Assessment of Tankfield Dike Lining Materials and Methods

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FOREWORD

The American Petroleum Institute (API) commissioned the following assessment of currently available tankfield lining materials and methods for secondary containment within a diked area to meet the needs of its members operating in jurisdictions that require these liners.

API believes that a universal requirement for lining tankfields is an unnecessary expense and inefficient solution to concerns about possible environmental contamination from petroleum storage operations. The petroleum industry, operating through API, has developed and maintains engineering standards, recommended practices, inspection codes, and inspector certification programs that together provide petroleum storage management practices that minimize environmental risk from petroleum operations.

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EXECUTIVE SUMMARY

This report documents a study performed for the American Petroleum Institute (API) to provide an assessment of tankfield dike lining materials and methods for secondary containment within a diked area of aboveground petroleum storage facilities. For the purposes of this study, "secondary containment" refers to the diked area of a storage tank facility and does not include lining the area beneath a storage tank. The study includes a review of the current regulatory environment and a survey of candidate liner materials and installation methods.

The concept of secondary containment refers to the use of systems designed to contain overflow or spills of stored product for a period long enough so that removal and cleanup can take place with minimal release to the environment.

The construction and operation of aboveground storage tanks (ASTs) is covered by federal and state regulations. These include the federal Spill Prevention, Control and Countermeasures program under the Clean Water Act and state or local fire, safety and environmental codes. Ongoing activities under the Oil Pollution Act of 1990 (OPA) may lead to additional secondary containment regulations for ASTs. OPA's spill prevention and response provisions have not yet resulted in new regulatory requirements; however, final rules are expected this year. Also, OPA's liner study should be completed and sent to Congress this year. Liner requirements already exist in some states, and local rules may apply in a given location.

Industry practice, consistent with these regulatory requirements, has been to provide secondary containment systems, which include dikes, berms or retaining walls surrounding storage tanks. To be effective, the walls and floor of the containment area must be impervious to the product stored long enough to allow cleanup to take place in the event of a spill. One method of improving the effectiveness of diked areas in controlling spills or overflows is the use of liners to increase the imperviousness of the tankfield floor and walls or dikes. Liners may be constructed of either natural materials, such as low permeability clay, or synthetic flexible membrane liners (geomembranes).

As a result of this study, four types of liner systems were identified which have found application for secondary containment of petroleum in diked areas surrounding ASTs:

(1) Supported coated fabrics or laminates, such as polymer films applied to a high-strength textile backing;

(2) Unsupported, extruded plastic sheet geomembranes, such as high density polyethylene (HDPE);

(3) Geosynthetic/clay composites (GCLs), which include a natural material such as bentonite affixed to a synthetic geotextile or plastic membrane backing; and

(4) Spray-on coatings that are applied to a geotextile backing.

Low permeability to the contained substance is an important criterion for liner selection. Two modes of transport must be considered: liquid transport (hydraulic conductivity) and vapor transport (molecular diffusion or permeation). Natural materials, such as soils or clay, allow movement of liquid by hydraulic conductivity, driven by hydraulic head. However, most geomembranes are essentially impermeable to liquids. They are permeable to vapor to a degree that depends on the solubility of the liquid in the polymer, temperature, and the thickness of the membrane. It is important to understand the distinctions between these modes of mass transfer and how they relate to liner selection, testing and performance standards.

The fundamental differences among the four liner system types make installation-related factors key to liner selection. Installation is as important to liner integrity as the physical properties, impermeability, and chemical resistance of the base liner material. Considerations include seaming techniques and methods used to join liner panels to existing structures such as tank ringwalls, pipes, or other tankfield equipment. Liner cover, tankfield drainage, and cathodic protection can also be important.

The AST containment field provides a challenging installation problem because the number of sealing and liner connection points is usually large. The integrity of the liner system is dependent on attaining a liquid tight seal at all attachment points. Experience in the waste containment industry shows that liner system leakage can usually be attributed to sealing problems at points of attachment rather than permeation through liner panels. Successful installation depends on quality assurance and careful attention to detail during the construction process.

The long-term integrity of a liner installation is dependent on sub-base preparation/settlement, the physical strength of the liner itself, its resistance to the effects of aging or environmental degradation, and its resistance to chemical attack in the event of a spill. A liner may degrade in performance over time due either to accidental or intentional damage, or due to the effects of exposure to the elements. In considering liner selection and liner system design, it is important to understand the failure modes that can affect the different liner types.

Over the long term any secondary containment liner system will require some degree of maintenance, inspection and repair to maintain performance as installed. The maintenance program may be integrated into the overall tank maintenance procedures as required to maintain safety standards and sustain tank operations.

Section 1
INTRODUCTION

This report documents work performed for the American Petroleum Institute (API) by TRI/Environmental, Inc. TRI, an independent contractor, performed an assessment of tankfield dike lining materials and methods for secondary containment of aboveground petroleum storage facilities. The work was performed under authorization of a Letter of Agreement from API dated December 19, 1991. The technical information was reviewed by API's Storage Tank Task Force, as well as staff members from API's Manufacturing, Distribution and Marketing Department and the Health and Environmental Affairs Department. API's Office of General Counsel provided information on federal and selected state requirements for secondary containment at facilities discussed in the report.

The scope of this work included a survey of the current technology base for tankfield dike lining materials and installation methods as well as a review of the current regulatory environment and a survey of candidate materials and installation/construction methods. The scope of the study was limited to lining materials and methods applicable to the diked area outside the storage tank itself. The study does not cover liner installations for secondary containment underneath tanks.

Section 2
BACKGROUND

The petroleum industry uses aboveground storage tank (AST) facilities for storing large quantities of crude oil, petroleum products and additives. The construction and operation of such facilities is covered by federal and state regulations. These include the federal Clean Water Act's Spill Prevention, Control and Countermeasures program and requirements being implemented under the Oil Pollution Act of 1990, as well as state and local fire, safety and environmental codes. Several industry standards have been provided by groups such as the National Fire Protection Association, the Western Fire Chiefs Association, and API. These standards form the basis for most state and local fire or safety codes that govern AST facility construction and operation. The industry practice consistent with these codes and standards has been to provide spill containment systems, including dikes, berms or retaining walls surrounding storage tanks. Berms were originally installed for lateral control. In recent years, many companies have begun to install liners for tank bottoms.

Secondary containment systems are designed to contain overflow or spills of stored material for a long enough period to allow removal and cleanup without release of spilled material to the environment. The volume contained within the diked area must exceed the capacity of the largest tank located within the field. One method of improving the effectiveness of diked areas in preventing groundwater contamination is to use liners to increase the imperviousness of the tankfield floor and walls or dikes. Liners may be natural materials such as low permeability clay or geomembranes (synthetic flexible membrane liners).

AST facilities range from very large installations such as tank farms at pipeline or shipping terminals to individual retail and oil production sites that may consist of as few as one tank. AST facilities currently are subject to state and local regulations which vary from state to state, covering many aspects of construction, operation, and maintenance. In some areas of the country, natural or synthetic liner materials have been installed to meet new state or local requirements for tankfield secondary containment. Liners can be retrofitted to an existing facility or installed as part of new construction.

At present there is no universal regulatory requirement or industry standard that requires the use of liners in the secondary containment (diked) area. The following considerations are important to liner selection. First, a wide array of synthetic liners is available, many of which were developed for other applications such as waste containment. However, the industry lacks a consistent basis for comparison and selection, and must depend heavily on manufacturers' claims for performance and durability. Also, the installation of tankfield liners is a relatively recent practice, and long term experience with the use of liners in the tankfield is lacking.

The petroleum industry has been, and continues to be, affected in a significant way by new environmental, safety and health regulations. The Oil Pollution Act of 1990 was passed by Congress in the interest of protecting the environment from releases of hydrocarbon fuels from sources such as petroleum AST's. Under the Act's mandate, the U.S. Environmental Protection Agency (EPA) has initiated a study of available technology for secondary containment of petroleum fuels and other hydrocarbons stored in bulk in aboveground facilities.

The purpose of the API liner study documented in this report is to provide a reference source for selection criteria, technical standards, field and laboratory evaluation of liner performance, as well as installation considerations for synthetic liner systems.

Section 3
REVIEW OF THE REGULATORY ENVIRONMENT

This section describes existing and proposed federal and selected state requirements that address the use of liners to reduce the permeability of tankfield floors and dikes, and the construction and operation of AST facilities in general. **The information is up to date through March 1993. However, there has been significant activity in both state and federal regulatory agencies to introduce new regulations for ASTs that may result in changes to the regulatory requirements presented below.** In any event, the summary of requirements discussed below is presented solely to provide a context for evaluating the materials and methods assessed in this report. It is not intended to provide legal advice as to particular regulatory requirements.

