XR GEOMEMBRANES
By Seaman Corporation

In Search of the Impermeable Geomembrane

INTRODUCTION

When we design a fluid barrier system, the concept is that it does more than slow transmission—it prevents transmission. That said, is anything fully impermeable? Most scientists say no, but permeability can be low enough that the fluid barrier system is essentially impermeable. This means that in its function, the permeability is low enough that measurable transmission is essentially zero.

Packaging films have approached the essentially impermeable state for many years. However, these are temporary applications where materials are not designed to withstand the same rigorous conditions as geomembranes. Therefore, there is typically a tradeoff between reliability and extremely low permeability. Laboratory testing showing extremely low permeability is pointless if it cannot be constructed without damage.

Consider the amount of flow through an orifice of a liquid compared to the amount of flow through a geomembrane of a vapor. Whether the hydraulic equivalent is 10^{-9} cm/sec or 10^{-13} cm/sec, the flow is essentially zero. These are typical numbers for a polymeric geomembrane. However, the flow through a ¼-inch diameter hole in a geomembrane, with a 1-foot hydraulic head is on the order of 1,000 gallons/day. That is a significant, measurable amount, which essentially makes the 2-order reduction in vapor transmissibility from 10^{-9} to 10^{-13} meaningless.

A geomembrane will rest on a subgrade and, in some applications, will have ballast placed on it. Precautions must be taken with the subgrade and the overlying ballast to avoid puncturing the geomembrane. With field conditions often difficult and variable, the geomembrane must be tough enough to compensate for imperfections in the subgrade/overburden or the preparation thereof.

Remember the reason a geomembrane was used in the first place: *lightweight, ease of installation, cost, barrier reliability.* If it is easily punctured, it is no longer reliable. Redundant protection layers have their constructability constraints as well.

In this paper, we'll explore laboratory and field tests conducted to compare Vapor Transmission and Survivability (puncture) of two commercially available geomembranes. These geomembranes are commonly used to protect lightweight EPS structural fill in transportation applications from failure when in contact with hydrocarbons. The tested products included:

- **9832 XR-5® G**
  Reinforced Ethylene Copolymer,
  30-mil, 650 lbs/in Grab Yield Strength
- **Linear Low Density Polyethylene Film**
  with a 1-mil Ethylene Vinyl Alcohol
  interior layer (LLDPE-EVOH),
  30-mil, 72 lbs/in Grab Yield Strength

LABORATORY TESTING

Vapor Transmission

Water Vapor or Solvent Vapor Transmission is a widely used method to establish laboratory transmission or conductivity through a polymeric geomembrane for comparative purposes. Solvent Vapor Transmission using ASTM D814, Inverted Cup, was conducted. ASTM D814 inverts the cups so the test liquid rests on the membrane. Weight change over time is measured until an equilibrium is reached. The perm cups are shown in Figure 1.

Test liquids were gasoline and diesel fuel. The test is a theoretical measure of the vapor transmission per Fick's Law of Vapor Permeation, which establishes that liquids pass through polymeric membranes in vapor form as opposed to natural materials that pass liquids in liquid form. The results are expressed as a theoretical quantity per area-time. The resulting perm, or Solvent Vapor Transmission (SVT), values are shown in Table 1. Also shown is a conversion to hydraulic conductivity, a more commonly used term among designers[1]. This conversion considers liquid properties, including specific gravity and vapor pressure, which are the theoretical force driving the liquid through the geomembrane.

As shown, the laboratory test produces a lower value for the LLDPE-EVOH film. The 1-mil EVOH layer within the polyethylene film is a packaging product that is designed to act as a vapor barrier while being physically protected by the LLDPE. The EVOH layer, being an alcohol, is adversely affected by water and thus, again, the polyethylene is designed to protect the alcohol layer.[2]

