2.4 | 4.5 | 4.0 |
| Leachate collected below liner during monitoring period: | | | | |
| Total cumulation, kg | 12.26 | 3.24 (not thru liner)[b] | none | 12.1 |
| Week leakage began | 20th | 29th | ---- | 1st |
| Coefficient of permeability[c], cm/sec: | | | | |
| Initial value | $1.2 \times 10^{-8}$ | $3.3 \times 10^{-9}$ | $1.5 \times 10^{-6}$[d] | $1.7 \times 10^{-3}$ |
| After 1 year's exposure to landfill leachate[e] | $7.4 \times 10^{-7}$<br>$9.3 \times 10^{-9}$<br>$<3.0 \times 10^{-10}$ | $<3. \times 10^{-10}$<br>$3.5 \times 10^{-9}$ | $1.5 \times 10^{-8}$[f]<br>$4.0 \times 10^{-7}$[g] | $1.3 \times 10^{-8}$<br>$2.8 \times 10^{-8}$ |

[a]See Appendix B for details regarding composition.

[b]On dismantling of generator, leak was found to be in epoxy seal.

[c]Back Pressure Permeameter (Ref. 4) tests made on cores cut from compacted liner specimen.

[d]Molded test specimen. Cores satisfactory for testing could not be cut from the compacted liner specimen.

[e]Value for core specimens cut from liner.

[f]Top section of Core 3.

[g]Bottom section of Core 4.

In the case of soil asphalt, the reverse took place with an increase in voids content and a hardening of the asphalt. As the asphalt in this material is a cut-back asphalt containing lower molecular weight hydrocarbons, it is possible that this admixture lost some of the lower molecular weight components.

We conclude, after 1 year of exposure to leachate, that the water permeability of the 4 admix materials has dropped. As pointed out above, the strength of these materials has been considerably reduced. It is anticipated that further changes will take place during subsequent exposure to leachate but they will be slow, suggesting that longer exposure periods be used.

Attempts were first made to measure the water permeability of the 2 asphalt membranes, one based upon blown asphalt and the other on emulsified asphalt, using the back-pressure permeameter. However, this equipment did not yield reliable information on materials having coefficients of permeability less than $10^{-9}$ cm/sec. This was true also of the polymeric membrane liners discussed below. We have been unable to measure the permeability of either of these 2 asphaltic materials in a satisfactory manner. A major problem in testing these materials has been their creep in the cells during exposure with loss of seal.

With respect to the polymeric membranes, the transmission of moisture and other dissolved materials depends largely upon diffusion activated flow. This is in contrast to the capillary flow that is encountered in the admix materials. This, of course, assumes no pinholes in the materials. Permeation by diffusion will be far slower than that by capillary flow. Consequently, the permeabilities of these materials will be several orders of magnitude lower than that of the admix materials. The asphalt membranes are also in this class.

As with the asphaltic membranes, we were unsuccessful in using the back-pressure permeameter to measure the permeability coefficients. The amounts of water which passed through the test specimens were much too low to get measurable values in reasonable time. We then measured water permeability of the polymeric membranes using the BW procedure described in ASTM Test Method E96-66. In this method a container, with a test specimen sealed on the top, is partially filled with water, inverted, and allowed to remain with air blowing across the specimen. The loss of moisture through the membrane over extended periods of time is measured and reported as the water vapor transmission. This method is intended for evaluating membrane materials in applications in which one side of the membrane is wetted and where the hydraulic head is relatively unimportant. The moisture transfer is governed by capillary and water vapor diffusion processes. The procedure, therefore, simulates a possible condition of a liner in a landfill.

Tests were made of specimens of the liner materials mounted in the bases of the generators and the results are reported in Table 8 in metric perms for films of one centimeter thickness. These results rate the 6 liner membranes as follows, from the least permeable to the most permeable:

TABLE 8. MOISTURE VAPOR TRANSMISSION THROUGH POLYMERIC MEMBRANES -- Test Method: ASTM E-96-66 Procedure BW - Modified[a]

| Item | Hypalon | Butyl | CPE | EPDM | PVC | PE |
|---|---|---|---|---|---|---|
| Liner no. | 6 | 7 | 12 | 16 | 17 | 21 |
| Thickness, mils | 36 | 66 | 32 | 52 | 21 | 10 |
| , cm | 0.0915 | 0.168 | 0.081 | 0.132 | 0.053 | 0.0267 |
| Test time, days | 40.5 | 45 | 45 | 40 | 17.5 | 34 |
| Rate of water vapor transmission WVT: | | | | | | |
| $g/m^2/24$ h | 0.825 | 0.26 | 0.61 | 0.58 | 3.69 | 1.28 |
| Water vapor permeance - water vapor transmission per mm Hg (WVT/$\Delta$P) | | | | | | |
| Metric perms | 0.062 | 0.0195 | 0.046 | 0.0435 | 0.277 | 0.096 |
| Water vapor permeability, permeance x thickness in cm: | | | | | | |
| Metric perms x thickness in cm | 0.0057 | 0.0033 | .0037 | 0.0057 | 0.015 | 0.0026 |

[a] In this procedure, the water cup with the membrane specimen cover is inverted to wet the specimen. It is intended for those applications in which one side is wetted under conditions where the hydraulic head is relatively unimportant and moisture transfer is governed by capillary and water vapor diffusion forces (from E-96). Test conditions: Temperature - Room temperature (68 - 78°F). Relative humidity varied 26 - 47% over a period of 7 months, averaging 37%. Surface area of specimen - 15.2 $cm^2$ (0.00152 $m^2$).

Polyethylene
Butyl
Chlorinated polyethylene
Ethylene propylene rubber
Hypalon
Polyvinyl chloride

Also related closely to the permeability of materials is the absorption of water. Small absorptions of water can drastically increase the permeability of a material. The absorption of water is diffusion dependent as well as related to the relative polarity of the polymer and water. The absorption can thus result in significant swelling of a liner and a significant increase in its permeability to water and possibly to dissolved components. The structure and composition of the polymeric membrane can greatly affect its swelling by water as may the ion content of the permeating fluid as reported for neoprene compositions (Ref. 1). It can be seen in Table 9 that the leachate, with its dissolved organic and inorganic components can cause additional swelling in some cases and reduction in others, e.g. neoprene. The ultimate swelling of a material is determined by (1) the relative polarity and molecular weight of a polymer, (2) the level to which the polymer is crosslinked, and (3) various compounding ingredients, particularly the plasticizers and fillers that are used.

In Table 9, the water and leachate absorptions by various polymeric liner materials are presented. The data include the water absorption after 2 hours at 100°C, water absorption after 1 year in water, and leachate absorption after 1 year's exposure. The materials which have shown the lowest amount of swell are polyethylene, polybutylene, and polypropylene, in which cases the absorptions are a few tenths of a percent, with the leachate being absorbed slightly more than water. These results would predict the low water transmission which was found for the polyethylene in the moisture vapor transmission shown in Table 8.

The 2 materials which show a relatively high absorption of both water and leachate are the 2 rubbery polymers which are unvulcanized, chlorinated polyethylene (CPE) and chlorosulfonated polyethylene (Hypalon). In addition, there is a significant variation among the Hypalon liners from the various suppliers.

Among the vulcanized rubbers, butyl, EPDM, and neoprene, the butyl is significantly lower in absorption of both leachate and water, although the water absorption by ethylene propylene rubber is very close to that of butyl. The neoprene, which swelled the most of all the materials in water, swelled considerably less in the leachate, which is probably a reflection of the ion content of the leachate (Ref. 1) and possibly the oil resistance of the neoprene.

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1. Murray, R.M., and D.C. Thompson. "The Neoprenes," E. I. duPont de Nemours and Co., pp 70-71, 1963.

TABLE 9. WATER AND LEACHATE ABSORPTION BY POLYMERIC LINERS
(Data in percent absorbed by weight)

| | Liner no. | Water-100°C 2 h | Water-RT 1 year | Leachate 1 year |
|---|---|---|---|---|
| Butyl rubber | 7[a] | 0.17 | 1.60 | 1.78 |
| | 22 | 0.23 | 1.70 | 2.32 |
| | 24 | 0.10 | 1.10 | 1.0 |
| Chlorinated polyethylene (CPE) | 12[a] | 2.93 | 13.10 | 9.0 |
| | 13S[b] | 12.96 | 19.60 | 12.4 |
| | 23 | 6.68 | 15.50 | 10.3 |
| Chlorosulfonated polyethylene (Hypalon) | 3 | 4.19 | 17.40 | 20.0 |
| | 4S | 5.16 | 18.00 | 19.0 |
| | 6S[a] | 7.17 | 9.20 | 13.64 |
| | 14S | 15.26 | 11.20 | 8.71 |
| Ethylene propylene rubber (EPDM) | 8 | 0.36 | 1.40 | 5.95 |
| | 16[a] | 0.47 | 4.80 | 5.50 |
| | 18 | 0.58 | -- | -- |
| | 25 | 0.23 | 1.50 | 5.59 |
| | 26 | 0.29 | 1.60 | 8.99 |
| Neoprene | 9 | 1.71 | 22.7 | 8.73 |
| Polybutylene | 20 | -- | 0.25 | 0.33 |
| Polyethylene | 21[a] | -- | 0.20 | 0.25 |
| Polypropylene | 27 | 0.24 | 0.28 | 0.40 |
| Polyvinyl chloride | 10 | 1.10 | 1.85 | 6.72 |
| | 11 | 0.95 | 1.85 | 5.0 |
| | 15 | 2.40 | 2.10 | 4.64 |
| | 17[a] | 2.15 | 1.85 | 3.29 |
| | 19 | 0.92 | 0.60 | 0.75 |

[a]Liners mounted in generator bases.

[b]S=fabric supported liner.

The polyvinyl chloride liner materials varied among the suppliers and swelled significantly more in the leachate than they did in water.

