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ASPHALT BARRIERS FOR WASTE ISOLATION

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ABSTRACT

Prior to the mid 1980s, asphalt barriers were primarily used to control water seepage from facilities such as ponds, impoundments and earth dams. Asphalt was applied as hot-sprayed buried asphalt membranes and as asphalt concrete for the barrier layers. The establishment of rules for hazardous and solid waste landfill designs focused the industry toward composite liners consisting of geomembranes and compacted soil. However, in the mid-1980s, resurgence into the use of asphalt concrete for waste isolation was initiated by the US Department of Energy in their quest for very-long-term (1000+ years) hydraulic barriers for radioactive and mixed waste sites. Existing data demonstrate that asphalt concrete barriers and fluid-applied asphalt layers can provide extremely low hydraulic conductivities ($<1x10^{-11}$ cm/s). On-going research results show that asphalt may have the robust properties for a service life approaching 1000 years. Field demonstration of the attributes of asphalt concrete barriers through test pads and monitored prototypes can answer the question of equivalency or superiority of asphalt concrete barriers for waste isolation.

INTRODUCTION

Asphalt containing materials have been used for hydraulic barriers for ages, possibly more than 5000 years (Freeman et al. 1994, Kays 1977, Asphalt Institute 1976). Hot-sprayed buried asphalt membranes have been used for lining water containment structures and controlling seepage through dams for about the last 60 years (Creegan and Monismith 1996, Hickey and Jones 1968, Smith 1962). Over the last 30 years, asphalt concrete has been used for hydraulic barriers and in some cases for liners for waste containment facilities (Asphalt Institute 1976). However, with the initiation of landfill composite (geomembrane + compacted soil) liner systems for waste disposal have dominated new and expanded facilities.

Most regulations allow for site-specific or alternative liner designs provided they meet environmental performance criteria set forth in the rules. Typical regulations provide performance criteria that alternative liners must meet such as the concentrations of specific constituents not be exceeded in the uppermost aquifer at a specific point of compliance. Given these possibilities for alternative liner (and cover) designs, it is worthwhile to examine the state of knowledge regarding asphalt barriers.

Asphalt concrete consists of asphalt and aggregate that are heated, mixed and typically placed in a hot condition, e.g., paving highways. It can also be used for hydraulic barriers. Typical mix ratios for pavements and hydraulic barrier applications are shown in Table 1. The main difference between the paving and hydraulic barrier applications is the percentage of asphalt in the mix; however, mixes for hydraulic applications also include dense graded aggregates and higher fines contents. For the barrier applications, the asphalt content is increased from about 5 percent (total weight basis) to 6 to 9 percent. The increased asphalt content decreases the volume of air voids in the asphalt concrete and thereby reduces the hydraulic conductivity.

Motivations for using asphalt concrete in hydraulic barrier applications include: asphalt tends to have an extremely low hydraulic conductivity, it resists desiccation and cracking, and displays some ability for “cold flow” or creep which may lead to “self-healing” of cracks or construction-formed voids (Kim et. al 1994). Asphalt also has been documented to provide a very long service life especially when buried.

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Table 1 – Comparison of Typical Mixes for Asphalt Concrete in Hydraulic Barrier (Asphalt Institute 1991) and Pavement Applications (Asphalt Institute 1996).

Constituent	Hydraulic Barrier		Pavements	
	Weight (%)	**Volume (%)**	**Weight(%)**	**Volume (%)**
Asphalt	6.5 to 9.5	14	5	13
Coarse Aggregate (>No. 4)	20 to 30	33	50	44
Fine Aggregate (<No. 4)	70-80	44	39	34
Mineral Dust (<No. 200)	8 to 15	5	6	5
Air	**	<4	**	>4

CASES FROM THE LITERATURE

There are numerous citations for the use of asphalt in hydraulic containment structures (Creegan and Monismith 1996). Most of the citations, beginning around the 1940s, refer to the use of hot-sprayed buried asphalt membranes (HSBAM) for controlling seepage of water. In many instances the HSBAM were used for potable water supplies. Asphalt concrete has also been used for hydraulic barriers and in at least one case was used for the low hydraulic conductivity liner for a municipal waste landfill (Asphalt Institute 1976). The literature cases with specific application to waste isolation are summarized in Table 2 and briefly discussed in the following.