FEDERAL RULES AND INITIATIVES

Federal requirements for ASTs include the Clean Water Act's Spill Prevention, Control and Countermeasures program and the Oil Pollution Act of 1990. The following sections describe current and proposed requirements.

Spill Prevention, Control and Countermeasures Program

The Spill Prevention, Control and Countermeasures (SPCC) regulations implement part of Section 311 of the Clean Water Act and apply to nontransportation-related facilities with aboveground oil storage capacity greater than 1,320 gallons, or greater than 660 gallons in a single aboveground tank. The existing SPCC rules appear in Title 40 Code of Federal Regulations (CFR) Part 112. These rules establish procedures, methods and requirements for equipment to prevent the discharge of oil into or upon "navigable waters" of the United States or adjoining shorelines. The term "navigable waters" has been interpreted very broadly, and includes wetlands, dry arroyos, and lakes under certain circumstances. See 40 CFR § 110 (definition of "navigable waters").

Proposed amendments to the SPCC Rules were introduced in the Federal Register on October 22, 1991 (56 FR 54612). The proposed rules evolved from recommendations of the interagency SPCC Task Force which had been assembled in response to a previous oil spill. The findings of the Task Force and a related GAO study formed the basis for the proposed changes. [1], [2] The proposed rules would tighten recommendations provided in the original SPCC rules by making certain aspects of the SPCC rules mandatory. They comprise Phase One of the SPCC Task Force's recommendations. Phase Two (nontransportation-related onshore facility response plan regulations), proposed February 17, 1993, 58 FR 8824, would address the requirements of a properly designed spill contingency plan and would implement certain provisions of the Oil Pollution Act of 1990.

The following language appears in the Phase One proposed rule, 56 FR 54635, to be codified at 40 CFR § 112.7(c):

> Appropriate containment and/or drainage control structures or equipment to prevent discharged oil from reaching a navigable water course shall be provided. The entire containment system, including walls and floor, shall be impervious to oil for 72 hours.... (Emphasis added.)

The most significant changes to the existing SPCC program, as they relate to secondary containment and liners, are that EPA has proposed substituting "shall" for "should," and has provided a time period (72 hours) to clarify the meaning of "impervious." In presenting the proposed rule, EPA stated that the specificity of the new 72-hour containment standard would provide the regulated community with greater clarification and flexibility than the phrase "sufficiently impervious" which appears in the current rule. The paragraph goes on to list prevention systems which may be used, including dikes, berms, retaining walls, and other kinds of structures to contain the product stored.

Oil Pollution Act of 1990

The Oil Pollution Act of 1990 (OPA) was enacted on August 18, 1990. Section 4113 requires that the President conduct a study to determine whether liners or other secondary means of containment should be used to prevent leaking or to aid in leak detection at onshore facilities used for the bulk storage of oil and located near navigable waterways. A one-year deadline was established for reporting the results of this study to Congress, and implementation of the report's recommendations was required six months after submission of that report.

Under the Act's mandate, EPA initiated a study of available technology for secondary containment of petroleum fuels and other hydrocarbons stored in bulk in aboveground facilities. The sponsoring office is EPA's Office of Emergency Response in Washington, D.C. As of this writing, the final report documenting the EPA's liner study is not yet available, although a preliminary draft has been reviewed. [3] The study included a review of the regulatory environment, analysis of liner options, a cost/benefit analysis, and a discussion of regulatory options.

REQUIREMENTS FOR SECONDARY CONTAINMENT IN SELECTED STATES

Selected state secondary containment requirements for bulk storage of petroleum in ASTs are summarized below. Other regulatory requirements may be applicable in these states. This information is current as of March 1993. It is not comprehensive; some states may have requirements in addition to those described below. To assure compliance with applicable requirements for petroleum storage in ASTs, state and local laws and regulations should be reviewed in detail.

California

California state law requires that petroleum AST facilities comply with federal SPCC requirements, which are incorporated by reference into state law.[1] There are no state laws or regulations with specific permeability rates for lining tank bottoms or diked areas where petroleum is stored in aboveground tanks.

Minnesota

There are no requirements in Minnesota law or regulations specifying permeability of secondary containment areas (including the area under tanks) where petroleum is stored in ASTs. The Tanks and Spills Section of the state Pollution Control Agency has guidance for soil or clay underlying such containment areas (6 inch soil or clay base with permeability not to exceed 10^{-7} cm/sec for water). There is no similar permeability specified in the state's guidance for secondary containment areas that use geomembranes.[2]

New Jersey

New Jersey regulations contain secondary requirements but do not specify numerical standards.

New York

AST regulations are contained in Title 6 of the New York State Code of Rules and Regulations.[3] Tanks are regulated at facilities where more than 1100 gallons of petroleum are stored. These requirements do not apply to production tanks. New tanks that are designed to rest on the ground are required to have a double bottom or be underlain by a barrier with a permeability equal to or less than 10^{-6} cm/sec for water.[4]

ASTs in existence in 1985 (when the regulation went into effect) were required to be retrofitted by November 30, 1990, with secondary containment around (not under) the base of tanks with a volume greater than 10,000 gallons, or to smaller tanks if the tank "could reasonably be expected to discharge petroleum to the waters of the State."[5] There is no permeability limit in the regulations; however, guidance used by the Bulk Storage Section of the Department of Environmental Conservation includes a range of permeability for secondary containment systems,

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[1] Cal. Health and Safety Code §§ 25270. - 25270.13 (West 1992).

[2] Minnesota Pollution Control Agency, Aboveground Storage Tank Program: Secondary Containment Guidance (October 12, 1992).

[3] N.Y. Comp. Codes R. & Regs. tit. 6, §§ 612-614 (1990).

[4] § 614.10.

[5] § 613.3(c)(6)(a)-(b).

depending on the service. For No. 6 oil storage, the permeability should be no greater than 10^{-5} cm/sec; the permeability should not exceed 10^{-6} cm/sec for gasoline.

South Dakota

New AST systems must have secondary containment systems under and around the system, which consist of native soils, clays, bentonite, or a synthetic liner equivalent to 60 mil high-density polyethylene or greater. Impermeability of at least 10^{-6} cm/sec for the substance being stored is required.

Existing AST systems located at facilities with a total capacity of 250,000 gallons or more must have secondary containment systems beneath any aboveground piping. The secondary containment must meet the same permeability requirements set for new AST systems.

Texas

Texas state laws and regulations do not include technical standards for secondary containment in diked areas or beneath tanks. Special requirements may apply in certain regions of the state, such as coastal areas and over the Edwards Aquifer.

OTHER STANDARDS

Fire and safety codes, including those established by the National Fire Protection Association (NFPA) and Western Fire Chiefs Association, address the design and construction of bulk storage facilities. Most states have adopted these codes in state fire safety regulations, which have been in place for some time. Such regulations are generally enforced by the state fire marshall or, in some cases, a state agency charged with industrial safety or labor relations. Also, various local safety and fire codes may apply and may be more stringent than the applicable state or federal regulations.

REFERENCE POINT PERMEABILITY

Phrases such as "impervious" and "sufficiently impermeable" are common in regulations requiring the use of geomembranes or natural liner materials; however, a clear definition or performance standard is not always provided. As is evident from the above review of state standards, permeability requirements vary by state.

The concept of a reference point permeability, or minimum specification for hydraulic conductivity of a liner, is only applicable to natural materials. Falling head or flexible-wall permeameter tests designed for soils are not applicable to geomembranes or composite products that include them. The distinction between mass transfer by hydraulic conductivity and diffusion (permeation) is more fully discussed in Section 5.

Section 4
SURVEY OF CANDIDATE LINERS

This section provides a summary of options available for secondary containment of petroleum products.

INTRODUCTION TO GEOSYNTHETICS

The term *geosynthetic* is used to refer to a category of manufactured products that are used in civil engineering for separation, filtration/drainage or reinforcement of soils. Products such as geotextiles, geonet, geogrid and geomembranes are included in the broad definition of geosynthetics. Reference 5 provides an excellent source of design guidance and engineering data for geosynthetics, including a comprehensive chapter on geomembrane liner applications.

Geomembranes are liquid or vapor barriers usually made from continuous polymeric, flexible sheets. They can also be made from the impregnation of geotextiles with asphalt or elastomer sprays. Geomembranes are not completely impermeable, but they are relatively impermeable when compared to soils, textiles, or even clays.

