Advanced Geomembrane Technology for Enhanced Protection of EPS Geofoam in Transportation Systems

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ABSTRACT

Construction grade expanded polystyrene (EPS), or geofoam, is dimensionally sensitive to hydrocarbons and is typically covered with a protective polyolefin geomembrane when used as a foundation material. Data has been generated showing that the geomembranes currently used in construction applications provide less protection than initially assumed, with liquid fuels diffusing through some in as little as 4 hours. Enhanced protection for EPS geofoam foundations can be achieved using barrier geomembrane products, which utilize multilayer polymer geomembrane technology for increased protective performance. Fuel spill experiments using a variety of geomembranes (composed primarily of either linear low density polyethylene (LLDPE), high density polyethylene (HDPE), ethylene interpolymer alloy (EIA), polyvinyl chloride (PVC), or chlorosulfonated polyethylene (CSPE-R)) show these geomembranes to have poor permeation resistance to gasoline, resulting in rapid degradation to encased blocks of EPS geofoam in only a few hours. In contrast, a multilayer barrier geomembrane was shown to provide considerable advantage in protecting the EPS foam by preventing gasoline permeation for over 1000 hours of continuous exposure. Additional testing has further demonstrated complete protection of the geofoam can be achieved even after 160 days (3840 hours) of exposure to gasoline.

INTRODUCTION

Low density expanded polystyrene (EPS) foam is commonly used in construction projects as a fill material behind retaining walls, in building foundations, and under roads, railways, bridges, and airport runways (Horvath). When used in these backfill applications, EPS is referred to as geofoam and is utilized to decrease lateral loads/pressures, reduce structure settlement, and increase slope stabilization relative to heavier soil backfilled designs. The current EPS market in the United States is estimated to be 600,000 tons in 2018, and global shipments of EPS geofoam are projected to increase 5% per year from 2018 to 2023, driven in large part by demand in the transportation sector (Grand View Research). In typical applications, the EPS geofoam is placed on top of a sand-leveling layer and under a geosynthetic plastic membrane (as shown in Figure 1). This geosynthetic membrane, or geomembrane, protects the geofoam from moisture and harmful chemical exposure, which can lead to geofoam degradation, foundational depression, and ultimate failure of the overlying architecture. Long-lasting protection of EPS geofoam is therefore of paramount importance in maintaining safe, reliable, and economical structures.

Moisture absorption by low density EPS geofoam has been extensively studied and found to typically be much less than 5% by volume, thus having little impact on the mechanical properties

or volume of an EPS foam block (Gnip). However, hydrocarbon-based chemicals are well known to cause rapid dissolution of polystyrene foam blocks, resulting in extreme shrinkage and corresponding loss of structural support capabilities. Aromatic hydrocarbons such as benzene, toluene, ethyl benzene, and xylene (BTEX) are particularly adept in this dissolution process and are significant components of both gasoline and diesel fuel, as are several other hydrocarbon chemical species. Therefore, fuel exposure by automobile accidents on roadways or fuel spills at construction sites could potentially allow fuel to seep through the topsoil and into the underlying sub-structure, causing extensive damage to the EPS geofoam foundation. These hydrocarbons are also common soil contaminants in brownfield industrial zones, and lateral hydrocarbon diffusion through soil could allow for penetration into geofoam foundations even if the hydrocarbon source is not located directly overhead. Complete protection of the geofoam from organic hydrocarbons is of critical importance and can be achieved using geomembrane covers. However, not all plastic geomembranes are effective diffusion barriers to the wide variety of chemicals contained in liquid fuels.
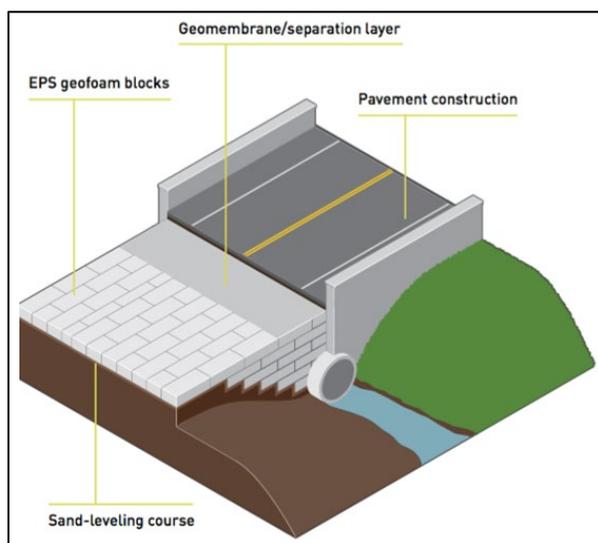
Figure 1. Schematic of EPS geofoam fill project.
Adapted from https://www.cellofoam.com/buried-structures.htm.