Liner Systems

In 1972, the Winnebago County Land Reclamation Site an abandoned gravel pit located in Rockford, Illinois was lined with 5 cm (2 in.) of asphalt concrete. The asphalt was covered with a tar emulsion to isolate the asphalt from naptha and other potentially disruptive solvents that might possibly leach from the waste. A 15-cm (6 in.) sand leachate collection layer was placed on top of the tar emulsion. This is the only municipal solid waste bottom liner of asphalt concrete documented in the surveyed literature. At the time, 1976, the liner apparently was working satisfactorily.

The US EPA's *Lining of Waste Impoundment and Disposal Facilities* (US EPA 1980) discusses asphalt concrete liners in section 3. Haxo and White (1976) measured laboratory conductivity of $3x10^{-9}$ cm/s on asphalt concrete with 9% asphalt cement. A test liner, exposed for 4.6 years was in good condition. The properties had not changed from those recorded initially. Haxo and White (1976) recommended the liner thickness be greater than 10 cm (4 in.).

Styron and Fry (1977) investigated the compatibility of an asphalt concrete liner and leachate from flue gas cleaning sludge (a high pH solution). They found that an 11%-asphalt content in a 5-cm (2-in.) liner met the conductivity requirement.

Cover Systems

The largest use of asphalt concrete barriers in waste containment applications has been for cover or capping systems. In these applications, the principal agent being contained is water from precipitation events. Typically, chemical compatibility with the water is not a primary issue since data show that water does not have any appreciable negative impact on the hydraulic conductivity of asphalt. There are however, lessons to be learned from this application that are directly applicable to asphalt concrete bottom liners.

In 1985, University of Texas at Austin (UT) labs tested asphalt concrete specimens prepared by a designer (Bowders 1999). Specimens prepared at 7.5% asphalt had conductivities averaging $2x10^{-6}$ cm/s while those containing 8% asphalt had conductivities less than $1x10^{-7}$ cm/s. The designer then proceeded with the project, a cover system for a superfund site in Montana and recovered cores from the completed asphalt concrete cover. The cores were tested in the UT labs. The conductivity ranged from $1x10^{-6}$ cm/s to $9x10^{-8}$ cm/s.

An asphalt concrete cap was placed over the Western Processing Co. superfund site in Kent, Washington in the mid-1980's (Repa et al. 1987). Eighteen asphalt concrete core samples were exhumed from the cap and tested in the laboratory. The resulting conductivities ranged from $3x10^{-1}$ cm/s to $1x10^{-2}$ cm/s. The conductivities exceeded the desired $1x10^{-7}$ cm/s by 5 to 6 orders of magnitude. The percentage of air voids in the cores ranged from 12 to 17 percent. This is 3 to 4 times greater than that recommended air voids for hydraulic barrier asphalt concrete (Asphalt Institute 1976, Creegan and Monismith 1996). Factors