Samples of membrane liners have been immersed in tap water for 3 years and, in most cases, continue to swell. In others, the swelling has levelled off. It is anticipated that a similar behavior will be encountered in the swelling caused by leachate. Therefore, it appears desirable to extend the leachate exposure period to at least 3 years in order to determine whether the swelling will continue. There is a possiblity that unvulcanized polymers which are chemically compatible with water may swell to the point where they dissolve.

After 1 year's exposure to leachate none of the materials under test has reached the condition where they will not serve as a barrier for the leachate that is being generated. On the other hand, high levels of swelling or extended periods of exposure may eventually cause some of the materials to become quite permeable. Longer exposure times will be necessary to determine this.

PERFORMANCE OF EQUIPMENT AND MATERIALS OF CONSTRUCTION

The overall design of the simulated sanitary landfills shown in Figure 1 has worked out well during the first year of operation. Basically, it consists of a leachate generator made of a 10-foot-high, 2-foot-diameter steel pipe, mounted on a concrete base in which the liner specimens are mounted and sealed to prevent by-passing by the leachate.

The conditions existing at the surface of the liners has simulated well the anaerobic conditions which a liner would encounter at the bottom of a sanitary landfill containing municipal refuse. During the year the temperature ranged from 10 to 20°C. The anaerobic conditions existed during almost the entire exposure period, except perhaps the first few days. The sealing of the pipes to the base, using neoprene sponge and butyl caulk, was airtight and showed no indication of leakage when the generators were dismantled.

The leachate drained well through the refuse; there was no stoppage in the refuse or in the sand above the liner. The column containing the refuse was removed with relative ease from the base without damage to the liner or to the buried specimens which had been placed in the sand above the liner.

It had been planned to use standpipes to indicate the level of the leachate within the generators and to drain from the generators on a bi-weekly basis. It was found, however, that there was considerable variation in the head that existed above the liners and, consequently, we changed the method of draining and collecting the leachate to maintain a constant head of 1-foot of leachate on the liner. A "U" tube was installed in the line so that a 1-foot head of leachate could be maintained on the liner and at the same time the leachate could drain continually from the generators into plastic bags. This was made possible through the use of bags made of polybutylene which could remain full over a period of time without failing. We had initially started with polyethylene bags, but found that they failed at the heat-sealed seams in a relatively short time.

We found that the polyethylene used to line the 2-foot steel pipes worked out satisfactorily. Very little water appeared to have come into contact with the steel pipes as there was very little rust generated except near the top of the pipes where air was available. The epoxy coating (Concresive 1170) used to cover the interior of the concrete bases showed no signs of softening or of failure from the concrete. The coating, however, stained.

The epoxy resin (Concresive 1217) used in preparing the rings for sealing the liners in place swelled at the surface and disintegrated in 2 cells during the exposure period causing a leakage in 1 base (the hydraulic concrete liner), but did not fail completely in the second. This particular epoxy resin was selected because of its rapid cure, but we now find that epoxies of this type are sensitive to moisture and to off-ratios when combining the 2 parts. The supplier (Adhesive Engineering Company) has since developed much more chemically resistant epoxy coating and casting resins (Concresive 1305 and 1310).

The polyvinyl chloride pipe and valve system worked satisfactorily.

SECTION XII

APPENDIX

TABLE A-1. PROPERTIES[a] OF POLYMERIC MEMBRANE LINERS AFTER 1 YEAR OF EXPOSURE TO LEACHATE FROM SIMULATED SANITARY LANDFILLS

| | Polyethylene[b] | | Polyvinyl chloride | | Butyl rubber | | Chloro-sulfonated polyethylene | | Ethylene-propylene rubber | | Chlorinated polyethylene | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | With | Across | With | Across | With | Across | With | Across | With | Across | With | Across |
| Liner no. | 21 | ---- | 17 | ---- | 7 | ---- | 6 | ---- | 16 | ---- | 12 | ---- |
| Generator no. | 19 | ---- | 20 | ---- | 21 | ---- | 22 | ---- | 23 | ---- | 24 | ---- |
| Thickness, mils | 11 | ---- | 21 | ---- | 64 | ---- | 38 | ---- | 51 | ---- | 35 | ---- |
| Tensile strength, psi | 2470 | 2460 | 2480 | 2190 | 1350 | 1400 | 1500 | 1780 | 1450 | 1460 | 2090 | 1530 |
| Elongation at break, % | 490 | 625 | 320 | 340 | 425 | 390 | 300 | 300 | 430 | 440 | 350 | 450 |
| Tensile set, % | 365 | 500 | 55 | 59 | 13 | 14 | 106 | 105 | 12 | 12 | 208 | 207 |
| S-100[c], psi | 1210 | 1010 | 1180 | 980 | 270 | 320 | 480 | 710 | 320 | 300 | 1020 | 460 |
| S-200 , psi | 1360 | 1050 | 1680 | 1420 | 630 | 740 | 1035 | 1455 | 770 | 710 | 1450 | 730 |
| S-300 , psi | 1590 | 1120 | 2310 | 1960 | 1010 | 1140 | 1480 | 1780 | 1110 | 1035 | 1860 | 1030 |
| Tear strength (Die C), ppi | 520 | 472 | 489 | 408 | 202 | 202 | 282 | 324 | 196 | 193 | 374 | 262 |
| Hardness (Durometer A) | | | | | | | | | | | | |
| Inst. rdg. | 70.5 | ---- | 67.5 | ---- | 55 | ---- | 67 | ---- | 53 | ---- | 70 | ---- |
| 10 sec. rdg. | 70 | ---- | 64 | ---- | 50.5 | ---- | 64 | ---- | 51.5 | ---- | 65.5 | ---- |
| Puncture resistance[d], lbs | 14.8 | ---- | 30.1 | ---- | 49.5 | ---- | 57.0 | ---- | 40.1 | ---- | 49.8 | ---- |
| Elongation, mm | 0.80 | ---- | 0.70 | ---- | 0.20 | ---- | 0.88 | ---- | 1.18 | ---- | 0.98 | ---- |
| Seam strength | | | | | | | | | | | | |
| Peel, ppi | e | ---- | 5.1 | ---- | 2.9 | ---- | 3.4 | ---- | 2.0 | ---- | 5.1 | ---- |
| Shear, ppi | 11.4 | ---- | 25.6 | ---- | 42 | ---- | 40.2 | ---- | 24.3 | ---- | 35 | ---- |
| Volatiles - air at RT, % | 0.336 | ---- | 4.14 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- |
| 105°C, % | 0.023 | ---- | 3.55 | ---- | 2.02 | ---- | 12.76 | ---- | 5.54 | ---- | 6.84 | ---- |
| Ash, % | 0.23 | ---- | 7.93 | ---- | 5.70 | ---- | 2.42 | ---- | 5.83 | ---- | 14.89 | ---- |

[a] See page 16 for list of test procedures.

[b] See also Appendix G.

[c] Stress at 100, 200, and 300% elongation, respectively.

[d] Rate of penetration: 20 inches per minute.

[e] Not enough tab to test.

TABLE A-2. PROPERTIES[a] OF POLYMERIC MEMBRANE LINERS AFTER 1 YEAR OF EXPOSURE TO LEACHATE FROM SIMULATED SANITARY LANDFILLS

| Item | Polyethylene[b] | | Polyvinyl chloride | | Butyl rubber | | Chloro-sulfonated polyethylene | | Ethylene-propylene rubber | | Chlorinated polyethylene | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | With | Across | With | Across | With | Across | With | Across | With | Across | With | Across |
| Liner no. | 21 | ---- | 17 | ---- | 7 | ---- | 6 | ---- | 16 | ---- | 12 | ---- |
| Generator no. | 19 | ---- | 20 | ---- | 21 | ---- | 22 | ---- | 23 | ---- | 24 | ---- |
| Thickness, mm | 0.279 | ---- | 0.533 | ---- | 1.103 | ---- | 0.965 | ---- | 1.29 | ---- | 0.89 | ---- |
| Tensile strength, MPa | 17.03 | 16.96 | 17.10 | 15.10 | 9.31 | 9.65 | 10.34 | 12.27 | 10.00 | 10.07 | 14.41 | 10.55 |
| Elongation at break, % | 490 | 625 | 320 | 340 | 425 | 390 | 300 | 300 | 430 | 440 | 350 | 450 |
| Tensile set, % | 365 | 500 | 55 | 59 | 13 | 14 | 106 | 105 | 12 | 12 | 208 | 207 |
| S-100[c], MPa | 8.34 | 6.96 | 8.14 | 6.76 | 1.86 | 2.21 | 3.31 | 4.90 | 2.21 | 2.07 | 7.03 | 3.17 |
| S-200[c], MPa | 9.38 | 7.24 | 11.58 | 9.79 | 4.34 | 5.10 | 7.14 | 10.03 | 5.31 | 4.89 | 10.00 | 5.03 |
| S-300[c], MPa | 10.96 | 9.72 | 15.93 | 13.51 | 6.96 | 7.86 | 10.20 | 12.27 | 7.65 | 7.14 | 12.82 | 7.10 |
| Tear (Die C), kN/m | 91.05 | 82.65 | 85.62 | 71.44 | 35.37 | 35.37 | 49.38 | 56.73 | 34.32 | 33.79 | 65.49 | 45.88 |
| Hardness - Inst. rdg. | 70.5 | ---- | 67.5 | ---- | 55 | ---- | 67 | ---- | 53 | ---- | 70 | ---- |
| (Duro A) 10 sec. rdg. | 70 | ---- | 64 | ---- | 50.5 | ---- | 64 | ---- | 51.5 | ---- | 65.5 | ---- |
| Puncture resistance[d], N | 65.83 | ---- | 133.88 | ---- | 220.18 | ---- | 253.54 | ---- | 178.36 | ---- | 221.51 | ---- |
| Elongation, mm | 20.3 | ---- | 17.8 | ---- | 30.5 | ---- | 22.4 | ---- | 30.0 | ---- | 24.9 | ---- |
| Seam strength | | | | | | | | | | | | |
| Peel, kN/m | e | ---- | 0.89 | ---- | 0.51 | ---- | 0.60 | ---- | 0.35 | ---- | 0.89 | ---- |
| Shear, kN/m | 2.00 | ---- | 4.48 | ---- | 7.35 | ---- | 7.04 | ---- | 4.25 | ---- | 6.13 | ---- |
| Volatiles - air at RT, % | 0.336 | ---- | 4.14 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- |
| 105°C, % | 0.023 | ---- | 3.55 | ---- | 2.02 | ---- | 12.76 | ---- | 5.54 | ---- | 6.84 | ---- |
| Ash, % | 0.23 | ---- | 7.93 | ---- | 5.70 | ---- | 2.42 | ---- | 5.83 | ---- | 14.89 | ---- |

[a]See page 16 for list of test procedures.