To evaluate the geomembrane permeation resistance to hydrocarbons and observe damage to geofoam exposed to diffusing hydrocarbon fuels, EPS-15 foam blocks were sealed in air-tight pouches made from a selection of geomembranes (listed in Table 1) and submerged in either gasoline or diesel fuel. Detrimental effects incurred by the geofoam due to permeation of the organic liquid chemicals through the geomembrane pouches were observed, with these visual aids providing valuable information in recommending geomembranes for improved geofoam protection.

MATERIALS

The geosynthetic membrane materials listed in Table 1 were formed into pouches (30 cm x 30 cm) using a hot bar sealer. Each pouch contained a cubic block (5.08 cm on each side) of

EPS-15 geofoam (ρ = 15 kg/m^3). Pouches were then submerged in large drums of either E-10 gasoline or #2 diesel fuel.

Table 1. Geosynthetic membranes evaluated

Geosynthetic Membrane	Abbr.	Principal Polymer Constituents
HydraFlex® HU30B	LLDPE	Linear Low Density Polyethylene
HydraLine™ HD40B	HDPE	High Density Polyethylene
EIA Chemically Resistant Membrane	EIA	Ethylene Interpolymer Alloy
CSPE M284B	CSPE-R	Chlorosulfonated Polyethylene Reinforced
HydraFlex® PVC30	PVC	Plasticized Polyvinyl Chloride
VaporBlock® Plus™ VBP20	LLDPE-B	Multi-Material Barrier

EXPERIMENTAL METHOD

Geomembrane pouches were formed by hot bar sealing two 30.5 cm square sheets of polymer with a 0.64 cm wide seam. A cubic polystyrene geofoam block (EPS-15) was sealed in the pouch to act as an organic chemical sensor for any fuels permeating the polymer pouch. Each geofoam block was measured (mass, volume) prior to pouch enclosure. Pouches were placed in racks and then submerged in large drums of either gasoline or diesel fuel (shown in Figure 2). Pouches were removed at specified times and carefully opened to determine if any volumetric degradation had occurred to the EPS geofoam block. Changes in mass and volume were used to characterize the extracted geofoam blocks. Each pouch-fuel combination was studied in several repeated trials in efforts to fully resolve the geofoam shrinkage-to-time relationship.


Figure 2. Experimental setup for submersion of geomembrane pouches in fuel drums.

RESULTS

As an initial estimation of diffusion parameters, 2.5 cm x 5.0 cm samples of each geomembrane were submerged in vials of gasoline and diesel fuel to determine maximum fuel absorption and the time required to reach this maximum absorption level. These results allowed for a rough ranking of gasoline and diesel permeation resistance, with permeation expected to occur first through PVC, followed by CSPE-R, EIA, LLDPE, and HDPE. This rough ranking also expected minimal-to-no permeation through the LLDPE-B barrier geomembrane. Results with diesel fuel revealed diffusion to occur at roughly a tenth of the rate of these gasoline trials, indicating a rough rule of thumb that permeation through the geomembranes should take 10x

longer than gasoline permeation. Based on these estimations, time frames for the pouch submersion studies were planned and implemented.