Also included in the discussion here are geosynthetic/clay composite liners (GCLs), which are hybrid products manufactured from a combination of natural and synthetic materials. One common configuration is to sandwich a layer of natural bentonite between two supporting geotextiles, resulting in mat product that can be manufactured as roll goods, and shipped and installed on site with relative ease. Bentonite-containing products must be saturated with water to gain their sealing characteristics.

Four classes of geosynthetic liners have found application for secondary containment of petroleum: (1) geomembranes which are coated fabrics or laminates, (2) extruded sheet geomembranes, (3) GCLs, and (4) geomembranes which are spray-on coatings, using a geotextile backing. The classes differ in materials and techniques of manufacture as well as the seaming and construction procedures that must be used to construct a liner system in the field.

COATED FABRICS AND LAMINATES

The first category of geomembranes includes polymer films that are coated or laminated onto a textile substrate by means of a manufacturing process such as calendaring or coating. A variety of different kinds of coatings have been used. These include polymer formulations of chlorosulfonated polyethylene, neoprene, ethylene interpolymer alloy, butyl rubber, epichlorohydrin rubber, ethylene propylene diene monomer (EPDM) and various combinations. Most products in this category have coatings that are elastomeric or rubbery in character. To a great extent, the physical properties and strength of the product are contributed by the substrate, which is usually a high-strength textile with a broad weave. Substrates include nylon, polyester and other textile fibers.

EXTRUDED FILM OR SHEET

This category includes polymer films that are manufactured in a one-step process, without the use of a textile backing or substrate. Geomembranes of this kind are manufactured from polyvinyl chloride (PVC), high density polyethylene (HDPE), polyethylene of lower densities, and elastomers. Because of chemical resistance considerations, the only sheet product to find wide acceptance for secondary containment of petroleum is HDPE. HDPE may be manufactured by either of two extrusion processes (direct extrusion via a wide die with multiple screws or blown film), and is available in thickness ranging from 20 mils to greater than 100 mils. The product as manufactured is a monolithic, single layer film and is sold in rolls usually greater than 20 feet in width.

GCLs

This category refers to products that are manufactured using a combination of natural and synthetic materials. GCLs offer some of the characteristics of natural materials such as clay or bentonite while reducing the requirements for on-site construction. The most common configuration involves the placement of a thin layer of dry bentonite between two geotextile layers. The geotextiles may be woven or non-woven, sometimes stitched together using a needle punch or sewing process. A second configuration involves the placement of a bentonite layer directly onto a sheet of HDPE or other polymer, thus providing a composite natural/synthetic liner.

All GCLs are manufactured with dry bentonite, resulting in a mat product that can be shipped and installed easily. The bentonite component must be saturated with water to gain its sealing characteristics.

SPRAY-ON COATINGS

This category includes products that are installed via spray equipment, using a geotextile or other material for backing. The resulting liner system has physical properties imparted by the geotextile backing. The coating thickness is variable and is a function of the spray dwell time, flow rate and operator technique. Elastomers are used, including polysulfide and polyurethane, both of which have good resistance to petroleum products. The resulting sprayed-on coating is impermeable to liquids and has added durability and physical strength because of the geotextile backing. Spray-on coatings using the same coating products and techniques are widely used for coating concrete or other containment structures where resistance and impermeability to petroleum is a requirement.

Section 5
LINER SELECTION CRITERIA

The primary goal of installing secondary containment within the diked area is to reduce the permeability of the walls and floor so that the contents will be retained for a period sufficient to effect cleanup (e.g., 72 hours according to the new SPCC proposed rules). This goal must be attained within the context of routine tank operations.

The following is a list of overall design and selection criteria:

1. The liner system should have minimal impact on existing tankage and ongoing operation of the facility.

2. The liner system should be compatible with existing standards which are applicable (e.g., NFPA 30; API 620, 650, 651, 652, and 653).

3. The liner system should be free of leaks and liquid tight as installed, considering both the basic material and penetrations or seams.

4. The liner should be protected from damage due to normal traffic, fire, and exposure to the weather. If exposed, it should not be a slipping safety hazard to personnel.

5. The liner should integrate with other facilities (tanks, pump bases, supports, etc.) without contributing to deterioration of these facilities. For example, because of the need for inspection, tank shells should not be covered.

6. The liner system should accommodate equipment roadways.

7. The liner system should allow standard cathodic protection systems to remain operationally effective, and to be tested and maintained.

8. The liner system must accommodate drainage of stormwater from the tankfield without release of hazardous materials, in accordance with NFPA 30 guidelines.

9. The liner system should have a long life, consistent with the planned operational cycle of the facility, and it must be repairable in the event of accidental damage.

The extent to which any given liner system can meet these criteria is a function of its physical properties and chemical resistance to the product contained. The physical configuration of the liner, as manufactured, determines the seaming and construction procedures which must be used to install it. The four liner types described in Section 4 require very different equipment and techniques for installation into a tankfield area. Several options are available for making the necessary connection to tank ringwalls and appurtenances, depending on the type of liner.

With respect to permeability, two modes of material transport must be considered: liquid transport (hydraulic conductivity) and vapor transport (diffusion). Most synthetic liners are essentially impermeable to liquid transfer. However, they are permeable to vapor to a degree that depends on the solubility of the liquid in the polymer, temperature, and the thickness of the membrane. It is important to understand the distinctions between these modes of mass transfer and how they relate to liner selection, testing and performance standards.

The following sections describe the technology base for assessing physical properties and chemical compatibility of geomembranes for secondary containment.

PHYSICAL PROPERTIES

The geosynthetics industry has developed an extensive base of technology for evaluating the physical and mechanical properties of geomembranes. The most important physical and mechanical attributes of the liner, which determine its suitability for a given application, are thickness, density, mass per unit area, tensile properties, tear resistance, hydrostatic resistance, and puncture resistance. Other key physical properties include linear expansion properties, cold temperature properties, resistance to ultraviolet light, resistance to soil burial, and dimensional stability. Reference 5 provides a very comprehensive presentation of physical properties and measurement methodology. Reference to manufacturers' product literature and technical representatives is also recommended. An additional source of information is NSF Standard ANSI/NSF 54-1991 [6] which is a standard for minimum performance of geomembranes. The document provides test method references and appendices indicating broadly accepted modifications to applicable testing standards. ANSI/NSF 54-1991 is widely used within the waste industry for specification of liner performance. Note, however, that not all liner types are addressed (for example, GCLs and sprayable coatings).

It is important to recognize that the same tests do not apply to each of the different categories of liners. For example, it is not possible to directly compare tensile strength of a supported sheet liner with an unsupported film such as HDPE because the appropriate test method is not the same. There are basic differences in construction and manufacturing which make the direct comparison of the mechanical properties of different liner types impossible.

Table 5-1 lists physical properties commonly used to characterize geomembrane liners, in accordance with general industry practice. Test methods may be found in the American Society for Testing Materials (ASTM) Annual Book of Standards, or U.S. Federal Test Method Standards (FTMS).

Table 5-1. Physical and mechanical test methods applicable to different liner types

Liner Type and Property	Coated Fabric or Laminate	Unsupported Film	Sprayable Coating	GCL
Thickness	ASTM D 751	ASTM D 3767	ASTM D 1777 (Coating thickness gauges used in the field)	ASTM D 1777
Specific gravity or density	N/A	ASTM D 1505	N/A	N/A
Tensile Properties	ASTM D 751	ASTM D 638	ASTM D 4595 or ASTM D 4632	ASTM D 4595 (finished composite); ASTM D 4632 (geotextile backing)
Tear Resistance or Strength	ASTM D 751 (tongue tear)	ASTM D 1004	ASTM D 4533 (Trapezoid)	ASTM D 4533 (Trapezoid; backing geotextiles only)
Puncture Resistance	ASTM D 751, Section 15.2 (Ball tip)	FTMS 101 Method 2065	ASTM D 4833 or ASTM D 3787	ASTM D 4833 or ASTM D 3787 (backing geotextiles only)
Low Temperature Properties	ASTM D 2136	ASTM D 746	No industry standardi-zation	No industry standardization
Dimensional Stability	ASTM D 1204	ASTM D 1204	ASTM D 1204	N/A
Resistance to Soil Burial	ASTM D 3083	ASTM D 3083	ASTM D 3083	N/A
Hydrostatic Resistance	ASTM D 751 Method A, Procedure 1	ASTM D 751 Method A, Procedure 1	ASTM D 3786	ASTM D 3786 (backing geotextiles only)

Table 5-1. Physical and mechanical test methods applicable to different liner types

Liner Type and Property	Coated Fabric or Laminate	Unsupported Film	Sprayable Coating	GCL
Ply Adhesion	ASTM D 413	N/A	N/A	N/A
Durometer Hardness	ASTM D 2240	ASTM D 2240	N/A	N/A
Environmental Stress Crack Resistance	N/A	ASTM D 1693	N/A	N/A
Carbon Black Content	N/A	ASTM D 1603	N/A	N/A
Carbon Black Dispersion	N/A	ASTM D 3015	N/A	N/A

PERMEABILITY

To provide effective secondary containment, the ideal liner would be completely impermeable to the material to be contained. However, all barrier materials, natural and synthetic, are permeable to some extent, however small. The definition and measurement of mass transfer through a barrier depends on the mode of transfer. There are two possible modes: liquid transfer (through hydraulic conductivity) and vapor transfer (through molecular diffusion). The former is applicable to natural materials, where transfer depends on the movement of liquid through pore structure of a soil and the driving force is hydraulic pressure or head. The latter is applicable to polymer barriers, where the driving force is the concentration gradient of the permeating chemical across the barrier.