[b]See also Appendix G.

[c]Stress at 100, 200, and 300% elongation, respectively.

[d]Rate of penetration: 0.508 m per min.

[e]Not enough tab to test.

TABLE A-3. PROPERTIES OF ADMIX LINERS AFTER 1 YEAR OF EXPOSURE TO LEACHATE FROM SIMULATED SANITARY LANDFILLS

| Item | Core no. | Asphalt concrete[a] | Core no. | Hydraulic asphalt concrete[b] | Core no. | Soil cement[c] | Core no. | Soil asphalt[d] | Bituminous seal[e] | Fabric + asphalt emulsion[f] |
|---|---|---|---|---|---|---|---|---|---|---|
| From generator no. | - | 13 | - | 14 | - | 15 | - | 16 | 17 | 18 |
| Thickness, cm (in.) | - | 5.9 (2.3) | - | 6.3 (2.5) | - | 10 (3.9) | - | 12 (4.7) | -- | -- |
| Density, $g/cm^3$ ($lb/ft^3$) | - | 2.406 (105.2) | - | 2.389 (149.1) | - | -- | - | 1.973 (123.1) | -- | -- |
| Voids ratio (vol. voids/ vol. solids x 100) | 3 | 4.3 | 1 | 1.5 | - | -- | 1 | 28.8 | -- | -- |
| | 4 | 4.4 | 3 | 3.4 | - | -- | 3 | 17.8 | -- | -- |
| | 6 | 4.0 | 5 | 0.75 | - | -- | 9 | 31.8 | -- | -- |
| | - | -- | 6 | 2.0 | - | -- | - | -- | -- | -- |
| Average | - | 4.2 | - | 1.9 | - | -- | - | 26.1 | -- | -- |
| Water content, g water per 100 g dry | 3 | 0.99 | 1 | 0.55 | - | -- | 1 | 10.3 | -- | -- |
| | 4 | 0.61 | 3 | 0.47 | - | -- | 3 | 7.7 | -- | -- |
| | 6 | 1.39 | 5 | 0.40 | - | -- | 9 | 10.7 | -- | -- |
| | - | -- | 6 | 0.39 | - | -- | - | -- | -- | -- |
| Average | - | 1.00 | - | 0.45 | - | -- | - | 9.6 | 2.6 | 4.8 |
| Water soluble solids extracted, % | - | -- | 1 | 0.007 | - | -- | 1 | 0.17 | -- | -- |
| | 4 | 0.008 | 3 | 0.006 | - | -- | 3 | 0.08 | -- | -- |
| | - | -- | - | -- | - | -- | 9 | 0.17 | -- | -- |
| Average | - | -- | - | $<0.01$ | - | -- | - | 0.14 | -- | -- |
| Compressive strength, MPa (psi) | - | 2.92 (423) | - | 2.41 (349) | - | 8.19 (1188) | - | 0.10 (15) | -- | -- |
| Fraction of original strength retained | - | 15 | - | 13 | - | 62 | - | 1.2 | -- | -- |
| Coefficient of permeability, cm/sec. | 1[g] | $7.4 \times 10^{-7}$ | 4 | $3.5 \times 10^{-9}$ | 3 | top-$1.5 \times 10^{-8}$ | 2 | $1.3 \times 10^{-8}$ | -- | -- |
| | 2 | $9.3 \times 10^{-9}$ | 2 | $<3 \times 10^{-10}$ | 4 | bot.$4.0 \times 10^{-7}$ | 3 | $2.8 \times 10^{-8}$ | -- | -- |
| Properties of extracted asphalt: Viscosity sliding plate @ $25^{\circ}C$, MP | | | | | | | | | | |
| @ 0.05 $sec.^{-1}$ | - | 8.8 | - | 3.3 | - | -- | - | 0.04 | 10.4 | 2.9 |
| @ 0.001 $sec.^{-1}$ | - | 15.3 | - | 4.3 | - | -- | - | 0.40 | 117 | 5.9 |
| Penetration @ $25^{\circ}C$ (calc. from viscosity) | - | 32 | - | 52 | - | -- | - | 390 | 34 | 55 |
| Softening point $^{\circ}C$ ($^{\circ}F$) | - | -- | - | -- | - | -- | - | -- | 89 (192) | -- |

[a]Composition: 7.1 asphalt; 100 aggregate.

[b]Composition: 9.0 asphalt; 100 aggregate.

[c]Composition: 95 soil; 5 Kaolin clay; 10 Type V cement; 8.8 water.

[d]Composition: 7.0 SC-800 liquid asphalt; 100 aggregate.

[e]Composition: Catalytically blown asphalt layer 4.7 $kg/m^2$ (8.7 pounds per square yard).

[f]Composition: Asphalt from emulsion spread on polypropylene nonwoven fabric-4.8 $kg/m^2$ (8.9 lb. per square yard).

[g]Core taken from area at center of liner which leaked during exposure period.

TABLE A-4. PROPERTIES[a] OF POLYVINYL CHLORIDE (PVC) MEMBRANES AFTER 1 YEAR OF EXPOSURE TO LEACHATE GENERATED IN A SIMULATED SANITARY LANDFILL, BURIED MEMBRANE SPECIMENS

| Item | Specimen[b] no. 10 | 11 | 15 | 17 | 19-1 | 19-2 | Liner 17 |
|---|---|---|---|---|---|---|---|
| Generator no. | 19 | 19 | 19 | 19 | 19 | 19 | 20 |
| Thickness, mils | 33.8 | 30.9 | 11 | 20 | 21.7 | 21.1 | 21 |
| Tensile strength, psi | 2550 | 2780 | 2000 | 2660 | 2745 | 2860 | 2350 |
| Elongation at break, % | 325 | 400 | 225 | 350 | 400 | 400 | 330 |
| Tensile set, % | 73 | 98 | 26 | 64 | 87 | 87 | 57 |
| S-100[c] psi | 1230 | 1220 | 1490 | 1200 | 1270 | 1295 | --- |
| S-200[c] psi | 1770 | 1740 | 1960 | 1700 | 1745 | 1790 | 1550 |
| S-300[c] psi | 2320 | 2260 | ---- | 2360 | 2220 | 2320 | ---- |
| Tear strength (Die C) ppi | 509 | 432 | 460 | 385 | 400 | 386 | 450 |
| Duro A - Inst. Rdg. | 77 | 79.5 | 78 | 77 | 77 | 785 | ---- |
| 10 Sec. Rdg. | 72.5 | 75.5 | 73 | 72 | 71 | 72 | 64 |
| Puncture resistance (Rate of penetration: 20 in. per minute): | | | | | | | |
| Force, lb | 41.5 | 45.1 | 36 | 24 | 29.8 | 28.8 | 30.1 |
| Elong., in | 0.26 | 0.38 | 0.35 | 0.40 | 0.44 | 0.45 | ---- |
| Volatiles at 105°C, % | 6.72 | 5.0 | 4.64 | 3.29 | 1.22 | 0.37 | 3.55 |
| Seam adhesive system | THF | THF | Solvent 6079 | > | > | THF | Mfgr |
| | --- | --- | Cement L-1552 | > | > | --- | --- |
| Seam strength: | | | | | | | |
| Peel, ppi | 10.4 | 10.2 | 2.1 | 2.2 | 4.9 | 3.0 | 5.1 |
| Locus of failure | LS | LS | AD | AD | AD | LS | --- |
| Shear, ppi | 81.8 | >65.3 | >9.5 | >30.6 | >36.2 | ---- | 25.6 |
| Locus of failure | BRK | BRK | BRK | BRK + AD | BRK | ---- | ---- |

[a]See Page 16 for test procedures.

[b]Matrecon liner material number plus number indicating seam variation.

[c]Stress at 100%, 200%, and 300% elongations, respectively.

TABLE A-5. PROPERTIES[a] OF CHLOROSULFONATED POLYETHYLENE (HYPALON) MEMBRANES AFTER 1 YEAR OF EXPOSURE TO LEACHATE IN A SIMULATED SANITARY LANDFILL, BURIED MEMBRANE SPECIMENS

| Item | Specimen[b] no. | | | | | | Liner |
|---|---|---|---|---|---|---|---|
| | 3.1 | 3.2 | 4.1 | 4.2 | 6 | 14 | 6 |
| Generator no. | 20 | > | > | > | 22 | 21 | 22 |
| Thickness, mils | 87 | 86.7 | 41.9 | 40.8 | 40 | 39.5 | 38 |
| Tensile strength, psi | 1415 | 1440 | 920/790 | 960/1140 | 1860 | 1230/3080 | 1640 |
| Elongation at break, % | 675 | 675 | 625 | 600 | 275 | 150 | 300 |
| Tensile set, % | 294 | 294 | 267 | 265 | 94 | 26 | 106 |
| S-100, psi | 200 | 280 | 240 | 260 | 690 | 1140 | ---- |
| S-200, psi | 260 | 380 | 290 | 295 | 1470 | ---- | 1245 |
| S-300, psi | 320 | 450 | 340 | 340 | ---- | ---- | ---- |
| Tear strength (Die C), ppi | 158 | 172 | 188 | 208 | 250 | 197 | 305 |
| Duro A - Inst. rdg. | 64.5 | 66 | 72 | 70.5 | 71 | 65.5 | 79 |
| 10 Sec. rdg. | 61 | 62.0 | 68.5 | 67.0 | 68.5 | 62.5 | 64 |
| Puncture resistance (Rate of Penetration: 20 in. per minute): | | | | | | | |
| Force, lb | 29.0 | 30.0 | 25.9 | 27.0 | 46 | 45.6 | 57 |
| Elongation, in | 0.85 | 0.88 | 0.42 | 0.38 | 0.36 | 0.30 | ---- |
| Volatiles at 105°C, % | 21.14 | 18.78 | 18.72 | 19.32 | 14.52 | 8.71 | 12.76 |
| Seam adhesive system | Heat Seal | 6079 | Heat Seal | 6079 | Cement | TCE | Cement |
| | ---- | L1552 | ---- | L1552 | 280Z | ---- | 280Z |
| Seam strength: | | | | | | | |
| Peel, ppi | ---- | 2.6 | 0(NT) | 0(NT) | 17 | 2.1 | 3.4 |
| Locus of failure | ---- | AD | AD | AD | AD | AD-LS | ---- |
| Shear, ppi | ---- | 18.0 | ---- | 0(NT) | >64.2 | 15.95 | 40 |
| Locus of failure | ---- | AD | ---- | AD | BRK | AD-LS | ---- |

[a]See Page 16 for test procedures.