As expected based on the estimated timeline, rapid gasoline permeation was indeed observed in PVC geomembranes. Figure 3A shows the resulting rapid geofoam shrinkage (i.e. remaining volume fraction of the geofoam block, X_v) with the onset of damage occurring after gasoline permeates the PVC membrane only a few hours after submersion (t_{sub}). Similar profiles are shown in Figure 3 graphs B through F, for LLDPE, EIA, CSPE-R, HDPE, and LLDPE-B geomembranes, respectively. These profiles clearly show an induction time where gasoline compounds are diffusing through the geomembrane, followed by adsorption of the chemicals into the geofoam cube, resulting in rapidly deteriorating volume to approximately 4% of the initial size. A selection of images of the shrunk geofoam specimens are highlighted in Figure 4 to show this shrinkage trend. The obvious exception to this degradation is that of the geofoam encased in LLDPE-B barrier geomembrane (Figure 3F, Figure 4F), which even after over 1000 hours of continuous submersion in gasoline has yet to experience any geofoam deterioration. Despite being the thinnest geomembrane tested, the LLDPE-B multilayer barrier geomembrane clearly demonstrates superior permeation resistance to the hydrocarbon chemicals encountered in gasoline, compared to the other standard geomembranes tested.
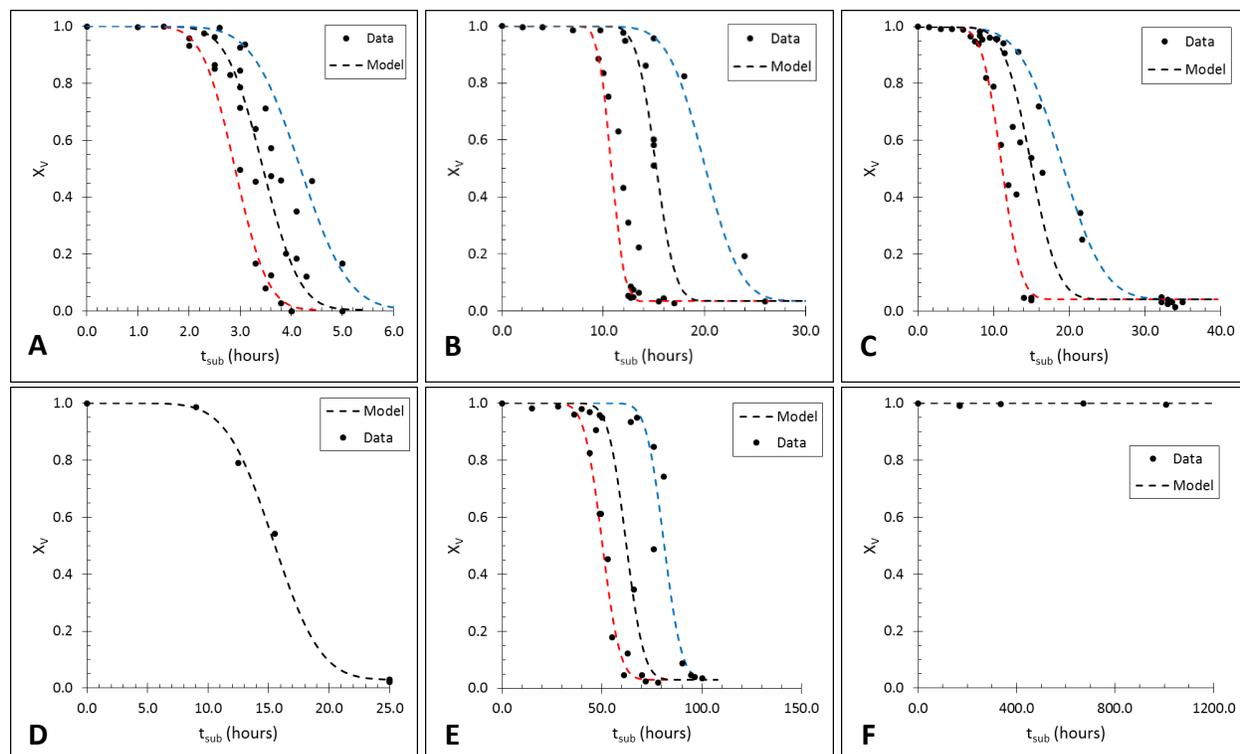
Figure 3. Induction time and onset of geofoam degradation due to chemical permeation through A) PVC, B) LLDPE, C) EIA, D) CSPE-R, E) HDPE, and F) LLDPE-B geomembranes.