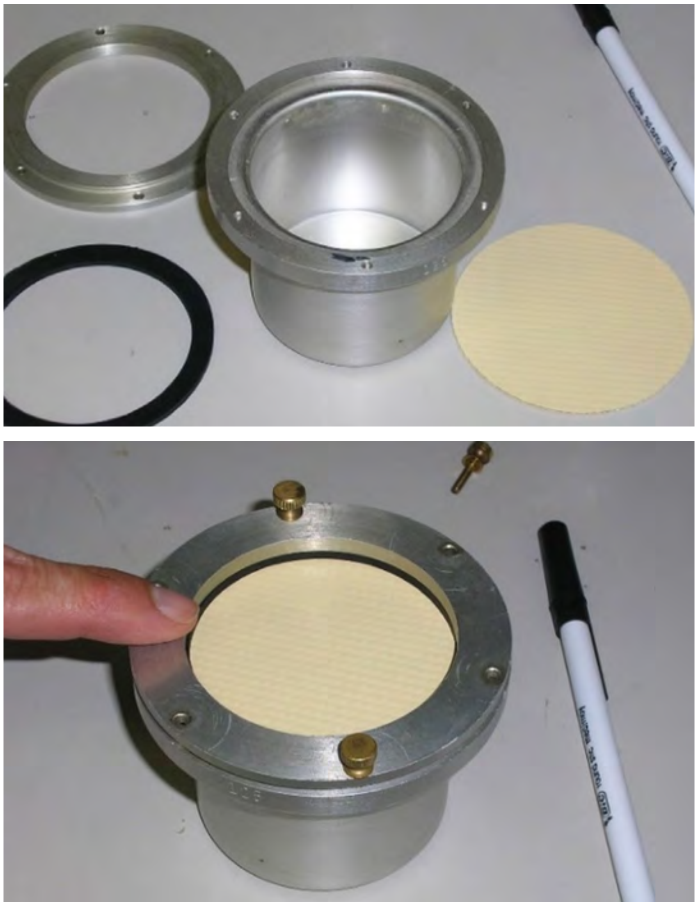


Figure 1. Vapor Transmission Cups for ASTM D814

Geomembrane	**SVT-Gasoline** (fl oz./ft^2/day)	**SVT-Diesel** (fl oz./ft^2/day)
9832 XR-5 G	0.3138	0.0030
LLLDE-EVOH	0.0030	0.0029

Solvent Vapor Transmission ASTM D814

Geomembrane	**SVT-Gasoline** (fl oz./ft^2/day)	**SVT-Diesel** (fl oz./ft^2/day)
9832 XR-5 G	2.5×10^{-11}	1.9×10^{-13}
LLLDE-EVOH	1.9×10^{-13}	1.9×10^{-13}

Table 1. Laboratory SVT/Hydraulic Equivalent Values

Puncture Resistance

The same two geomembranes were tested to compare puncture resistance. This test uses a probe to measure the amount of point load carried prior to puncture. Figure 2 shows the test apparatus.

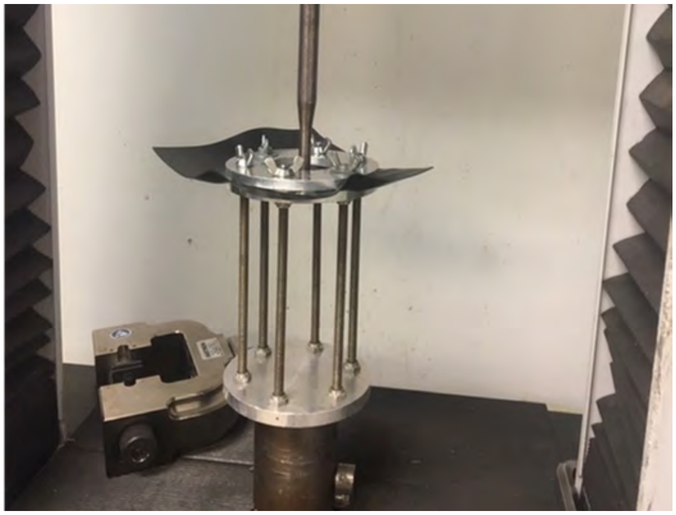


Figure 2. Laboratory Puncture Test Apparatus for ASTM D4833

The results of five tests were averaged and are shown in Table 2. As expected, the reinforced ethylene copolymer exhibited substantially higher puncture resistance in a laboratory testing environment.

Geomembrane Type	Test Puncture Value *ASTM D4833, lbf*
9832 XR-5 G	290
LLLDE-EVOH	78

Table 2. Results of Laboratory Puncture Testing

Field Testing

Field tests were conducted to compare actual resistance to puncture for the same materials that were tested in the laboratory. The field tests were designed to simulate conditions typically encountered during installation and then during the service life of the fluid barrier to evaluate survivability.

The materials tested were a polyester reinforced ethylene copolymer and a 40-mil LLDPE film with an EVOH internal layer. Note the LLDPE-EVOH product is the same used in the laboratory puncture testing but is 30% thicker.

Field test setup procedure:

1. Approximately 1-square-foot geomembrane samples were placed over a crushed stone base at a construction site.
2. Then, stone was randomly placed over the samples.

This environment simulates conditions often encountered in construction projects, using a common construction aggregate, crushed limestone. Figure 3 illustrates the samples used in the simulation, along with their placement and the aggregate placement over the samples.

Figure 3. Samples (40-mil LLDPE-EVOH was used for the field test in order to measure a more robust product.) (inset) and Placement (top and bottom) for Field Puncture Simulation

Figure 4. Field Puncture Simulation

After placement of the stone over the geomembrane, a vehicle was driven over the samples and then reversed, resulting in the weight of the front of the vehicle passing over both samples twice with assumed equal loading. The purpose was to evaluate the ability of these materials to withstand common construction activities so the barrier properties remain intact. Figure 4 is a photograph of the vehicle and samples placement prior to the testing.