[b]Matrecon liner material number plus number indicating seam variation.

[c]Stress at 100%, 200%, and 300% elongations, respectively.

TABLE A-6. PROPERTIES[a] OF CHLORINATED POLYETHYLENE (CPE) MEMBRANES AFTER 1 YEAR OF EXPOSURE TO LEACHATE GENERATED IN SIMULATED SANITARY LANDFILLS, BURIED STRIP SPECIMENS

| Item | Specimen[b] no. 12-1 | 12-2 | 12-3 | 12-4 | 13.1 | 13.2 | 13.3 | 13.4 | 23.1 | 23.2 | 23.3 | 23.4 | Liner 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Generator no. | 22 | 22 | 22 | 22 | 24 | 24 | 24 | 24 | 23 | 23 | 23 | 23 | 24 |
| Thickness, mils | 35.9 | 36.1 | 35.0 | 35.9 | 40.2 | 40.2 | 40.9 | 40.9 | 18.0 | 18.0 | 18.2 | 18.5 | 35 |
| Tensile strength, psi | 2000 | 1940 | 2005 | 1840 | 1020/ 3110 | 980/3230 | 1020/ 200 | 1120/ 3220 | 2360 | 2290 | 2180 | 2040 | 1810 |
| Elongation at break, % | 375 | 350 | 350 | 325 | 150 | 175 | 150 | 150 | 325 | 300 | 300 | 300 | 400 |
| Tensile set, % | 202 | 178 | 185 | 178 | 81 | 77 | 74 | 68 | 78(?) | 173 | 168 | 169 | 208 |
| S-100[c], psi | 990 | 990 | 980 | 980 | 930 | 930 | 980 | 1060 | 1670 | 1640 | 1240 | 1160 | ---- |
| S-200, psi | 1380 | 1380 | 1420 | 1405 | ---- | ---- | ---- | ---- | 2220 | 2200 | 1730 | 1600 | 1090 |
| S-300, psi | 1780 | 1780 | 1830 | 1830 | ---- | ---- | ---- | ---- | 2360 | 2290 | 2180 | 2040 | ---- |
| Tear strength, ppi (Die C) | 258 | 306 | 246 | 267 | 278 | 372 | 356 | 449 | 169 | 333 | 306 | 300 | 320 |
| Duro A - Inst. rdg. | 73.5 | 74 | 74 | 76 | 65 | 65 | 64 | 65.5 | 75 | 77 | 76.0 | 77 | ---- |
| 10 sec. rdg. | 66 | 67 | 66 | 68.5 | 57.5 | 58.5 | 57 | 59 | 69 | 70.5 | 69.5 | 71 | 65.5 |
| Puncture resistance (Rate of Penetration 20 ipm): | | | | | | | | | | | | | |
| Force, lb | 43.8 | 42.0 | 44.0 | 45.0 | 59 | 61 | 60.5 | 60 | 23.0 | 23.6 | 24.2 | 24.6 | 49.8 |
| Elongation, in | 0.40 | 0.39 | 0.51 | 0.53 | 0.20 | 0.21 | 0.17 | 0.21 | 0.41 | 0.44 | 0.44 | 0.45 | ---- |
| Volatiles at 105°C, % | 9.38 | 9.50 | 10.22 | 8.99 | 12.78 | 11.44 | 12.18 | 13.09 | 11.32 | 10.78 | 10.90 | 8.40 | 6.84 |
| Seam adhesive system | Fuller SC-1556 | 50 Toluene 50-THF | 60 TCE 40 Toluene | Fuller SC-1554 | Fuller SC-1556 | 50 Toluene 50 THF | 60 TCE 40 Toluene | Fuller SC-1554 | Fuller SC-1556 | 50 Toluene 50 THF | 60 TCE 40 Toluene | Fuller SC-1554 | 50 Toluene 50 THF |
| Seam strength: | | | | | | | | | | | | | |
| Peel, ppi | 2.2 | 2.4 | 3.0 | 8.3 | 3.8 | 2.5 | 1.2 | 5.8 | 1.0 | 4.8 | 2.7 | 5.4 | 5.1 |
| Locus of failure | AD-LS | LS | LS | AD | AD-LS | LS | LS | AD-LS | AD-LS | LS | LS | AD-LS | ---- |
| Shear, ppi | 46.0 | 56.0 | 51.0 | 48.1 | >122 | 57.6 | 43 | >57.7 | ---- | >30.9 | >32.5 | >33.6 | 35 |
| Locus of failure | AD-LS | LS | LS | AD-LS | BRK-AD-LS | BK | LS | BK-AD | ---- | BK | BK | BK | ---- |

[a] See Page 16 for test procedures.

[b] Matrecon liner material number plus number indicating seam variation.

[c] Stress at 100%, 200%, and 300% elongations, respectively.

TABLE A-7. PROPERTIES[a] OF BUTYL AND ETHYLENE PROPYLENE RUBBER MEMBRANES AFTER 1 YEAR EXPOSURE TO LEACHATE GENERATED IN SIMULATED SANITARY LANDFILLS, BURIED STRIP SPECIMENS

| Item | Butyl Rubber | | | Ethylene-Propylene Rubber (EPDM) | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Specimen[b] no. | 7 | 22 | 24 | 7* | 8 | 16 | 25 | 26 | 16* |
| Generator base no. | 21 | 21 | 21 | 21 | 17 | 23 | 24 | 18 | 23 |
| Thickness, mils | 65 | 74.8 | 95.5 | 64 | 65 | 58 | 65.5 | 34.5 | 51.0 |
| Tensile strength, psi | 1360 | 1300 | 1470 | 1395 | 1780 | 1140 | 1610 | 1660 | 1477 |
| Elongation at break, % | 450 | 575 | 425 | 410 | 575 | 475 | 525 | 425 | 410 |
| Tensile set, % | 17 | 65 | 7 | 14 | 25 | 11 | 22 | 7 | 12 |
| S-100[c], psi | 270 | 320 | 340 | ---- | 300 | 240 | 390 | 340 | ---- |
| S-200 , psi | 600 | 480 | 720 | 685 | 720 | 530 | 820 | 820 | 740 |
| S-300 , psi | 940 | 620 | 1120 | ---- | 1130 | 780 | 1160 | 1290 | ---- |
| Tear strength, ppi (Die C) | 211 | 169 | 207 | 202 | 240 | 197 | 117 | 88 | 195 |
| Duro A - Inst. rdg. | 49 | 57.5 | 60.5 | ---- | 59 | 52 | 64.5 | 57 | ---- |
| 10 sec. rdg. | 44 | 52 | 55 | 50.5 | 54.5 | 49 | 60 | 54 | 51.5 |
| Puncture resistance (Rate of Penetration 20 ipm) | | | | | | | | | |
| Force, lb | 41.0 | 43.2 | 58.2 | 49.5 | 53.6 | 42.1 | 45.3 | 26.3 | 40.1 |
| Elongation, in | 0.58 | 0.60 | 0.55 | ---- | 0.60 | 0.69 | 0.56 | 0.59 | ---- |
| Volatiles at 105°F, % | 1.54 | 2.32 | 1.0 | 2.02 | 5.95 | 5.50 | 5.59 | 8.99 | 5.54 |
| Seam adhesive system | Cement 8800 | Cement 8800 | Cement 8800 +Tape | Cmt. 8800 Tape + Sealant | > | Solvent 374 Cmt. MAG 1265 | Cmt. 8800 w/cold Tape + Sealant | > | Mfgr. |
| Seam strength | | | | | | | | | |
| Peel, ppi | 3.7 | 5.1 | 2.8 | 2.9 | 7.3 | 2.1 | 8.0 | 5.6 | 2.0 |
| Locus of failure | AD-LS | AD | AD-LS | ---- | AD | AD-LS | AD-LS | AD | ---- |
| Shear, ppi | 37.3 | 27.3 | 37.2 | 37.2 | 45.0 | 15.95 | 42.3 | 41.3 | 24.3 |
| Locus of failure | AD-LS | AD-LS | AD-LS | ---- | AD | AD-LS | AD-LS | AD | ---- |

[a] See Table 4 for test procedures.

[b] Matrecon liner material number.

[c] Stress at 100%, 200%, and 300% elongations, respectively.

*Mounted liner.