Hydraulic Conductivity and Vapor Diffusion

Figure 5-1 illustrates the seepage of liquid through a pervious soil sample. Darcy's Law governs the movement of liquid through saturated soil, and states that the total discharge is a function of the soil profile area A, the hydraulic gradient, and the permeability coefficient, k:

$$Q = kiA$$

where Q = discharge velocity
k = permeability coefficient
i = dh/L (hydraulic gradient)
A = soil sample profile area.

The permeability coefficient, k, is a function of the soil's porosity characteristics and moisture content. "k" is expressed in units of volume per area per time (e.g., cm^3/cm^2-sec or cm/sec).

Figure 5-2 illustrates the process of molecular diffusion. Diffusion is driven by the mutual chemical solubility of the permeant with the barrier material and the concentration gradient that exists across the barrier. The fundamental law of mass transport by diffusion was derived by Fick and may be stated as follows:

$$J = -D\, dC/dx$$

where J = mass flux of a substance diffusing across a unit area in unit time
D = proportionality constant or diffusion coefficient
dC/dx = concentration gradient.

Diffusion is a complex summation of all polymer-polymer, penetrant-polymer and penetrant-penetrant interactions. Each different penetrant-polymer combination has a unique diffusion coefficient describing the diffusive process.

As shown in Figure 5-2, diffusion has three stages: surface adsorption, diffusion (where the penetrant front advances through the barrier) and desorption (permeant vapor molecules are released into air on the opposite side of the barrier).

Figure 5-3 illustrates the diffusion or vapor permeation process through a polymer barrier in graphical form. There is an initial period during which there is no detection of the permeant. The first detection of measurable concentration on the opposite side is termed breakthrough time. The concentration gradually builds, eventually reaching a steady state condition characterized by a constant rate of concentration increase. The slope of this line at equilibrium is the steady state or equilibrium permeation rate.

In summary, the fundamental difference between hydraulic conductivity and diffusion is that, for porous materials, liquid is conducted through the soil's pore structure by the driving force of hydraulic head. For liquid tight barriers, such as polymer films, the mode of transport is molecular diffusion driven by solubility and the concentration gradient across the barrier.

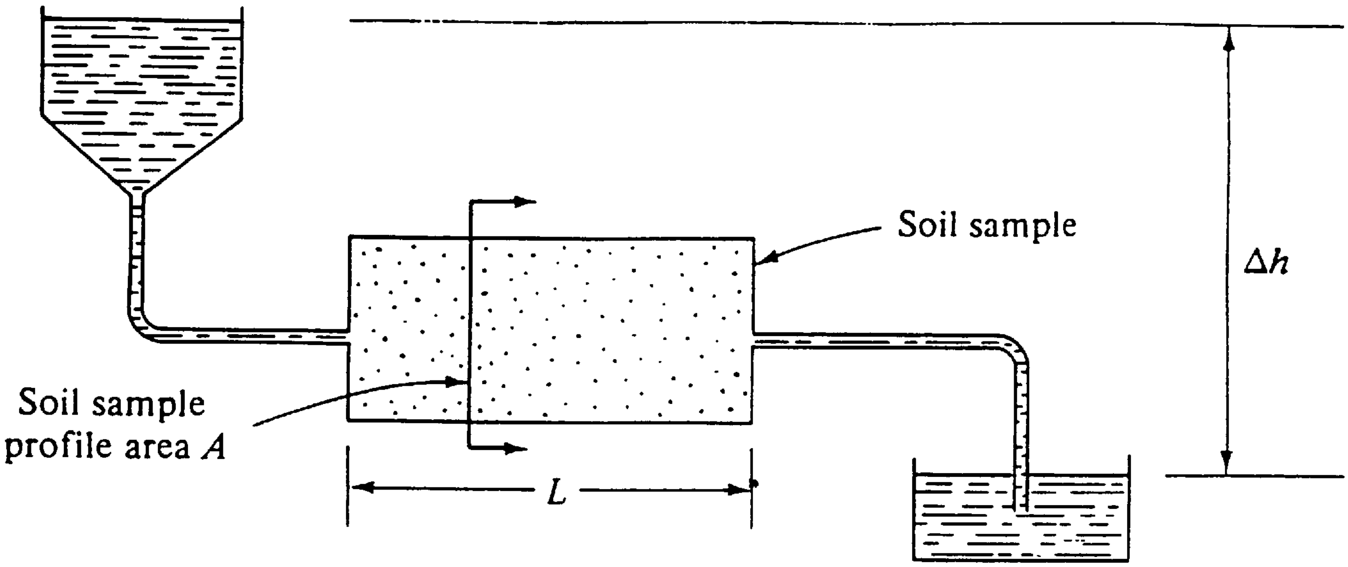

Figure 5-1. Hydraulic conductivity of soils.

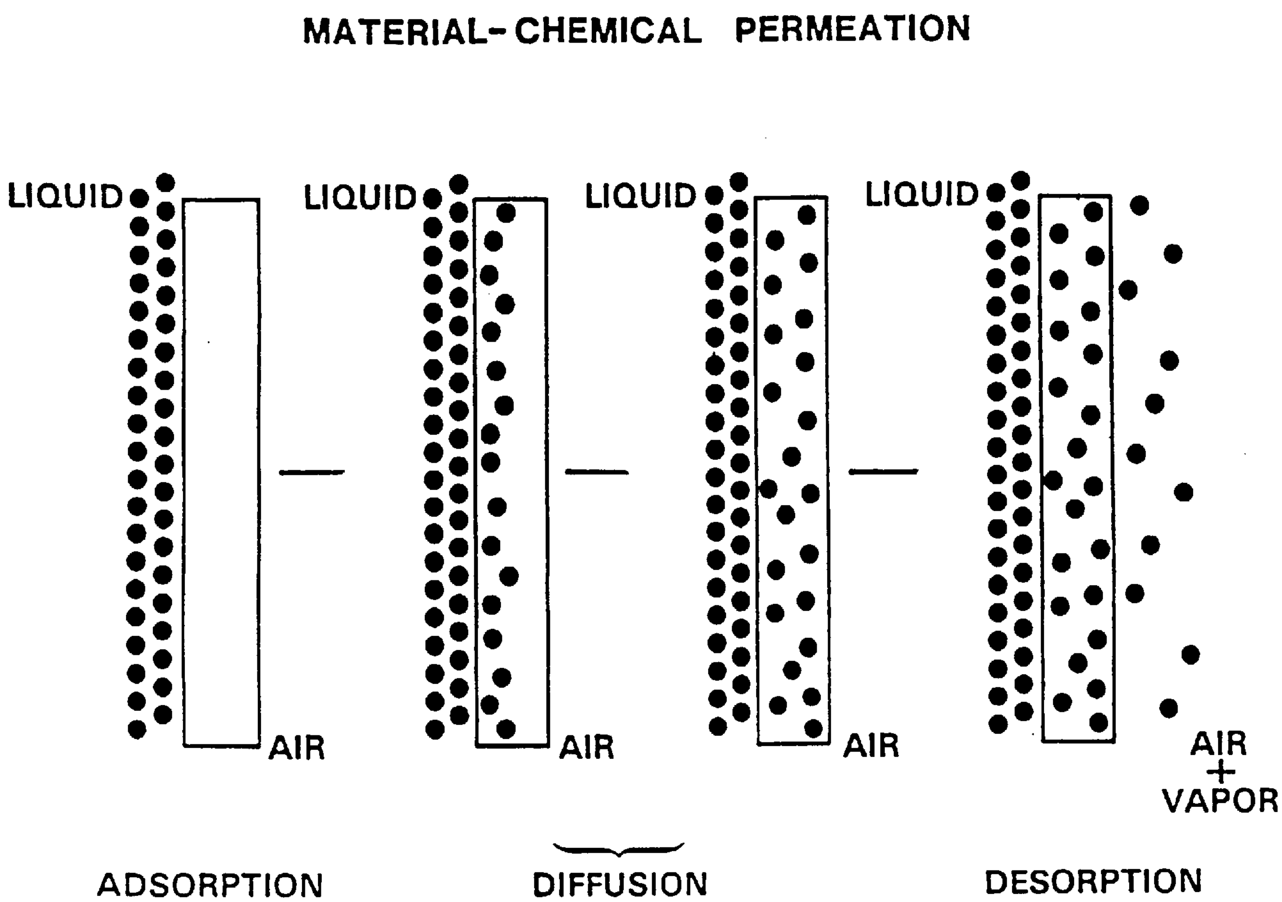

Figure 5-2. Diffusion in polymers.