Table 2 - Asphalt Concrete Hydraulic Barriers for Waste Isolation

Project/Location	Application	Hydraulic Conductivity	Status	Reference
Winnebago County Landfill, Rockford Illinois, 1972	-MSW liner -5 cm asphalt concrete -Tar emulsion surface -15 cm sand layer LCS	None reported	-1972 receiving 500 metric tons of waste/day -Current status unknown.	The Asphalt Institute (1976)
Liner Exposed to Simulated Landfill Leachate, 1976	-9% asphalt cement -6 cm asphalt concrete	-Water – 3x10^{-9} cm/s -Use >10 cm thick. For leachates	-Liner in good condition after 4.6 years of exposure	US EPA (1980)
Flue Gas Sludge Leachate/Liner Compatibility, 1977	-11% wt basis asphalt cement -5-cm asphalt concrete liner	None reported	-Met hydr. cond. requirements	US EPA (1980)
Superfund site, Montana, 1985	-Cover for former surface impoundment	-Lab: 7.5% asphalt – 2x10^{-6} cm/s -Lab: 8% asphalt cement- <10^{-10} cm/s -Field cores: 1x10^{-6} to 9x10^{-8} cm/s	-Poor construction quality control	Bowders (1999)
Western Processing Company, Kent Washington, 1987	-Cover for waste site -6% asphalt cement -Hi-way paving mix	-3x10^{-1} to 1x10^{-2} cm/s cores from cover	-12 to 17% air voids -Insufficient compaction	Repa et al (1987)
Landfill Cover, Oregon, 1990	-Cover and roadway	-Field test: <1x10^{-7} cm/s (SDRI)	-Sealed double ring infiltr. field test	Bowders (1999)
Hanford Permanent Isolation Barrier Program, Hanford, Washington, 1994	-Prototype cap -7.5% asphalt cement -Two 15-cm layers of asphalt concrete -FAA on surface	Asphalt concrete: -Field cores: 1.3x10^{-9} to 1.2x10^{-10} cm/s -Field SRIs: 1.1x10^{-7} to1.9x10^{-9} FAA: 1.8x10^{-11} cm/s	-Variation in single ring k values likely due to measurement technique (SRI)	Freeman at al (1994) Mancini at al (1995)
Rocky Flats, Denver, Colorado, 1997	-Fluid applied asphalt above the asphalt concrete	-FAA: 1.0x10^{-11} cm/s or lower	-Lower limit of k test device. -No effect on k of gravel embedment.	Glade and Nixon (1997)
Industrial waste, pulp & paper ash landfill, British Columbia, Canada 1998	-Cover for landfill -Asphalt cement included petroleum contaminated soils -15-cm of AC	None reported	-1999, cover performing well.	Kilback and Barrett (1998) Kilback (1999)
Port of Tacoma, Washington, 1999	-Cover for a slag dump	<1x10^{-7} cm/s	-Cover serves as a parking lot	Richardson (1999)

believed contributing to the high conductivities include: a standard highway paving mix was used with the specification for at least 6 percent asphalt but no other specification regarding hydraulic conductivity. Also, field compaction may have been insufficient due to light weight equipment and inclement weather.

The evaluators of the Western Processing cap made the following recommendations for achieving low conductivity asphalt concrete caps in the field:

- Asphalt content at 6 to 9.5%,
- Mineral filler content from 8 to 13%,
- Aggregate should be sized so as not to bridge coarse aggregate,
- Test under lab and field conditions,
- Subgrade must be adequately drained and be stable,

- Slope joint edges to ensure good compaction,
- Apply tack coat to joint edges to ensure bonding,
- Compact asphalt concrete to <4% air voids, and
- Apply an asphalt sealer to the surface.

In the early 1990's a portion of a cover system around a municipal solid waste landfill in Oregon was also required to serve as a roadway. An asphalt concrete was used for the roadway and doubled as the cover for that section of the landfill cover. The in situ conductivity was less than 1x10^{-7} cm/s as measured using a sealed double-ring infiltrometer. The final conductivity was likely to be lower but the test was discontinued since the liner met the required conductivity (Bowders 1999).

The US Department of Energy (US DOE) initiated the Hanford Site Permanent Isolation Barrier Development Program (HPIB) in 1985 to develop engineered barriers to isolate waste for long terms (Wing and Gee 1994). The objective of the design is to use natural materials to develop maintenance-free surface barriers that isolate the waste for 1,000 years. The barriers must limit the infiltration of water through the barrier and into the waste to 0.05 mm of water per year (infiltration rate) which corresponds to a hydraulic conductivity of 1.6x10^{-9} cm/s. A composite asphalt barrier has been identified and field-tested. The barrier consists of a fluid-applied asphalt and an asphalt concrete layer (Figure 1). The asphalt composite is being presented as the alternative to compacted clay/geomembrane barrier.