TABLE A-8. PROPERTIES[a] OF MISCELLANEOUS POLYMERIC MEMBRANES AFTER 1 YEAR OF EXPOSURE TO LEACHATE GENERATED IN SIMULATED SANITARY LANDFILLS

| | Neoprene | Poly-butylene | Poly-propylene | Polyethylene liner of steel pipe containing refuse | | | | | | Polyethylene liners in base | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Bottom | | Middle | | Top | | | |
| | | | | With | Across | With | Across | With | Across | With | Across |
| Specimen[b] no. | 9 | 20 | 27 | 21 | ---- | 21 | ---- | 21 | ---- | 21 | ---- |
| Generator base no. | 20 | 19 | 17 | ---- | ---- | ---- | ---- | ---- | ---- | 19 | ---- |
| Thickness, mils | 71.7 | 9.8 | 10 | 11 | ---- | ---- | ---- | ---- | ---- | 11 | ---- |
| Tensile strength, psi | 1620 | 5330 | 6560 | 2618 | 2436 | 2400 | 1700 | 2210 | 1080 | 2470 | 2460 |
| Elongation at break, % | 350 | 350 | 825 | 500 | 500 | 450 | 475 | 420 | 335 | 490 | 625 |
| Tensile set, % | 2 | 220 | 595 | ---- | ---- | ---- | ---- | ---- | ---- | 365 | 500 |
| S-100[c], psi | 340 | 2220 | 3040 | 1273 | 1125 | 1360 | 1040 | 1320 | 980 | 1210 | 1010 |
| S-200 , psi | 910 | 3070 | 3120 | 1420 | 1165 | 1500 | 1060 | 1430 | 990 | 1360 | 1050 |
| S-300 , psi | 147 | 4440 | 3200 | 1635 | 1200 | 1730 | 1145 | 1680 | 1040 | 1590 | 1120 |
| Tear strength (Die C), ppi | 180 | 800 | 480 | 520 | ---- | 475 | 490 | 520 | 500 | 520 | 472 |
| Duro A - Inst. rdg. | 60.5 | 80.5 | 83 | 70.5 | ---- | ---- | ---- | ---- | ---- | 70.5 | ---- |
| 10 sec. rdg. | 57 | 80 | 82 | 69.5 | ---- | ---- | ---- | ---- | ---- | 70 | ---- |
| Puncture resistance (rate of penetration 20 ipm): | | | | | | | | | | | |
| Force, lb | 55.9 | 21.2 | 20.5 | 21.8 | ---- | ---- | ---- | ---- | ---- | 14.8 | ---- |
| Elongation, in | 0.60 | 0.33 | 0.34 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- |
| Volatiles at 105°F, % | 8.73 | 0.335 | 0.40 | 0.25 | ---- | ---- | ---- | ---- | ---- | 0.36 | ---- |
| Seam adhesive system | Cement N-100 | Heat Seal | ---- | Heat Seal | ---- | ---- | ---- | ---- | ---- | Heat Seal | ---- |
| Seam strength | | | | | | | | | | | |
| Peel, ppi | 4.9 | 10.8 | ---- | 10.3 | ---- | ---- | ---- | ---- | ---- | 11.4 | ---- |
| Locus of failure | AD-LS | LS | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- |
| Shear, ppi | 62.2 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- |
| Locus of failure | AD-LS | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- |

[a]See page 16 for list of test procedures.

[b]Matrecon liner material number.

[c]Stress at 100%, 200%, and 300% elongations, respectively.

TABLE A-9. PROPERTIES OF MISCELLANEOUS POLYMER COMPOSITIONS AFTER 1 YEAR OF EXPOSURE TO LEACHATE

| | TPR[a] | | Natural[b] rubber | Styrene[b] butadiene | Urethane[b] rubber | Neoprene[b] | Neoprene[c] sponge |
|---|---|---|---|---|---|---|---|
| | 1600 | 1900E | | | | | |
| Specimen number | 28 | 29 | 30 | 31 | 32 | 33 | 34 |
| Generator base | 17 | 18 | 18 | 18 | 18 | 17 | 18 |
| Tensile strength, psi | - | - | 1280 | 820 | 1390 | 1000 | 100 |
| Elongation at break, % | - | - | 650 | 200 | 550 | 575 | 250 |
| Tensile set, % | - | - | 6 | 12 | 19 | 11 | 58 |
| S-100, psi | - | - | 100 | 530 | 440 | 90 | 50 |
| S-200, psi | - | - | 150 | 820 | 560 | 170 | 80 |
| S-300, psi | - | - | 210 | - | 635 | 270 | - |
| Duro A, instant reading | 54 | 90.5 | 34.5 | 71.5 | 82 | 31 | - |
| 10 sec. reading | 47 | 87.5 | 34.5 | 68 | 77 | 31 | - |
| Volatiles at 105°C, % | 3.98 | 1.79 | 4.09 | 5.36 | 2.21 | 8.94 | 44.45 |

[a]TPR=Thermoplastic rubber, ethylene propylene block polymer, in a molded slab.

[b]Sheet gasket materials.

[c]Neoprene sponge used to make airtight seals between flanges of the steel columns and the bases.

TABLE S-1. PROPERTIES OF POLYMERIC LINER MEMBRANES INSTALLED AS BARRIERS (FROM TABLE I, "FIRST INTERIM REPORT")

| Item | Polyethylene | | Polyvinyl chloride | | Butyl rubber | | Hypalon, with nylon scrim | | Ethylene-propylene-diene (EPDM) rubber | | Chlorinated polyethylene | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cell no. | 1,19 | | 2,20 | | 3,21 | | 4,22 | | 5,23 | | 6,24 | |
| Liner no. | 21 | | 17 | | 7 | | 6 | | 16 | | 12 | |
| Thickness, mils | 10-12 | | 20-21 | | 61-65 | | 32-36 | | 49-53 | | 31-32 | |
| Water absorption, % | | | | | | | | | | | | |
| 2 h @ 100°C | 0.61 | | 2.15 | | 0.17 | | 7.17 | | 0.47 | | 2.93 | |
| 7 days @ 25°C | 0.38 | | 0.95 | | 0.18 | | 2.04 | | 0.61 | | 1.43 | |
| 70 days @ 25°C | ---- | | ---- | | 0.52 | | 4.52 | | 1.90 | | 5.31 | |
| Puncture resistance,[a] 1 ipm | | | | | | | | | | | | |
| Max. force, lb | ---- | | ---- | | 33.5 | | 29.5 | | 31.6 | | 33.8 | |
| Elongation, in | ---- | | ---- | | 1.14 | | 1.01 | | 1.38 | | 1.03 | |
| Puncture resistance,[a] 20 ipm | | | | | | | | | | | | |
| Max. force, lb | 13.9 | | 25.8 | | 44.8 | | 32.9 | | 39.4 | | 47.0 | |
| Elongation, in | 0.76 | | 0.69 | | 1.22 | | 0.60 | | 1.44 | | 1.04 | |
| Seam strength | | | | | | | | | | | | |
| Peel, ppi | 15.6 | | 4.0 | | 3.8 | | 30 | | 2.5 | | 10 | |
| Shear, ppi | 20.2 | | 37.2 | | 30 | | 50 | | 14.6 | | 57 | |
| Hardness (Duro A) | | | | | | | | | | | | |
| Inst. rdg. | 98 | | 81 | | 55 | | 81 | | 57 | | 85 | |
| 10 sec. rdg. | 98 | | 76 | | 51 | | 79 | | 54 | | 87 | |
| Direction of test (re grain) | With | Across | With | Across | With | Across | With | Across | With | Across | With | Across |
| Tensile strength, psi | 1700 | 2590 | 2640 | 2520 | 1440 | 1430 | 1920 | 1610 | 1510 | 1440 | 2460 | 2080 |
| Elongation at break, % | ---- | ---- | 270 | 290 | 360 | 430 | 250 | 250 | 420 | 400 | 300 | 520 |
| Tensile set, % | 177 | 667 | 68 | 77 | 15 | 18 | 115 | 106 | 13 | 19 | 199 | 230 |
| S-100,[b] psi | 1270 | 1030 | 1260 | 1130 | 350 | 290 | 1000 | 860 | 350 | 350 | 1220 | 520 |
| S-200,[b] psi | 1470 | 1050 | 2080 | 1850 | 770 | 610 | 1710 | 1330 | 760 | 760 | 1820 | 840 |
| S-300,[b] psi | 1680 | 1120 | ---- | ---- | 1230 | 1000 | ---- | ---- | 1120 | 1120 | 2460 | 1200 |
| Tear strength,[c] ppi | 415 | 360 | 352 | 317 | 180 | 180 | 320 | 280 | 181 | 181 | 270 | 240 |

[a] Method 2065, Fed. Test Methods 101.

[b] Stress at 100, 200, and 300% elongation, respectively.

[c] ASTM D624, Die C.