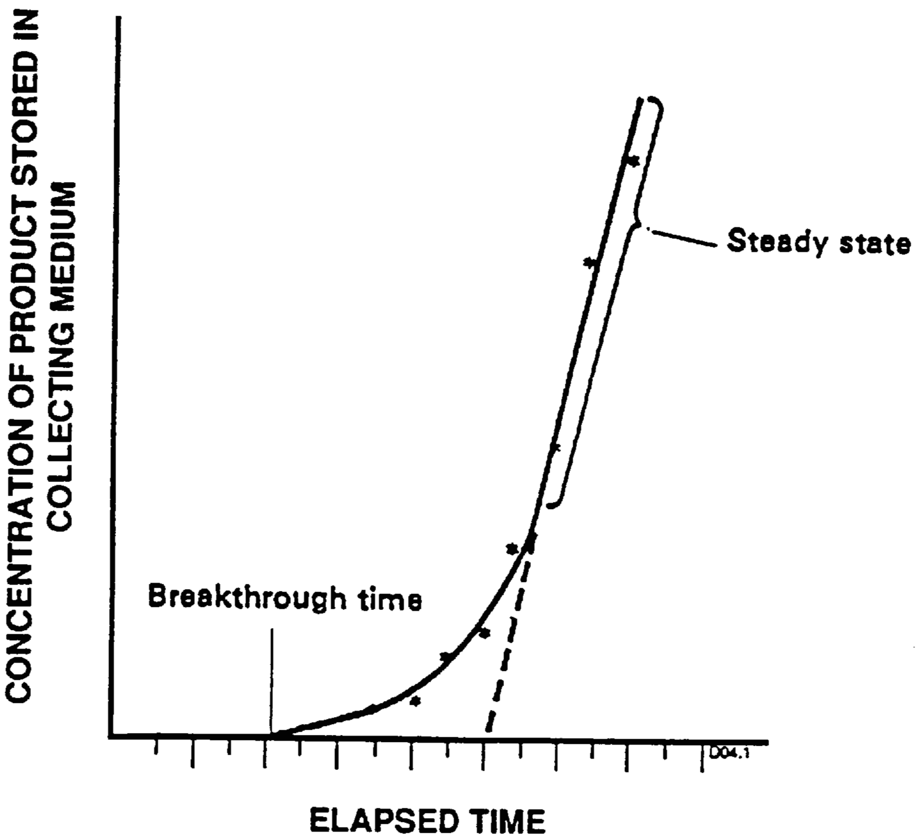

Figure 5-3. Graphical depiction of vapor permeation across a polymer barrier.

Measurement of Hydraulic Conductivity and Vapor Permeation

The definition and measurement of mass transfer through a barrier depend on the mode of transfer. Hydraulic conductivity (or permeability) is determined through measurement of the rate of flow under controlled conditions. One testing standard is ASTM D 5084 which utilizes a flexible-wall permeameter to measure rate of liquid transfer through a soil. Various field tests exist to make the same determination *in situ* (see Section 6). Diffusivity or molecular permeation cannot be determined in this manner since liquid is not transferred through the barrier. The following methods are available for assessing the permeation of chemicals through polymer barriers:

- Weight gain or loss. Test methods such as ASTM E 96 [4] may be used to measure the vapor transmission rate of a permeant through a barrier film by weight loss of contained permeant in a closed cup covered with a specimen of known area. Another technique is to determine D, the diffusion coefficient, through immersion/weight gain or sorption studies. [7], [8]

- Analytical determination of chemical permeation. The most accurate and sensitive means to detect and measure the rate of vapor permeation is the analytical permeation test, as described in ASTM F 739. The test was developed for the protective clothing industry and is applicable to any liquid tight barrier. The test utilizes a cell having two hemispheres, separated by the barrier material of interest. The permeant is introduced on one side, and the atmosphere on the opposite side is monitored for presence of permeating vapor by the use of analytical instrumentation. Figure 5-4 illustrates the ASTM F 739 test cell.

Unit Conversions

The rate of vapor permeation is analogous to the permeability coefficient for soils, k, except that it is measured in mass per unit area per time interval, (e.g., g/m^2-24 hr), rather than volume (e.g., cm^3/cm^2-sec or cm/sec). It is theoretically possible to convert the vapor permeation rate or vapor permeance into customary units for k, the soil permeability coefficient, through manipulation of units and dimensions. The procedure for making this conversion is given in Reference 5, Page 367. When the measured water vapor transmission rates for geomembranes such as HDPE or proprietary fabric coating formulations are converted into permeability units, the results fall within the general range 10^{-12} to 10^{-10} cm/sec. The permeation rates for various petroleum products may be quite different, however.

CHEMICAL RESISTANCE

The overriding consideration in selection of type of material used in manufacture of a secondary containment liner is its chemical resistance to the contained liquid. Chemical resistance must be considered separately from the liner's permeability, or permeation resistance. Chemical resistance refers to the ability of the material to retain its physical strength and chemical barrier properties during and after direct contact with the liquid.

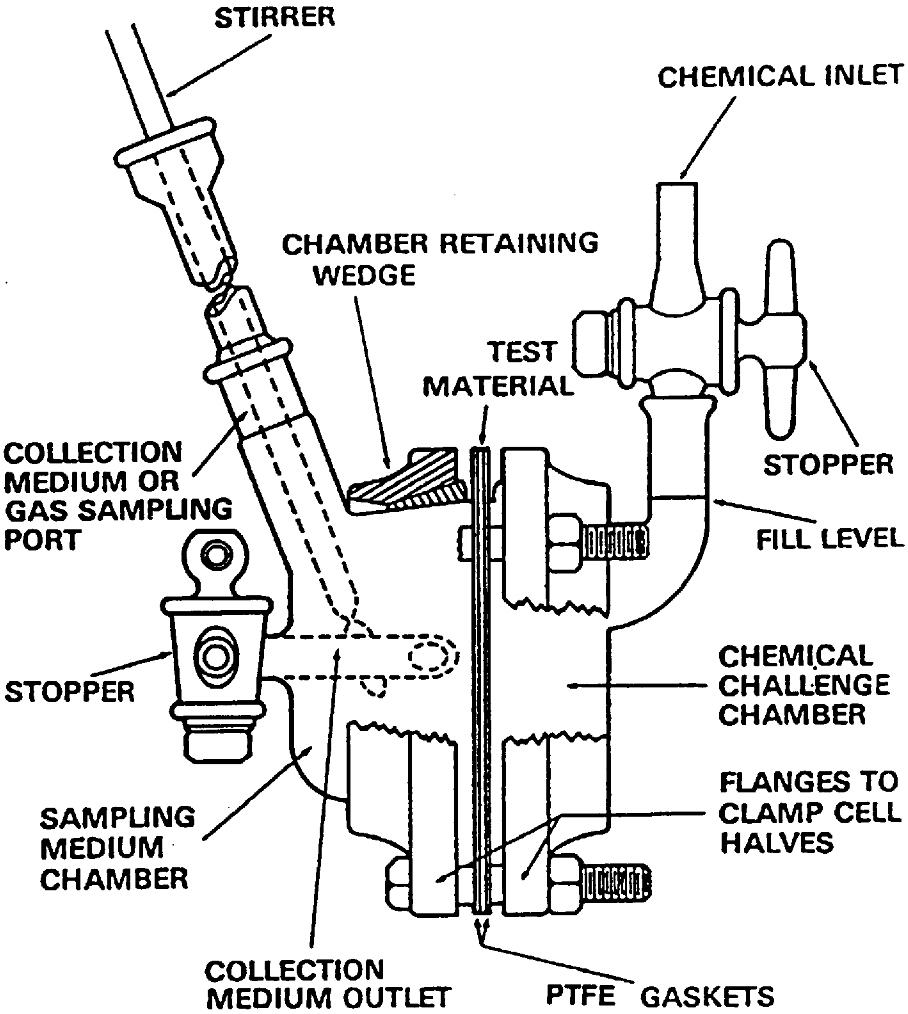

Figure 5-4. Configuration of ASTM F 739 permeation test cells.