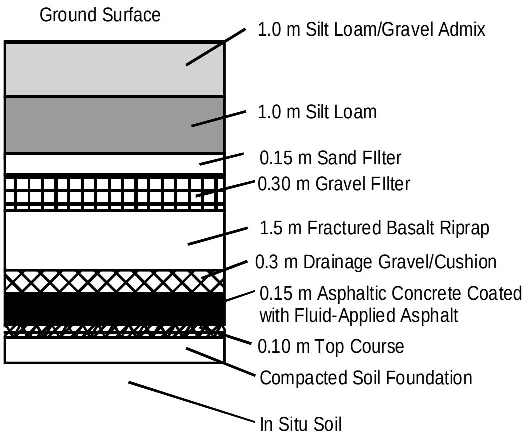

Figure 1 – Cross-Section of Hanford Prototype Permanent Isolation Surface Barrier (Freeman et al. 1994)

The asphalt concrete (AC) and fluid-applied asphalt (FAA) coating make up the hydraulic barrier. The overlying layers constitute drainage and protection layers. A prototype barrier 0.65 hectares (1.6 acres) was constructed in 1994. The asphalt barrier was placed on a 2-degree slope with the joints staggered and layers terraced down slope. The asphalt barrier consists of two 7.5-cm (3-in.) courses of compacted hot mix asphalt concrete containing 7.5 wt% asphalt. Core samples were taken and laboratory hydraulic conductivity tests were performed on them. In addition, a field falling-head permeability test was developed and used on the prototype to measure in situ hydraulic conductivity of the asphalt barrier.

Field measurements of the hydraulic conductivity of the prototype barrier showed hydraulic conductivity decreased with time over a period of 5 days. Eighteen measurements were made over the five days in five locations on the prototype barrier. Two of the measurements exceeded the 1x10^{-7} cm/s criterion but these were attributed to leakage of the test apparatus. The remaining conductivities were in the range from 1x10^{-8} to 1x10^{-9} cm/s. These conductivities are assumed to be conservative (higher than actual) since the bentonite used for sealing the test apparatus to the asphalt was still absorbing water and the test rings only penetrated 5 cm into the asphalt thus allowing lateral flow in addition to vertical flow of water.

Laboratory measured hydraulic conductivity on five asphalt concrete cores averaged 4.7x10^{-10} cm/s. This is well below the goal of 1.6x10^{-9} cm/s. Conductivity tests on the FAA yielded an average hydraulic conductivity of 1.9x10^{-11} cm/s. This was the lower limit of measurement for the testing procedure used.

The DOE is also considering an AC + FAA cover system the Rocky Flats facility near Denver Colorado. In tests on the FAA, Glade and Nixon (1997) found the conductivity to be less than 1x10^{-11} cm/s. In related work, Glade et al (1997), found no detrimental effect on the conductivity due to aggregate embedment into the FAA layer. They also found that thickness of the FAA should be greater than 1.5 mm for conductivity requirements and less than 3 mm for long term creep considerations. Creep rate of the FAA tends to increase with increasing thickness of FAA.

Kilback and Barrett (1998) reported on the use of an asphalt concrete in the cover for a industrial waste, pulp and paper ash landfill located in British Columbia. The asphalt concrete was designed to have a low hydraulic conductivity and to incorporate hydrocarbon contaminated soil into the mix as a method of stabilizing the contaminated soils. The site was preloaded for 12 months prior to asphalt placement to reduce settlements once the asphalt cover was in place. Although 7.5 cm (3 in.) of asphalt concrete was sufficient to meet the hydraulic conductivity requirement, a 15-cm (6-in.) thickness was placed. The asphalt concrete barrier is performing well to date (Kilback 1999). No information is available on how the issue of asphalt solubility in hydrocarbons in the contaminated soil was addressed or on settlement tolerance limits for the asphalt concrete cover.

A 0.4 m (16-in.) thick asphalt concrete cap was used to cover a slag dump at the Port of Tacoma, Washington (Richardson 1999). The cap serves as a parking area. The low hydraulic conductivity layer was an asphalt-coated geotextile placed in the asphalt concrete section. The hydraulic conductivity was less than $1x10^{-7}$ cm/s.

OTHER CONSIDERATIONS FOR USING ASPHALT BARRIERS

Asphalt liners are generally not resistant to organic solvents and chemicals, in particular hydrocarbons, so they may not be acceptable liners for petroleum derived wastes or oils, fats, aromatic solvents or hydrogen halide vapors (Kays 1977). Asphalt has shown good resistance to inorganic chemicals and corrosive gases such as hydrogen sulfide and sulfur dioxide. Test results indicated a low permeability of the asphalt materials to radon (Nixon et al 1994). Carbonate-containing aggregates should be avoided if the waste stream or resulting leachates might be acidic (Kays 1977).