TABLE S-2. STRENGTH OF SEAMS[a] OF POLYMERIC LINER MATERIALS (FROM TABLE II, "FIRST INTERIM REPORT")

| Material | Matrecon Liner & Joint No. | Buried in Cell No. | Thickness, mil | Method of Seaming | Peel Test: Strength ppi | Peel Test: Locus of Failure[b] | Shear Test: Strength ppi | Shear Test: Locus of Failure[a] |
|---|---|---|---|---|---|---|---|---|
| Polyethylene* | 21* | 1,19 | 10-12 | **Heat seal | >15.6 | LS-at heat seal | >20.2 | No BRK |
| Polybutylene | 20 | 1,19 | ----- | Heat seal | 13.0 | LS-LS | >30 | No BRK and LS |
| Polyvinylchloride | 10 | 1,19 | 32 | Solvent Tetrahydrofuran (THF) | 13.3 | AD-LS | >64.5 | BRK |
| Polyvinylchloride | 11 | 1,19 | 30 | Solvent THF | 14.6 | AD-LS | >54 | BRK |
| Polyvinylchloride | 15 | 11,17 | 10 | Solvent 6079 + Cement L-1552 | 5.0 | AD-LS | 19.6 | BRK |
| Polyvinylchloride* | 17*-1 | 2,20* | 20-21 | **Solvent 6079 + Cement L-1552 (factory) | 2.0 | AD-AD | 27.2 | BRK and AD-AD |
| | -2 | 11,17 | ----- | Solvent 6079 + Cement L-1552 | 4.0 | AD-AD | 37.2 | AD AD |
| Polyvinylchloride | 19 -1 | 1,19 | 22 | Solvent 6079 + Cement L-1552 | 5.9 | AD-AD | >39.5 | BRK |
| | 2 | 1,19 | ----- | Solvent THF | 8.6 | AD | >35.6 | BRK |
| Chlorinated polyethylene | 23 -1 | 5,23 | 15-16 | Cement SC-1556 | 1.0 | AD-LS | >29.6 | BRK |
| | 2 | 5,23 | ----- | Solvent 50 Toluene: 50 THF | 9.5 | AD | >27 | BRK |
| | 3 | 5,23 | ----- | Solvent 60 Trichloroethane: 40 THF | 6.5 | AD | >30.4 | BRK |
| | 4 | 5,23 | ----- | Cement SC-1554 | 6.4 | AD-LS (Adh hard) | >30.4 | BRK |
| Chlorinated polyethylene* | 12*-1 | 4,22 | 31-32 | Cement SC-1556 | 2.0 | AD-LS | 38.6 | AD-LS |
| | 2 | 6,24* | ----- | **Solvent 50 Toluene: 50 THF | 10 | AD | 57 | BRK and AD |
| | 3 | 4,22 | ----- | Solvent 60 Trichloroethane: 40 THF | 3.9 | AD | 50 | BRK and AD |
| | 4 | 4,22 | ----- | Cement SC-1554 - | 7 | AD-LS (Adh hard) | 48 | AD-LS (Adh hard) |
| Chlorinated polyethylene | 13 -1 | 6,24 | 36-38 | Cement SC-1556 | 10 | AD-LS (Adh hard) | >200 | BRK |
| | 2 | 6,24 | ----- | Solvent 50 Toluene: 50 THF | 10 | AD | >218 | BRK and AD |
| | 3 | 6,24 | ----- | Solvent 60 Trichloroethane: 40 THF | 2 | AD | 127 | AD |
| | 4 | 6,24 | ----- | Cement SC-1554 | 6.8 | AD-LS | 170 | BRK |

-continued-

TABLE S-2 (continued)

| Material | Matrecon Liner & Joint No. | Buried in Cell No. | Thickness, mil | Method of Seaming | Peel Test | | Shear Test | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Strength ppi | Locus of Failure[b] | Strength ppi | Locus of Failure[a] |
| Hypalon | 3-1 | 2,20 | 31 | Heat seal (factory) | >20.8 | BRK | >26.2 | BRK |
| | 2 | 2,20 | ----- | Solvent 6079 + Cement L-1552 | 2 | AD-AD and AD-LS | 17 | AD-LS |
| Hypalon, nylon reinforced | 4-1 | 2,20 | 33-34 | Heat seal (factory) | >24 | DEL | >61 | BRK |
| | 2 | 2,20 | ----- | Solvent 6079 + Cement L-1552 | 0 | AD-AD-no test | 0 | AD-AD - no test |
| Hypalon with nylon scrim | 6* | 4,22* | 32-36 | **Cement 280Z | 30 | BRK and DEL | >50 | BRK |
| Hypalon, reinforced | 14 | 3,21 | 32-39 | Solvent Trichlorethylene | 1 | AD | 50.5 | AD |
| Butyl rubber | 7* | 3,21* | 61-65 | **Cement 8800 | 3.8 | AD-LS (Tacky) | 30 | AD-LS (Tacky) |
| Butyl rubber | 24 | 3,21 | 99-100 | Cement 8800 + cold seal tape | 3.3 | AD-LS (Tacky) | 41.5 | AD-LS (Tacky) |
| Butyl rubber | 22 | 3,21 | 72-75 | Cement 8800 | 6.5 | AD-LS (Tacky) | 32.5 | AD-LS (Tacky) |
| EPDM rubber | 26 | 12,18 | 35 | Cement 8800 + cold seal tape | 6.0 | AD | 45.5 | AD |
| EPDM rubber | 8 | 8,17 | 62-65 | Cement 8800 | 4.5 | AD-(Tacky) | 37 | AD-(Tacky) |
| | 25 | 6,24 | ----- | Cement 8800 + cold seal tape | 6.8 | AD-(Tacky) | 33 | AD-(Tacky) |
| EPDM rubber | 16 | 5,23 | 49-53 | Solvent 374 + Cement MAG 1265 | 2.5 | AD-LS | 14.6 | AD-LS |
| | 18* | 5,23 | ----- | **Solvent 374 + Cement MAG (factory) | 5.4 | AD-LS | 44.5 | BRK and AD-LS |
| Neoprene | 9 | 2,20 | 60 | Cement N-100 | 12.4 | AD-LS | 85 | AD |

* Material being tested as barrier in leachate generator/exposure cells.

**Splice system used in barrier.

[a]Except for the factory-made seams and the heat-seal seams, all splices are 2 inch lap seams.

[b]Locus of failure - code:
- BRK = Break of liner material outside of the seam
- DEL = Delamination of the liner material
- OR = Failure of the reinforcing fabric
- AD = Failure within the adhesive
- AD-AD = Failure between two coats of adhesive
- LS = Failure at liner surface
- AD-LS = Failure between adhesive and liner surface

TABLE S-3. PROPERTIES OF ADMIX LINERS MOUNTED AS BARRIERS (FROM TABLE III, "FIRST INTERIM REPORT")

| Admix Material | Asphalt Concrete[a] | Hydraulic Asphalt Concrete[b] | Soil Cement[c] | Soil Asphalt[d] | Bituminous Seal[e] | Fabric + Asphalt Emulsion[f] |
|---|---|---|---|---|---|---|
| Cell No. | 7,13 | 8,14 | 9,15 | 10,16 | 11,17 | 12,18 |
| Particle size distribution of aggregate | | | | | | |
| Passing 4 mesh, % | 90.7 | 89.4 | 88.9 | 79.2 | ----- | ----- |
| Passing 8 mesh, % | 61.0 | 67.1 | 70.8 | 55.8 | ----- | ----- |
| Passing 16 mesh, % | 45.1 | 50.9 | 53.7 | 39.9 | ----- | ----- |
| Passing 30 mesh, % | 30.1 | 33.7 | 38.8 | 27.3 | ----- | ----- |
| Passing 50 mesh, % | 19.4 | 21.5 | 29.2 | 18.5 | ----- | ----- |
| Passing 100 mesh, % | 11.2 | 12.4 | 20.8 | 13.4 | ----- | ----- |
| Passing 200 mesh, % | 6.6 | 7.2 | 15.0 | 11.4 | ----- | ----- |
| Soil tests | | | | | | |
| Sand equivalent | ---- | ---- | 27 | 31 | ----- | ----- |
| Liquid limit | ---- | ---- | 17.6 | 17.0 | ----- | ----- |
| Plastic limit | ---- | ---- | non-plastic | non-plastic | ----- | ----- |
| Plasticity index | ---- | ---- | non-plastic | non-plastic | ----- | ----- |
| Asphalt tests | | | | | | |
| Penetration at 25°C | 68 | 68 | ---- | ----- | ----- | ----- |
| Penetration (extracted) asphalt | 44 | 62 | ---- | ----- | ----- | ----- |
| Softening point °C (°F) | ---- | ---- | ---- | ----- | 192 | ----- |
| Viscosity, capillary at 60°C, cSt | ---- | ---- | ---- | 1101 | ----- | ----- |
| Viscosity, sliding plate at 25°C, at 0.05 $sec^{-1}$, MP | 14.5 | 9.7 | ---- | 0.20 | 8.5 | 4.5 |
| Viscosity, sliding plate at 25°C, at 0.001 $sec^{-1}$, MP | 20.0 | 14.5 | ---- | 0.14 | 19.3 | 6.0 |
| Microductility at 25°C, mm | 40 | 76 | ---- | 7 | 2 | 29 |
| Tests on barrier specimens | | | | | | |
| Thickness of barrier, inch | 2.2 | 2.4 | 4.5 | 4 | 0.3 | 0.3 |
| Density, $g./cm^3$ | 2.387 | 2.416 | 2.169 | 2.228 | ----- | ----- |
| Density, $lb/ft^3$ | 149.0 | 150.8 | 135.4(dry) | 139.1 | ----- | ----- |
| Void ratio (vol. voids/vol. solids), % | 6.4 | 2.9 | ---- | 10.4 | 0 | ----- |
| Water swell, mil | 1 | 0 | 0 | 17 | ----- | ----- |
| Coefficient of permeability, cm/sec (Ref. 4) | $1.2 \times 10^{-8}$ | $3.3 \times 10^{-9}$ | $1.5 \times 10^{-6}$[g] | $1.7 \times 10^{-3}$ | $<10^{-9}$ | $<10^{-9}$ |
| Compressive strength, psi | 2805 | 2712 | 1910 | 1218 | ----- | ----- |
| Compressive strength after 24 h immersion[h] | 2230 | 2328 | 1323 | 184 | ----- | ----- |
| % strength retained | 80 | 86 | 69 | 15 | ----- | ----- |

[a]Composition: 7.1 asphalt; 100 aggregate

[b]Composition: 9.0 asphalt; 100 aggregate

[c]Composition: 95 soil: 5Kaolin clay: 10 type 5 cement: 8.8 water

[d]Composition: 7.0 SC-800 liquid asphalt; 100 aggregate

[e]Composition: Catalytically blown asphalt layer 4.7 $kg/m^2$ (8.7 pounds per square yard)

[f]Composition: Asphalt from emulsion spread on polypropylene nonwoven fabric-4.8 $kg/m^2$ (8.9 lb. per square yard)

[g]Measured on molded specimen

[h]Asphalt Cement and Hydraulic Asphalt Cement immersed in water at 60°C, Soil Asphalt and Soil Cement at R.T.