Chemical resistance may be assessed by incubating samples in the laboratory and measuring changes in physical properties as a function of immersion. If a material lacks chemical resistance to a given liquid, its physical properties will be degraded upon contact to such an extent that its permeability is no longer relevant.

The following tests may be used to assess chemical resistance: [5]

- Physical property tests: These include thickness, volume, or weight changes.
- Mechanical property tests: Tensile properties, puncture resistance, tear resistance and other mechanical properties may be assessed as a function of exposure or incubation in the contained liquid.
- Transport property tests: These include vapor permeation tests or hydraulic conductivity tests using the contained liquid in place of water.

The method and time of incubation must be selected so that a valid test will result which provides a reasonable simulation of expected service conditions. Testing conditions to consider are incubation temperature, exposure time, and concentration of permeant. Testing may be performed at elevated temperatures to provide some degree of acceleration, as in EPA Method 9090 (SW 846), a widely used method for determining liner compatibility with landfill leachates.

Koerner [5] has discussed the assessment of results of the changes observed on incubated samples. Table 5-2 lists guidelines for chemical resistance acceptance criteria from that reference.

Table 5-2. Chemical resistance criteria (after Koerner, [5]).

Property	Maximum acceptable value or percentage change for thermoset and thermoplastic polymers	Maximum acceptable value or percentage change for semicrystalline polymers (HDPE)
Permeation rate	0.9 g/m^2-hr	0.9 g/m^2-hr
Change in weight	10%	1% - 3%
Change in volume	10%	0.5% - 1%
Change in tensile strength at break	20%	N/A
Change in 100% or 200% tensile modulus	30%	N/A

Table 5-2. Chemical resistance criteria (after Koerner, [5]).		
Property	Maximum acceptable value or percentage change for thermoset and thermoplastic polymers	Maximum acceptable value or percentage change for semicrystalline polymers (HDPE)
Change in tensile strength at yield	N/A	20%
Change in elongation at yield	N/A	20% - 30%
Change in modulus	N/A	30%
Change in tear strength	N/A	20%
Change in puncture strength	N/A	30%

Some polymers absorb volatile organics, including petroleum products and additives, resulting in changes in physical properties with associated gains in weight and volume. After the polymer is removed from immersion or contact with the permeant, the diffusion process is reversed and, after a period of time, physical properties regain their former levels, as measured for unexposed sheet liner. This effect is important since it indicates that the liner exposed to a spill or accidental release may not be affected permanently by short term contact with the petroleum product. When conducting chemical resistance studies, many investigators recommend that physical properties be measured after allowing the immersed samples to vent, or dry, for a period of time.

For geosynthetic clay composites, the approach described above is not applicable. The ability of clay composites to seal is dependent on the moisture content of the bentonite component (except for products that incorporate a polymeric liner). Research indicates that clay- or bentonite-containing liners which are saturated with water have low permeability to petroleum products. [9], [10] However, petroleum products are not capable of "hydrating" a dry liner and will readily penetrate dry bentonite. Most manufacturers of GCLs recommend that the products not be used in arid climates, since rainfall may not be sufficient to keep a covered liner saturated.

INSTALLATION-RELATED FACTORS

Proper installation is critical with any liner system. The fundamental differences between the four types of liner systems make the liner selection process sensitive to installation-related factors. Installation considerations are as important as the physical properties, impermeability and chemical resistance of the base liner material.

Methods used to join liner panels to existing structures such as tank ringwalls, pipes, or any other structure within the tankfield are important. Seaming and attachment methods differ depending upon the liner type. Additional considerations include the use of soil, backfill or aggregate as cover over the installed liner, drainage in the tankfield, and cathodic protection. These issues are addressed in more depth in Section 6.

Seams

The most important aspect of installation for geomembranes is seaming. Manufactured liner panels or rolls must be assembled together either at the factory or in the field to meet the site-specific configuration. Seaming can be done in the factory for many supported liners or coated fabrics, a process that results in consistent joints of good quality. Some manufacturers provide panels with factory-attached closures which can be assembled in the field. With unsupported liners such as HDPE, all seaming is accomplished in the field. However, almost any synthetic liner installation will require some field seaming.

Of the four liner types, only coated fabrics and extruded sheet geomembranes require field or factory seaming. Sprayable coating systems and GCLs, because of their construction, need not be seamed by sewing, welding or bonding. Refer to Section 6 for more information on installation procedures for these liner types.

Whatever liner system is selected, an experienced installer with knowledge of the product is essential to success of the project.

Sprayable Coatings

Sprayable coatings are installed by means of applying a layer of elastomeric material onto a geotextile substrate. The geotextile panels are first deployed in the area to be contained with an overlap at the edges. The adjoining geotextile panels may be cemented together with an adhesive and anchored to the subgrade. The liner application process consists of spraying the coating suspended in a solvent carrier directly onto the geotextile substrate. Most sprayable liners consist of a two-part mixture which results in a very rapid cure once applied. When cured, the coating has elastomeric, or rubber-like, properties. The usual procedure is to mix the two parts together in the proper proportion immediately before application, as the time available before the mixture cures ("pot life") may be short. This class of liner does not require field seaming since the sprayed-on coating is continuous.

The expertise and experience of the installation crew is critical to the success of sprayable liner coating systems. Most manufacturers of sprayable, impermeable coatings work through a network of approved installers who have received factory training in proper application methods.

GCLs

Geotextile-backed GCLs are installed by placing the liner over exposed berms and floor with an overlap between subsequent panels. No field seaming is required, making this one of the easier systems to install in almost any basin configuration. When hydrated, adjacent liner panels are sealed together by the bentonite's swelling action, resulting in an effective, continuous seal. For GCLs with geotextile backing, the process is as follows. GCLs are manufactured, shipped and installed in a dry state. The bentonite component is retained between backing geotextiles by means of proprietary adhesive materials or needlepunching methods. At installation, adjacent panels are overlapped a minimum of 12 inches at the edges. When hydrated, the bentonite layer expands and swells to many times its original thickness. As a result of its interaction with water, a colloidal suspension is formed. The hydrated bentonite swells through the porous geotextile backing and seals with the adjacent, hydrated panel forming a continuous colloidal barrier layer.

Geomembrane-backed GCLs are also available. For secondary containment, the manufacturer's recommendation is to install these products with the bentonite side down. An extrusion seam may be used between adjacent exposed liner panels.

REPAIR CONSIDERATIONS

Repair of installed liners after installation must be considered in selecting a secondary containment system. In the normal operations of a bulk storage facility some damage to the liner system may be expected, especially if it is exposed. This may occur through accidental damage, vandalism, or other causes. With geomembranes, repair is accomplished through patching using a seaming or bonding procedure like that used to join the panels at installation. HDPE has the disadvantage that factory installation extrusion equipment must be on hand to effect a proper seal.

Many geomembranes of the coated fabric type can be repaired using adhesives, although the resulting seam may have less integrity than the original installation. Most coated fabric products used for secondary containment incorporate thermoplastic polymer coatings and, hence, may be sealed by heat bonding. This process results in a continuous coating at the seam having the same composition as the base material coating. Although heat bonding is the preferred method, adhesives must be used if heat sealing equipment is not available. For example, patches may be used to repair damage after installation. Patching results in an adhesive bond joining two adjacent coating areas, rather than a continuous coating. Such a bond may not have the same integrity and strength as a properly constructed heat weld.

Sprayable coatings are readily repaired and sealed by means of brushing on the elastomeric coating compound, making patching a relatively straightforward operation. With GCLs, cuts, tears or irregular shapes may be easily repaired by covering the area with enough liner to provide a 6-inch overlap on all sides. Repair pieces are stapled or glued in place until cover can be replaced. Bentonite granules or grout may be used to seal against tank walls or pipes. Installation and repair work is performed with the bentonite in its dry, unswelled state.

One disadvantage of liner systems requiring soil or aggregate cover is that the liner system cannot be easily inspected or repaired once the installation is complete. This may be offset by the added protection afforded by the cover material.

Section 6
SURVEY OF INSTALLATION CONSIDERATIONS

Table 6-1 provides a summary of installation considerations for AST bulk storage secondary containment in the diked area.