Geomembrane pouches were also prepared for submersion in drums containing diesel fuel. From our rule of thumb that the induction time would be 10x larger than that of the gasoline trials, it was anticipated the diesel fuel permeation trials would take several weeks to perform. In fact,

after six weeks of continuous testing, geofoam damage due to diesel fuel permeation was only observed to occur through PVC and LLDPE geomembranes. These results indicate that while diesel fuel is fully capable of causing damage to geofoam foundations, several of the geomembrane
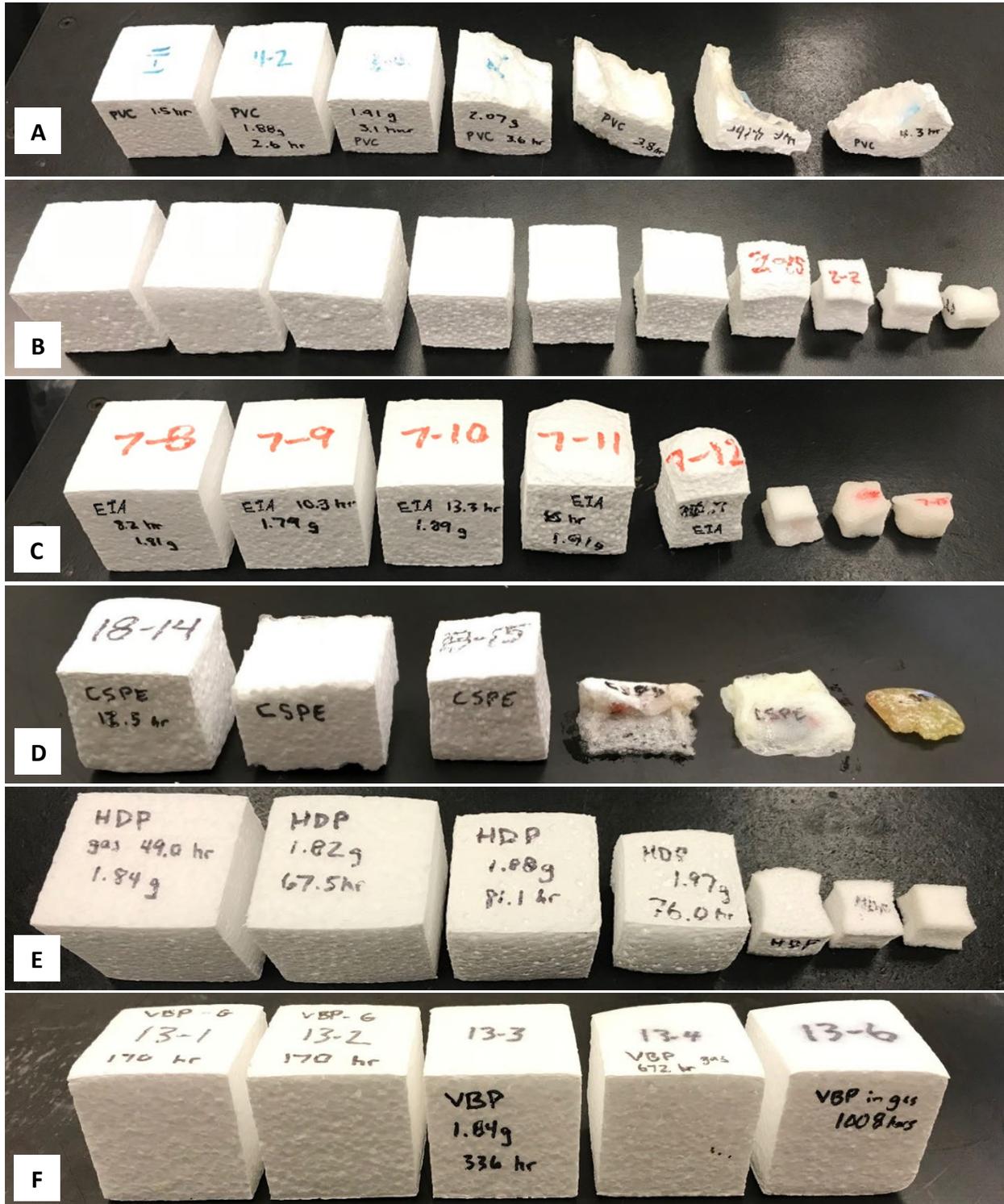

Figure 4. Time resolved geofoam degradation due to gasoline permeation through A) PVC, B) LLDPE, C) EIA, D) CSPE-R, E) HDPE, and F) LLDPE-B geomembranes.

materials are capable of providing a sufficient protection time in the case of an overhead diesel fuel spill. While protection against lateral diffusion of hydrocarbon species must still be assured, the remainder of this paper will focus on protection from gasoline diffusion, which occurs more rapidly and is therefore more of a threat to foundational geofoam structures.