In regard to performance lifetimes, if the aggregate in the asphalt concrete mixture is inert, then our attention is focused on the asphalt itself. What is the effective lifetime of asphalt? In their quest for a 1000+ year barrier, the US DOE has performed several evaluations of the effective lifetime for asphalt (Freeman and Romine 1994). Accelerated aging tests on asphalts were performed and the resulting aged specimens evaluated. In addition, testing was performed on asphalt artifacts. Buried asphalt artifacts are analogous to the buried asphalt concrete barrier. Artifacts provide information on the long-term aging behavior of asphalt, which can be used to assess the effect on asphalt concrete barriers.

Mullen (1967) reported on the results of hydraulic conductivity and beam flexure tests for asphaltic concrete samples from pavements in Maryland. The pavements ranged from new to 17 years old. Asphalt cement content ranged from 5 to 6 percent. Samples with less than 6% voids had hydraulic conductivities of less than $1x10^{-7}$ cm/s and limited aging of the asphalt cement. The low-void samples tended to retain ductile load-deflection behavior after years of service. High void samples tended to be dried out and exhibit brittle load-deflection behavior. High asphalt cement content coupled with low void compaction yields low hydraulic conductivity, high ductility, extended life asphalt concrete.

Kays (1977) discusses asphalt concrete liners in general and more specifically as seepage and erosion barriers for earth dams. He stresses analysis of the total design including the nature of the subsurface below the intended liner and the risks associated with leakage from the facility. Kays was ahead of the regulatory agencies in suggesting that performance standards might be more appropriate for design of a liner than simply requiring a prescribed design. Kays (1977) and Creegan and Monismith (1996) provide general design guidance for asphalt concrete hydraulic barriers.

LESSONS LEARNED

Results of laboratory and field efforts with asphalt concrete and fluid applied asphalt illustrate low hydraulic conductivities can be achieved with these barriers given proper design and high level construction quality control. Several lessons to be learned from the existing data include:

- The percentage of air voids must be below 4% (vol. basis) to achieve low hydraulic conductivity,
- Asphalt cement content must be above 6% (wt basis) to achieve low hydraulic conductivity,
- Increase fines content (fraction less than 0.02 mm) to 8% - 15% to insure a dense graded mixture,
- Use at least two layers of asphalt concrete, minimum thickness of 5 cm/layer,
- Apply an asphalt cement tack coat between layers, stagger the joints, and slope them for good compaction,
- The fluid asphalt applied layer should be between 1 and 3 mm thick, and
- The subgrade must be stable and adequately drained.

AREAS REQUIRING FURTHER RESEARCH AND DEVELOPMENT

Results of past laboratory and field efforts indicate several areas in need of further research and development prior to wide acceptance of asphalt barriers for waste isolation. Most of the issues below can be solved through the introduction of instrumented test pads and prototypes. These issues include:

1. Compatibility
    - Liquids (or gases) that might chemically interact with the asphalt or aggregate.
    - Strain possibly causing cracking or distress in the barrier.
2. Construction
    - Procedures for attaining desired compaction and air voids content.
    - Procedures for placing and compacting asphalt on slopes.
    - Standard procedures for Construction Quality Control and Quality Assurance.
3. Performance Monitoring
    - In situ hydraulic conductivity measurements.
    - In situ deformation measurements.
    - Long-term monitoring to assess effective design lifetimes.

CONCLUSIONS

Asphalt materials are being chosen over conventional compacted soil/geomembrane barriers for high level waste isolation because of their low conductivity and promise for long term performance. Similar consideration should be given for all waste isolation applications. Asphalt barriers may be a better long-term solution than currently accepted designs for many situations, in particular, covers for all types of facilities and liners for non-hazardous and inert waste facilities. The challenge to our community is to take on the development of asphalt barriers – a long-term solution for many waste isolation situations.

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