PRE-LINER SITE WORK/UTILITY RELOCATION

Because the liner will have to last for at least 10-20 years, necessary provisions must be made to minimize liner penetrations and account for future maintenance access over the liner. At existing installations, utilities such as product and drainage piping, distributed anode cathodic protection (CP) systems, conduits and stairways as well as roads and drives often must be relocated before a dike liner installation. In addition, significant drainage and grading work is often necessary to prepare the area for placement of the liner. The lined dike will require greater storm water handling capabilities than the unlined dike. Storage and removal facilities must be designed into the preparation work. Finally, any liner system needing cover will require that the entire lined area be excavated to 6-18 inches below grade which increases labor requirements and cost.

FIELD AND FACTORY SEAMING

Field or factory seams may be used to join coated fabrics or supported liner panels. Most of the liner products appropriate for secondary containment in this class are thermoplastic. Dielectric or other heat sealing methods are used both in the factory and in the field to join liners of this class. Adhesives may also be used, especially for repair or patching operations. The usual procedure is to use a strip cut from the same base materials, and bond it to one or both sides to cover the joint. The joint itself may or may not be lapped.

Many manufacturers of coated fabrics perform custom factory seaming so that the material delivered on site can be installed with a minimum of field seams. Because of weight considerations, and the large size of manufactured rolls, this option is not available for HDPE.

Some coated fabrics manufacturers provide custom assembled panels with factory-attached closures which can be assembled in the field. This procedure is used for undertank applications but is not used in the diked area because of shear strength considerations.

Two types of seaming are used with semicrystalline, HDPE extruded or blown film liner panels. The extrusion method is used where seaming is performed near structures with little room to maneuver. The wedge weld technique is much more efficient, but can only be used in open areas.

Table 6-1. Installation considerations for dikefield secondary containment

Table 6-1. Installation considerations for dikefield secondary containment

Liner Type	Seaming	Attachment to Ringwall or Tank Chime	Attachment to Pipes and Other Appurtenances	Cover
Unsupported Sheet Geomembrane: HDPE	Field seamed: extrusion or hot wedge method	Retrofit: attached via compression seal with batten strip and anchor bolts New construction: Liner panel welded to HPDE attachment strip cast into wall	Liner panels seamed to preformed HDPE boots and attached via compression gasket	Cover optional with carbon black-stabilized liner; some manufacturers recommend soil cover for protection
Supported Sheet or Coated Fabric Geomembrane Polyurethane Polymer alloys Others with proprietary trade names	Pre-cut panels may be factory or field seamed using thermal methods. Closures may be used for field assembly of factory-seamed panels.	Mechanical attachment via batten strips and anchor bolts	Mechanical attachment via pipe boots, sleeves and compression gaskets	Sand or gravel ballast recommended, 6-18" depth over installed liner to prevent ballooning

Table 6-1 (con't). Installation considerations for dikefield secondary containment

Table 6-1. Installation considerations for dikefield secondary containment

Liner Type	Seaming	Attachment to Ringwall or Tank Chime	Attachment to Pipes and Other Appurtenances	Cover
GCL	Panels are overlapped a minimum of 6" or as recommended by manufacturer. Seal produced by saturation and swelling of bentonite. No seaming required.	Bead of granular bentonite placed below edges of panel. Panel lapped 4" - 6" against concrete slab.	Bentonite mastic or granular bentonite troweled or poured around appurtenances	Cover required; minimum 6" depth or as recommended by manufacturer. Aggregate (pea gravel) or backfill recommended; no calcium based materials
Sprayable Coatings Polysulfide Polyurethane	Overlapping geotextile substrates do not require seaming; coating is continuous. 4" overlap recommended. Second geotextile underlayment used for protection.	Countinuous coating applied over primed concrete or metal surface. Precoated fabric placed around exterior circumference and adhered to concrete and edge of liner panel.	Precoated fabric skirt wrapped around primed pipe and adhered to liner panel. Continous coating applied over primed surfaces.	Not recommended. Cast access walkways may be placed over installed liner for tank access and liner protection.

ATTACHMENT TO TANKS, RINGWALLS AND APPURTENANCES

Each manufacturer has developed equipment and methods for making the connection to tanks, ringwalls, pipes and other appurtenances such as pumps, walkways or any other obstruction that may exist in the floor of the diked area. The most common methods in use were described in Table 6-1. The tank chime attachment (without ring wall) has been a difficult detail, since inspection must be facilitated and penetrations through the tank wall are to be avoided.

The integrity of the liner installation is highly dependent on attaining a liquid tight seal at all attachment points. Experience in the waste containment industry suggests that *de minimis* leakage may be expected in almost any liner installation. This leakage is usually attributed to factors other than permeation through liner panels, including seepage at seams or points of attachment. The concept of *de minimis* leakage is recognized in various federal and state regulations covering landfill design and construction. For example, hazardous waste containment cells built under RCRA Subtitle C are required to have double composite liner systems. In such facilities, leachate detection and recovery systems collect leachate that migrates through the primary liner system.

The AST containment field provides a challenging installation problem because of its relatively small size compared to other liner applications and the many appurtenances that usually exist. To further complicate the situation, it is usually not possible to hydro test the installed liner system, as would be the usual practice for landfill or pond liner construction. This procedure requires that the containment field be filled with water, which could cause problems for tanks and equipment installed within the diked area. Therefore, it may not be possible to verify the leaktightness of a liner system once installed. These points underscore the importance of careful attention to detail and quality assurance during the construction process.

ANCHOR TRENCH, SUBGRADE AND COVER REQUIREMENTS

Liner manufacturers have developed specific recommendations for design of the anchor trench used to retain liner panels at the top of the dike, and for the condition of the subgrade under the floor of the containment area. Anchor trench design and maximum recommended slopes for dikes are largely dependent on the weight and frictional properties of the liner panels.

In general, a well-compacted subgrade with a minimum of sharp angular stones is recommended. Coarse sand or smoothed clay soil may be used. Where gravel or sharp aggregates are unavoidable, a geotextile fabric may be used as a cushion.

Table 6-1 indicates manufacturer recommendations for the use of cover soil for each liner type. Cover is optional and subject to the discretion of the designer with some liner systems, but is a necessary requirement for others, especially GCLs with geotextile backing.

For GCLs, the cover should be of a material that will not degrade the chemical composition of the bentonite. One documented failure of a GCL material installed for AST secondary containment in Long Island, New York, was reported to have been caused by the use of dolomitic limestone cover. According to the manufacturer, dolomitic limestone provides a source of positively charged calcium and magnesium ions which, in the presence of water, can exchange with the sodium present in bentonite material. This process increases the permeability and decreases the swelling capacity of the bentonite.[11]

The use of sand or gravel ballast is recommended for supported, coated fabrics since their light weight makes them vulnerable to ballooning in heavy wind. Some facilities have used bricks or concrete blocks in lieu of cover. Backfilling must be done carefully to avoid damage to the liner.

DRAINAGE AND CATHODIC PROTECTION

The liner system must accommodate drainage of stormwater from the tankfield without release of hazardous materials, in accordance with NFPA 30 guidelines. This requires careful attention to the stormwater drainage system in the design phase. If required to meet stormwater quality standards, treatment of collected stormwater will need to be implemented to prevent release of contaminants.

The liner must not compromise the performance of CP systems. Geomembranes usually act as effective electrical insulators, which affects the design of undertank cathodic protection systems where such liners are used. This is usually not a concern for lining systems within the diked area, except for piping systems. Accommodations need to be made to provide access to CP equipment as needed.

CONSTRUCTION QUALITY ASSURANCE

For any secondary containment liner project, the installer should demonstrate a proven track record of experience with the selected product and provide a documented, auditable construction quality assurance plan. A system for assuring the integrity of field and factory seams and connections should be in place. Liner conformance with factory and user specifications should be demonstrated through certification or independent laboratory testing prior to installation.

FIELD TESTS

A field test would be desirable to evaluate the extent to which installed liner systems can provide an impermeable barrier to migration of contained substances. The ideal test would be accurate, repeatable and fully validated, simple-to-run, applicable to all potential materials as well as to seams or attachment points, and suitable for field use.

The concept of field testing for geomembranes incorporating a polymer barrier must be considered separately from field testing of clay liners or GCLs. Performance of geomembranes depends on properties of the manufactured barrier material and seams constructed in the field. However, "field testing" of geomembranes to establish impermeability does not make sense and cannot reasonably be done. This is because leakage by movement of liquid water does not take place so long as the liner and seams maintain physical integrity. The mechanism of water movement through a polymer barrier is vapor permeation, a process that is difficult or impossible to measure under field conditions. Field testing programs for geomembranes must address seaming and construction quality assurance.