Ref. 4 Vallerga and Dicks J. Materials, 3 (1) 73 (1968)

TABLE S-4. PROPERTIES OF POLYMERIC LINER MEMBRANES BURIED IN LEACHATE GENERATORS (FROM APPENDIX A, "FIRST INTERIM REPORT")

| Item | Polyethylene | | Polyethylene* | | Polypropylene | | Polybutylene | |
|---|---|---|---|---|---|---|---|---|
| Cell no.[a] | 1, 19 | | Collection bags | | 11, 17 | | 1, 19 | |
| Liner no. | 21 | | 35 | | 27 | | 20 | |
| Thickness, mils | 10-12 | | 11 | | 9-12 | | 8-10 | |
| Water absorption, % | | | | | | | | |
| 2 h @ 100°C | 0.61 | | 0.16 | | 0.24 | | ---- | |
| 7 days @ 25°C | 0.38 | | ---- | | 0.29 | | 0.41 | |
| 70 days @ 25°C | ---- | | ---- | | ---- | | ---- | |
| Puncture resistance[b], 1 ipm | | | | | | | | |
| Max. force, lb | ---- | | ---- | | ---- | | ---- | |
| Elongation, in | ---- | | ---- | | ---- | | ---- | |
| Puncture resistance[b], 20 ipm | | | | | | | | |
| Max. force, lb | 13.9 | | ---- | | 16.9 | | 9.8 | |
| Elongation, in | 0.76 | | ---- | | 0.48 | | 0.32 | |
| Hardness (Duro A) | | | | | | | | |
| Inst. rdg. | 97 | | 95 | | 95 | | 98 | |
| 10 sec. rdg. | 97 | | 95 | | 95 | | 98 | |
| Direction of test (re grain) | With | Across | With | Across | With | Across | With | Across |
| Tensile strength, psi | 1700 | 2590 | 2610 | 2290 | 2000 | 6590 | 2950 | 5770 |
| Elongation at break, % | 320 | 690 | 510 | 670 | 520 | 860 | 225 | 410 |
| Tensile set, % | 177 | 667 | 500 | 667 | 430 | 710 | 132 | 248 |
| Stress @ 100%, psi | 1270 | 1030 | 1520 | 1220 | 1360 | 2650 | 2210 | 2310 |
| 200%, psi | 1470 | 1050 | 1540 | 1240 | 1340 | 2760 | 2730 | 3280 |
| 300%, psi | 1680 | 1120 | 1680 | 1280 | 1360 | 2740 | ---- | 4710 |
| Tear strength[c], ppi | 415 | 360 | ---- | ---- | 898 | 775 | 500 | 544 |

[a]Underline = installed as barrier

[b]Method 2065, Fed. Test Methods 101

[c]ASTM D624, Die C

*Used in making leachate collection bags

-continued-

TABLE S-4 (continued)

| Item | Polyvinyl-chloride | | Polyvinyl-chloride | | Polyvinyl-chloride | | Polyvinyl-chloride | | Polyvinyl-chloride | | Polyvinyl-chloride | | Polyvinyl-chloride | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cell no.[a] | ---- | | ---- | | 1,19 | | 1,19 | | 11,17 | | 2,20 11,17 | | 1,19 | |
| Liner no. | 1 | | 2 | | 10 | | 11 | | 15 | | 17 | | 19 | |
| Thickness, mils | 20 | | 30-31 | | 32 | | 30 | | 10 | | 20-21 | | 22 | |
| Water absorption, % | | | | | | | | | | | | | | |
| 2 h @ 100°C | ---- | | ---- | | 1.10 | | 0.95 | | 2.40 | | 2.15 | | 0.91 | |
| 7 days @ 25°C | ---- | | ---- | | 0.42 | | 0.54 | | 1.52 | | 0.95 | | 0.30 | |
| 70 days @ 25°C | ---- | | ---- | | 1.05 | | 1.26 | | ---- | | ---- | | ---- | |
| Puncture resistance[b], 1 ipm | | | | | | | | | | | | | | |
| Max. force, lb | ---- | | ---- | | 36.2 | | 34.8 | | 9.65 | | ---- | | ---- | |
| Elongation, in | ---- | | ---- | | 0.67 | | 0.92 | | 0.67 | | ---- | | ---- | |
| Puncture resistance[b], 20 ipm | | | | | | | | | | | | | | |
| Max. force, lb | ---- | | ---- | | 42.9 | | 40.2 | | 12.8 | | 25.8 | | 24.0 | |
| Elongation, in | ---- | | ---- | | 0.62 | | 0.67 | | 0.61 | | 0.69 | | 0.71 | |
| Hardness (Duro A) | | | | | | | | | | | | | | |
| Inst. rdg. | 87 | | 86 | | 87 | | 87 | | 77 | | 81 | | 80 | |
| 10 sec. rdg. | 81 | | 82 | | 82 | | 82 | | 72 | | 76 | | 72 | |
| Direction of test (re grain) | With | Across | With | Across | With | Across | With | Across | With | Across | With | Across | With | Across |
| Tensile strength, psi | 1610 | 1540 | 1970 | 1900 | 3400 | 2840 | 3230 | 2800 | 2360 | 2630 | 2640 | 2520 | 2780 | 2260 |
| Elongation at break, % | 210 | 260 | 230 | 280 | 280 | 300 | 300 | 310 | 200 | 300 | 270 | 290 | 330 | 340 |
| Tensile set, % | 15 | 20 | 34 | 46 | 108 | 130 | 116 | 132 | 35 | 82 | 68 | 77 | 97 | 105 |
| Stress @ 100%, psi | 1200 | 1040 | 1030 | 980 | 1680 | 1340 | 1520 | 1330 | 1680 | 1230 | 1260 | 1130 | 1150 | 1060 |
| 200%, psi | 1480 | 1380 | ---- | ---- | 2610 | 2080 | 2390 | 1930 | 2360 | 1880 | 2080 | 1850 | 1890 | 1590 |
| 300%, psi | ---- | ---- | ---- | ---- | ---- | 2840 | 3230 | 2720 | ---- | 2630 | ---- | ---- | 2620 | 2170 |
| Tear strength[c], ppi | ---- | ---- | ---- | ---- | 390 | 380 | 380 | 370 | 290 | 270 | 352 | 317 | 295 | 275 |

[a]Underline = installed as barrier

[b]Method 2065, Fed. Test Methods 101

[c]ASTM D624, Die C

*Used in making leachate collection bags

-continued-

TABLE S-4 (continued)

| Item | Chlorinated polyethylene | | Chlorinated polyethylene | | Chlorinated polyethylene | | Hypalon | | Hypalon, nylon reinforced | | Hypalon with nylon scrim | | Hypalon, supported | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cell no.[a] | 5,23 | | 6,24 | 4,22 | 6,24 | | 2,20 | | 2,20 | | 4,22 | 4,22 | 3,21 | |
| Liner no. | 23 | | | 12 | 13 | | 3 | | 4 | | | 6 | 14 | |
| Thickness, mils | 15-16 | | | 31-32 | 36-38 | | 31 | | 33-34 | | | 32-36 | 32-39 | |
| Water absorption, % | | | | | | | | | | | | | | |
| 2 h @ 100°C | 6.68 | | | 2.93 | 13.0 | | 4.19 | | 5.16 | | | 7.17 | 15.3 | |
| 7 days @ 25°C | 3.15 | | | 1.43 | 6.49 | | 2.36 | | 2.80 | | | 2.04 | 4.08 | |
| 70 days @ 25°C | ---- | | | 5.31 | 13.7 | | 7.31 | | 8.66 | | | 4.52 | 7.13 | |
| Puncture resistance[b], 1 ipm | | | | | | | | | | | | | | |
| Max. force, lb | ---- | | | 33.8 | 83.6 | | 17.6 | | 33.5 | | | 29.5 | 41.9 | |
| Elongation, in | ---- | | | 1.03 | 0.54 | | 1.18 | | 0.53 | | | 1.01 | 0.51 | |
| Puncture resistance[b], 20 ipm | | | | | | | | | | | | | | |
| Max. force, lb | 22.8 | | | 47.0 | 70.2 | | 25.4 | | 30.6 | | | 32.9 | 67.9 | |
| Elongation, in | 0.92 | | | 1.04 | 0.31 | | 1.16 | | 0.24 | | | 0.60 | 0.41 | |
| Hardness (Duro A) | | | | | | | | | | | | | | |
| Inst. rdg. | 87 | | | 85 | 79 | | 86 | | 82 | | | 81 | 76 | |
| 10 sec. rdg. | 85 | | | 77 | 76 | | 83 | | 81 | | | 79 | 73 | |
| Direction of test (re grain) | With | Across | With | Across | With | Across | With | Across | With | Across | With | Across | With | Across |
| Tensile strength, psi | 2510 | 1160 | 2460 | 2080 | ---- | 960 | 1710 | 1430 | 1020 | 1050 | 1920 | 1610 | 1750 | 1560 |
| Elongation at break, % | 325 | 300 | 300 | 520 | 70 | 250 | 580 | 640 | 420 | 170 | 250 | 250 | 150 | 160 |
| Tensile set, % | 173 | 86 | 199 | 230 | ---- | 162 | 370 | 380 | 350 | 170 | 115 | 106 | ---- | ---- |
| Stress @ 100%, psi | 750 | 480 | 1220 | 520 | strip- | 890 | 670 | 520 | 720 | 950 | 1000 | 860 | 1750 | 1540 |
| 200%, psi | 1700 | 740 | 1820 | 840 | ped | 920 | 850 | 620 | 820 | ---- | 1710 | 1330 | stripped | |
| 300%, psi | 2370 | 1130 | 2460 | 1200 | fiber | ---- | 1030 | 760 | 850 | ---- | ---- | ---- | fiber | |
| Tear strength[c], ppi | 240 | 190 | 270 | 240 | 516 | 476 | 290 | 270 | 303 | 365 | 320 | 280 | 333 | ---- |