ANALYSIS AND DISCUSSION

The rate of degradation of the EPS geofoam in pouches made of common polyolefin geomembranes exposed to hydrocarbon-based fuels was even more rapid than initially expected. Testing of several specimen sets allowed for excellent resolution of the time-shrinkage relationship. Technical literature (Igwe) and internal laboratory evaluations confirm that ordinary LLDPE, CSPE-R, and PVC quickly absorb large amounts of hydrocarbon fuels, reaching full saturation in only several hours. These saturated materials can swell and gain up to almost 40 weight percent in hydrocarbons, which may then diffuse from a high concentration region (the membrane) into a low concentration region (the geofoam). The implication of these results is that if a fuel spill is not cleaned up before it reaches the geofoam geomembrane, a substantial portion of the hydrocarbon fuel is likely to reach the sensitive EPS geofoam through slow diffusion of the fuel contained within the geomembrane. Gravity induced diffusion can also cause geofoam damage, even after the original hydrocarbon source is removed. These persistent hydrocarbons may continue to contaminate brownfield sites long after the original spill, making long-term protection essential for new geofoam foundations and structures.

From Figure 3, it is also clear there is variation in the data regarding the time to permeate (i.e. induction time) the geomembrane. Initially, this variation was thought to be due to imperfect membrane thickness or slow failing seam welds, but over the course of multiple trial sets, it was determined that on cooler fall (September) days, the induction time was consistently longer than those observed on warmer summer (August) days. From these first tests in August to last tests in early October, daily temperatures were observed to drop from as high as 35 °C to as low as 7 °C. Although the temperature in this study was not precisely tracked, the local temperature history was used to confirm the slower permeation data was in fact observed on colder days and faster permeation data observed on warmer days. After confirming this, the red and blue trend lines (denoting the warmer days and colder days, respectively) were added to Figure 3 to further differentiate the proposed temperature influence on through-membrane diffusion. While temperature considerations were not originally a part of this study, it is now recognized that the Arrhenius temperature effect is likely to play a significant role on the through-membrane diffusion properties, and further investigation into the temperature dependence is certainly warranted.

Using the Fickian based models shown in Figure 3, linear flow rates were calculated by simply dividing the geomembrane thickness by the observed average induction time. A summary of these induction times and linear flow rates is shown in Table 2, which aligns well with the anticipated diffusion parameters. Using data from these experimental trials, the diffusion coefficients were also calculated, with the results showing agreement with those seen in other references (McWatters).

Furthermore, the results of this work agree with studies performed by Norberg and Kolbasuk, where after only a few days of submersion in ASTM gasoline significant damage was observed in geofoam blocks encased in LLDPE or HDPE geomembranes (Norberg). In this work

by Norberg, LLDPE-B barrier geomembranes proved capable of completely protecting enclosed geofoam blocks even after 160 days of exposure to ASTM gasoline (Figure 5, Norberg). The present study is continuing to evaluate the permeation resistance of these LLDPE-B barrier geomembranes to gasoline, to both compare to the previous study by Norberg and also determine if the LLDPE-B barrier geomembrane can protect geofoam from gasoline induced damage beyond the 160-day timeframe.

Table 2. Induction time and linear flow rate of gasoline through geomembranes

Geomembrane	$t_{95\%}$ (hours)	h (mm)	v (m/s)	ρ (g/cm^3)	$D_{i, gas}$ (m^2/s)
PVC	2.5	0.79 ± 0.01	9.2E-08	1.25	4.3E-11
CSPE-R	10.4	1.05 ± 0.09	2.8E-08	1.24	2.4E-11
EIA	9.4	1.09 ± 0.01	3.4E-08	1.19	3.5E-11
LLDPE	12	0.69 ± 0.02	1.7E-08	0.92	6.3E-12
HDPE	52	1.14 ± 0.07	6.7E-09	0.93	2.0E-12
LLDPE-B	∞*	0.49 ± 0.02	0*	0.98	0*