Two tests have been widely accepted within the engineering community for evaluation of clay liner permeability. [12] These are the sealed double-ring infiltrometer field permeability test and the two-stage borehole field permeability test. The tests are designed to measure water infiltration and are not applicable to measurement of chemical or fuel seepage. They are described briefly in the following paragraphs.

Sealed Double-Ring Infiltrometer Field Permeability Test

Upon realization that standard open ring infiltrometer tests fail to provide an accurate measure of flow at very low rates, the sealed double-ring infiltrometer field permeability test (SDRI) was developed. Infiltrometer tests were used mainly to ensure that a soil had a high enough hydraulic conductivity so that it would drain adequately. They were not used to evaluate moisture barrier performance. Two problems limit the use of the standard infiltrometer: the large component of lateral flow beneath the ring, and the inability to measure small changes in water level.

The principle behind development of the SDRI is to measure the amount of water flowing into the ground directly, rather than measuring a drop in elevation. The test device consists of two concentric rings built above a test pad. Measurement of flow is made by connecting a flexible bag, filled with a known weight of water, to a port on the inner ring. As water infiltrates into the ground from the inner ring, an equal amount of water flows into the inner ring from the bag. Weight loss from the bag is measured and converted to volume. An infiltration rate is then determined from this measurement, the area of the inner ring, and the time interval over which this amount of flow was measured.

Installation of SDRI equipment is as follows. The outer ring is embedded in 12-18 inches of soil. A trench is excavated for this purpose. The inner ring is embedded in a narrower trench 4-6 inches deep. The rings are then sealed in placed with bentonite grout. Tensiometers are placed at various locations to establish the position of the wetting front. The rings are filled and testing conducted for a variable length of time, depending on how long it takes to reach steady state flow conditions.

Calculation of infiltration is straightforward and the method has been shown to be very effective in measuring low permeability rates. Many states require use of the method to support construction of RCRA waste containment facilities.

Advantages include the ability to test large areas and the fact that the test models the case where water is ponded on the surface. However, it can include long test times (two weeks to three months), lack of overburden, and significant costs (estimated at between $8,000-$12,000 per test). The test cannot be performed *in situ* but requires construction of a test pad.

Two-Stage Borehole Field Permeability Test

The two-stage borehole (TSB) method is a falling-head infiltration test conducted in a cased borehole, typically 4 inches in diameter. The first stage is performed with the bottom of the hole flush with the bottom of the casing for maximum effect of vertical permeability. After steady state is achieved, the hole is advanced some 6 to 8 inches below the bottom of the casing so that horizontal permeability has a greater effect. The test has been successful in evaluating both compacted and natural material with permeabilities as low as 10^{-9} cm/sec.

The TSB method is quick, simple and relatively inexpensive. It is possible to achieve results in days, rather than months as can be the case with SDRI measurements. Many state regulatory authorities have accepted this method for evaluation of clay liner permeability in the field. Borehole-type tests such as the TSB method are feasible for applications such as secondary containment where a long-term test pad evaluation is not possible.

Applicability of Field Testing for Secondary Containment

For the AST secondary containment application, field testing of liner permeability is generally not useful since it applies to compacted clays rather than installed, premanufactured liner products. The permeability and chemical resistance of synthetic liner systems must be established in the laboratory setting. It is the responsibility of the facility owner to verify that the material purchased and installed is essentially identical to that which was evaluated in the laboratory. Once this is established with confidence, field liner permeability testing is unnecessary, and the integrity of the installation will depend primarily on the quality of workmanship of seams and points of attachment.

Section 7
DURABILITY

The long-term integrity of a liner installation is dependent on the physical strength of the liner itself, its resistance to the effects of aging or environmental degradation, upkeep and maintenance of cover, and its resistance to chemical attack in the event of a spill. A liner may degrade in performance over time due either to accidental or intentional damage, or due to the effects of exposure to the elements. In considering liner selection and liner system design, it is important to understand the failure modes that can affect the different liner types.

MATERIAL COMPATIBILITY WITH PETROLEUM PRODUCTS

Any liner system proposed for secondary containment for bulk storage must be resistant to attack by the products contained. However, the secondary containment application does not require long term, continuous contact with the contained substance. According to SPCC guidelines, the worst-case spill scenario would be cleaned up within 72 hours. Therefore, the requirements for liner performance in secondary containment may be less rigorous than would be placed on a primary barrier.

To date, all of the polymers which have been used widely for secondary containment have relatively good resistance to most crude oil, petroleum products and additives. That is, physical properties are only moderately affected by exposure in the short term. This is true for HDPE, proprietary-coated fabric geomembranes, polysulfide, and oil-resistant polyurethanes. However, highly oxygenated petroleum products and additives have a more severe effect. As a general rule, as the degree of volatility and extent of oxygenation increase, the effect on polymer barriers will become more significant.

There is little research in the open literature to compare chemical resistance of different liner materials to crude oil and petroleum products. Information is available from manufacturers. Some oil companies are performing internal research to evaluate liner performance. Of special concern are oxygenates such as methyl *tert*-butyl ether (MTBE) and ethanol, which are known to degrade or soften some polymers much more severely than fuels such as unleaded gasoline or jet fuel. Reformulation of fuels under the Clean Air Act Amendments of 1990, which require oxygenate addition, has increased the level of concern.

Chemical compatibility information is usually presented in the form of a chart listing relative chemical resistance of liners versus generic chemicals or solvents. Some form of arbitrary ranking is often used. An example of such a chemical resistance chart appears in Reference 5, and similar information may be obtained from most manufacturers. However, manufacturer-supplied data usually include only the manufacturer's own product. Details about test procedures or ranking criteria are usually not provided.

Since directly comparable data are completely lacking in the open literature, it was not possible to include a chemical compatibility chart in this report.

FAILURE MODES

The life expectancy of a liner system is dependent on its resistance to the effects of environmental aging, and its resistance to damage caused by misuse or accident. Table 7-1 lists failure modes and preventive measures that apply to the various liner types.

Long-term liner system integrity is very dependent on installation quality control. Selecting a good contractor and supervising installation are critical to the success of the system.

Table 7-1. Summary of failure modes and preventive measures for different liner types.

Liner Type	Failure Modes	Preventive Measures
HDPE	Environmental stress cracking	Avoid installation configurations which apply tensile load across seams
	Thermal expansion and contraction; failure due to contraction in cold weather	Follow manufacturer's recommendations for installation temperature and degree of tautness
	Seam separation	Rigorous construction quality assurance at installation
	Tearing or puncture	Use extreme care to avoid scratching or gouging liner during and after installation; limit access and inspect frequently

Table 7-1. Summary of failure modes and preventive measures for different liner types.

Liner Type	Failure Modes	Preventive Measures
Supported Films, Coated Fabrics	Billowing, liner movement	Use aggregate or backfill for ballast
	Weathering; UV degradation of exposed liner panels	Cover all exposed liner; select premium, UV resistant grades if exposure cannot be prevented
	Separation of field-assembled panel closures	Inspect frequently; seal per manufacturer's recommendations
	Chemical induced degradation; loss of physical properties due to petroleum exposure	Verify that liner selected is resistant to contained liquids
	Fungal or biological deterioration	Select premium liner grades compounded for resistance
Sprayable Coatings	Inadequate coating thickness; leakage	Construction quality assurance; frequent checks of coating buildup during application
	Failure to cure	Strictly follow instructions for mixing and proper application; use qualified installer
	Damage due to equipment access	Use cast plastic walkways for access within containment area
GCLs	High permeability due to inadequate bentonite moisture content	Do not use in arid regions; ensure that installed, covered liner will remain saturated
	Loss of bentonite hydration and swelling capability due to reaction with fill cover	Use only fill materials which do not contain calcium (see Section 6)

LINER PROTECTION AND MAINTENANCE

Any secondary containment liner system will require some degree of maintenance, inspection and repair to maintain performance as installed over the long term. The maintenance program may be integrated into the overall tank maintenance procedures as required to maintain safety standards and sustain operation. The following should be addressed at a minimum:

- Exposed areas should be inspected periodically.
- Points of attachment using compression clamps and gaskets should be periodically checked for tightness and potential leakage.
- Stormwater drainage and treatment systems should be inspected and monitored continuously to ensure proper operation.
- The liner system should be installed in a manner allowing visual inspection of critical tank surfaces.
- Operational procedures should be established to provide protection for the installed liner. In particular, access to the contained area should be strictly limited and vehicular traffic restricted.

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