[a]Underline = installed as barrier

[b]Method 2065, Fed. Test Methods 101

[c]ASTM D624, Die C

*Used in making leachate collection bags

-continued-

TABLE S-4 (continued)

| Item | Butyl rubber | | Butyl rubber | | Butyl rubber | | EPDM rubber | | EPDM rubber | | EPDM rubber | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cell no.[a] | 3,21,3,21 | | 3,21 | | 3,21 | | 12,18 | | 8,17,6,24 | | 5,23,5,23 | |
| Liner no. | 7 | | 24 | | 22 | | 26 | | 8,25 | | 16,18 | |
| Thickness, mils | 61-65 | | 99-100 | | 72-75 | | 35 | | 62-65 | | 49-53 | |
| Water absorption, % | | | | | | | | | | | | |
| 2 h @ 100°C | 0.17 | | 0.10 | | 0.23 | | 0.29 | | 0.36 | | 0.47 | |
| 7 days @ 25°C | 0.18 | | 0.24 | | 0.44 | | 0.48 | | 0.34 | | 0.61 | |
| 70 days @ 25°C | 0.52 | | ---- | | ---- | | ---- | | 0.74 | | 1.90 | |
| Puncture resistance[b], 1 ipm | | | | | | | | | | | | |
| Max. force, lb | 33.5 | | ---- | | ---- | | ---- | | 43.5 | | 31.6 | |
| Elongation, in | 1.14 | | ---- | | ---- | | ---- | | 1.33 | | 1.38 | |
| Puncture resistance[b], 20 ipm | | | | | | | | | | | | |
| Max. force, lb | 44.8 | | 64.9 | | 47.7 | | 30.0 | | 56.9 | | 39.4 | |
| Elongation, in | 1.22 | | 1.24 | | 1.24 | | 1.25 | | 1.46 | | 1.44 | |
| Hardness (Duro A) | | | | | | | | | | | | |
| Inst. rdg. | 55 | | 60 | | 58 | | 63 | | 61 | | 57 | |
| 10 sec. rdg. | 51 | | 57 | | 54 | | 61 | | 56 | | 54 | |
| Direction of test (re grain) | With | Across | With | Across | With | Across | With | Across | With | Across | With | Across |
| Tensile strength, psi | 1440 | 1430 | 1500 | 1500 | 1170 | 870 | 1890 | 1820 | 1900 | 1850 | 1510 | 1440 |
| Elongation at break, % | 360 | 430 | 360 | 430 | 620 | 525 | 460 | 490 | 560 | 600 | 420 | 400 |
| Tensile set, % | 15 | 18 | 15 | 18 | 73 | 48 | 12 | 13 | 26 | 24 | 13 | 9 |
| Stress @ 100%, psi | 350 | 290 | 330 | 250 | 290 | 230 | 330 | 300 | 280 | 290 | 350 | 350 |
| 200%, psi | 770 | 610 | 750 | 620 | 430 | 370 | 850 | 760 | 610 | 620 | 760 | 760 |
| 300%, psi | 1230 | 1000 | 1240 | 1020 | 580 | 510 | 1350 | 1240 | 990 | 1000 | 1120 | 1120 |
| Tear strength[c], ppi | 180 | 180 | 205 | 216 | 144 | 140 | 168 | 173 | 230 | 240 | 181 | 181 |

[a]Underline = installed as barrier

[b]Method 2065, Fed. Test Methods 101

[c]ASTM D624, Die C

*Used in making leachate collection bags

-continued-

TABLE S-4 (continued)

| Item | Natural rubber | | Styrene-butadiene rubber | | Urethane rubber | | Asphalt-impregnated fiberglass | |
|---|---|---|---|---|---|---|---|---|
| Cell no.[a] | 12,18 | | 12,18 | | 12,18 | | 3,21 | |
| Liner no. | 30 | | 31 | | 32 | | 5 | |
| Thickness, mils | 146-148 | | 130 | | 47-62 | | 64-75 | |
| Water absorption, % | | | | | | | | |
| 2 h @ 100°C | ---- | | ---- | | ---- | | 1.73 | |
| 7 days @ 25°C | ---- | | ---- | | ---- | | 1.56 | |
| 70 days @ 25°C | ---- | | ---- | | ---- | | 10.3 | |
| Puncture resistance[b], 1 ipm | | | | | | | | |
| Max. force, lb | ---- | | ---- | | ---- | | 5.7 | |
| Elongation, in | ---- | | ---- | | ---- | | 0.14 | |
| Puncture resistance[b], 20 ipm | | | | | | | | |
| Max. force, lb | ---- | | ---- | | ---- | | 8.7 | |
| Elongation, in | ---- | | ---- | | ---- | | 0.16 | |
| Hardness (Duro A) | | | | | | | | |
| Inst. rdg. | 50 | | 88 | | 78 | | 78 | |
| 10 sec. rdg. | 50 | | 86 | | 75 | | 67 | |
| Direction of test (re grain) | With | Across | With | Across | With | Across | With | Ac |
| Tensile strength, psi | 2870 | ---- | 850 | ---- | 8010 | ---- | 760 | 550 |
| Elongation at break, % | 775 | ---- | 150 | ---- | 620 | ---- | ---- | ---- |
| Tensile set, % | 14 | ---- | 6 | ---- | 4 | ---- | 4 | 3 |
| Stress @ 100%, psi | 75 | ---- | 780 | ---- | 620 | ---- | ---- | ---- |
| 200%, psi | 140 | ---- | ---- | ---- | 810 | ---- | ---- | ---- |
| 300%, psi | 220 | ---- | ---- | ---- | 1280 | ---- | ---- | ---- |
| Tear strength[c], ppi | ---- | ---- | ---- | ---- | 392 | ---- | 40 | ---- |

[a]Underline = installed as barrier

[b]Method 2065, Fed. Test Methods 101

[c]ASTM D624, Die C

*Used in making leachate collection bags

TABLE S-4 (continued)

| Item | Neoprene | | Neoprene | | Neoprene foam gasket | Thermoplastic rubber | Thermoplastic rubber |
|---|---|---|---|---|---|---|---|
| Cell no.[a] | 2,20 | | 11,17 | | 12,18 | 11,17 | 12,18 |
| Liner no. | 9 | | 33 | | 34 | 28 | 29 |
| Thickness, mils | 60 | | 125-137 | | 245-248 | 71-76 | 67-76 |
| Water absorption, % | | | | | | | |
| 2 h @ 100°C | 1.71 | | ----- | | ----- | ----- | ----- |
| 7 days @ 25°C | 1.80 | | ----- | | ----- | ----- | ----- |
| 70 days @ 25°C | 7.88 | | ----- | | ----- | ----- | ----- |
| Puncture resistance[b], 1 ipm | | | | | | | |
| Max. force, lb | 33.5 | | ----- | | ----- | ----- | ----- |
| Elongation, in | 1.05 | | ----- | | ----- | ----- | ----- |
| Puncture resistance[b], 20 ipm | | | | | | | |
| Max. force, lb | 58.7 | | ----- | | ----- | ----- | ----- |
| Elongation, in | 1.16 | | ----- | | ----- | ----- | ----- |
| Hardness (Duro A) | | | | | | | |
| Inst. rdg. | 71 | | 50 | | ----- | 64 | 88 |
| 10 sec. rdg. | 66 | | 49 | | ----- | 62 | 87 |
| Direction of test (re grain) | With | Across | With | Across | | ----- | ----- |
| Tensile strength, psi | 2320 | 2090 | 1500 | 1280 | 65 | | |
| Elongation at break, % | 340 | 340 | 720 | 675 | 220 | ----- | ----- |
| Tensile set, % | 11 | 13 | 27 | 23 | 36 | ----- | ----- |
| Stress @ 100%, psi | 640 | 560 | 110 | 94 | 37 | ----- | ----- |
| 200%, psi | 1320 | 1150 | 190 | 160 | 62 | ----- | ----- |
| 300%, psi | 2060 | 1830 | 270 | 250 | --- | ----- | ----- |
| Tear strength[c], ppi | 220 | 210 | 104 | 87 | 14 | ----- | ----- |

[a]Underline = installed as barrier

[b]Method 2065, Fed. Test Methods 101

[c]ASTM D624, Die C

*Used in making leachate collection bags

-continued-

# TECHNICAL REPORT DATA

*(Please read Instructions on the reverse before completing)*

| | | |
|---|---|---|
| 1. REPORT NO. EPA-600/2-76-255 | 2. | 3. RECIPIENT'S ACCESSION NO. |
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| | | 6. PERFORMING ORGANIZATION CODE |
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15. SUPPLEMENTARY NOTES


16. ABSTRACT This report presents available information covering the first year's exposure of liner materials to sanitary landfill leachate. Included in the report are descriptions of the monitoring and disassembly of the generators to recover the liner specimens, the results of the testing of the exposed liners, and a discussion of the results.

The year's exposure did not result in losses of impermeability in any of the liners. There were losses, however, in the compressive strength of the admix liner materials. There were some losses in the physical properties of some of the polymeric membranes and swelling of most of these membranes. The seams of several lost strength, with the heat-sealed seams holding up best as a group.

Among the polymeric membranes, the crystalline types of polyethylene, polypropylene, and polybutylene sustained the least change during the year's exposure. However, these liners, or films, are prone to puncture and tear and are generally difficult to handle in the field. The thermoplastic membranes, chlorinated polyethylene, chlorosulfonated polyethylene (Hypalon), and polyvinyl chloride, tended to swell the most. The vulcanized rubbery liner materials, e.g. butyl and EPDM, changed little during the exposure period but had the lowest initial seam strength.

The data presented must be considered as preliminary in an ongoing project; it is premature at this point to make estimates of the service life of the various materials or to make relative comparisons among them for use in a given installation without consideration to costs and to the specifics of the installation.


17. KEY WORDS AND DOCUMENT ANALYSIS

| a. DESCRIPTORS | b. IDENTIFIERS/OPEN ENDED TERMS | c. COSATI Field/Group |
|---|---|---|
| Linings, Leaching, Refuse Disposal, Pollution, Decomposition reactions, Plastic | solid waste management | 13B |

| | | |
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