*no permeation observed after 1000 hours of testing
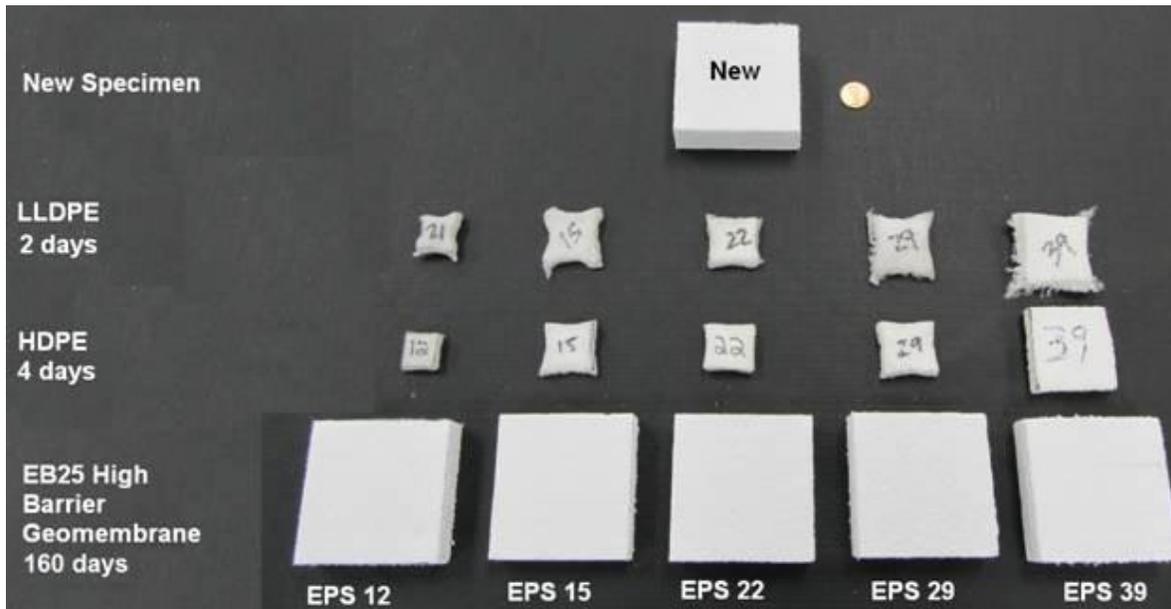
Figure 5. EPS geofoam blocks removed from protective pouches after submersion in ASTM gasoline (Norberg and Kolbasuk).

CONCLUSIONS

Expanded polystyrene (EPS) geofoam must be protected from hydrocarbon exposure when used as a foundation material in construction projects. Many existing polyolefin geomembranes do not provide adequate permeation protection, even though these may be marketed as resistant to hydrocarbon chemicals. The results of this study clearly show that geomembrane resistance to chemical breakdown is not equivalent to impermeability by the same chemicals. The use of Raven's barrier geomembrane (LLDPE-B) with improved multilayer technology has been demonstrated to provide enhanced protection to EPS geofoam blocks in liquid fuel exposure

experiments. Specifically, PVC, CSPE-R, EIA, LLDPE, and HDPE geomembranes were shown to uptake hydrocarbons in only a few to several hours, resulting in rapid deterioration of EPS geofoam in two or less days. EPS geofoam was completely protected with Raven's barrier geomembrane, which in two separate studies was shown to provide complete protection to the geofoam blocks for six weeks, and even up to 160 days of continuous submersion in liquid hydrocarbon fuel. Other barrier products or configurations will need to be studied to determine their ultimate protection capability. This long-term protection is essential for geofoam foundations, which may exist in industrial locations with either a risk of future hydrocarbon exposure or unknown brownfield contamination from past events.

Future work will continue to examine the long-term protective capabilities of the LLDPE-B barrier geomembrane along with other barrier materials against hydrocarbon permeation, as well as an assessment of barrier performance against other chemical compounds. Physics-based models are also under development. Additionally, the foam block compressive strength may be measured, as the block densification during shrinkage may provide a relevant indicator of hydrocarbon exposure.

ACKNOWLEDGEMENTS

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