SEE THE TEST ITSELF IN A SHORT VIDEO CLIP

After the field test, the samples were retrieved and visually inspected for any damage. The LLDPE-EVOH sample had visible punctures, but none could be visually detected with the 9832 XR-5 G, as shown in Figure 5.

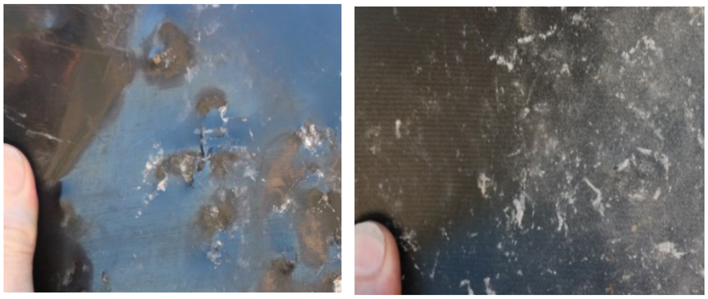


Figure 5. Geomembrane Samples After Field Puncture Test
Left: 40-mil LLDPE-EVOH, Right: 30-mil 9832 XR-5 G

To better quantify the penetrations, a laboratory light box was used, which is illustrated in Figure 6. The next set of photos in Figure 7 show the samples on the light box with the room lights on, as well as with the room lights out and with the light box illuminated in the darkened room.

While on the light tables, the samples were evaluated visually. There were no visual punctures in the Reinforced Ethylene Copolymer. There were 26 holes in the LLDPE-EVOH, conservatively averaging 0.1 inch (2.5 mm) in diameter.

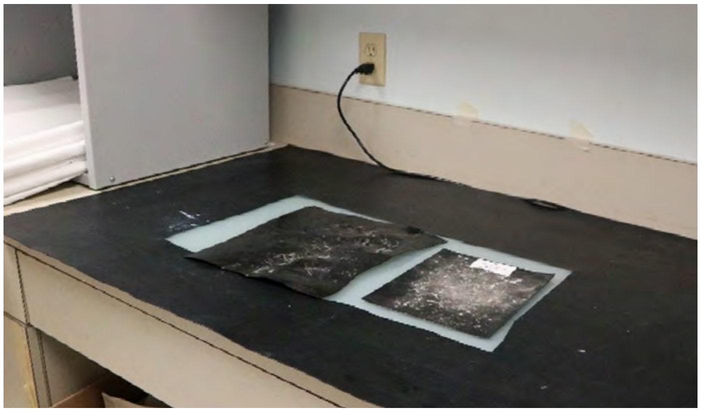
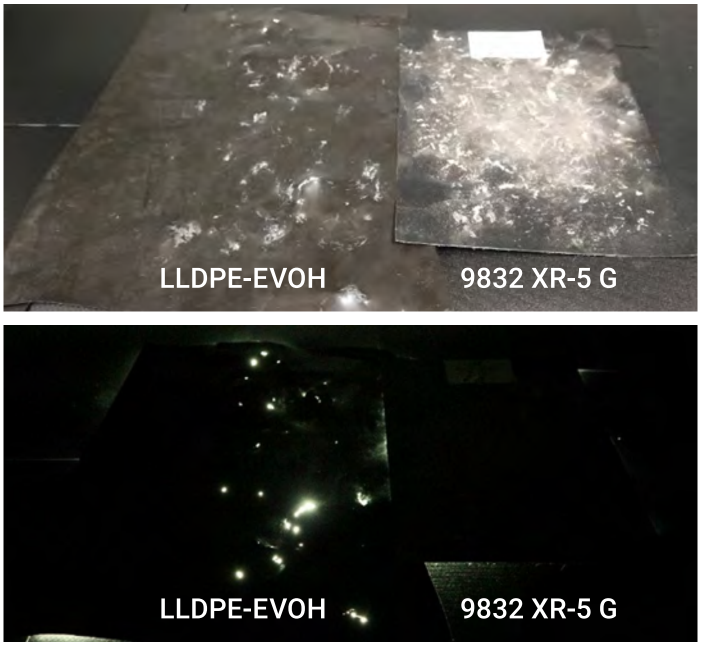


Figure 6 [Above]. Laboratory Light Box With Samples

Figure 7 [Below]. Geomembrane Field Puncture Test Samples on Light Table. Top photo: Room Light On, Bottom photo: Room Light Off



ANALYSIS

There are many factors which influence the amount of liquid transmission through a hole, or breach, in a geomembrane, including:

- Degree of intimate contact between the geomembrane and the underlying soil or aggregate.
- The type of geomembrane and its susceptibility to thermal expansion-contraction during installation.
- The presence of an engineered porous layer under the geomembrane, such as a geotextile.
- The thickness and porosity of the underlying soil or aggregate.
- The amount and type of overburden.
- The configuration and spacing of any breaches in the geomembrane.
- The hydraulic or solvent head on the breach.

One could assume the maximum flow could be represented by comparing it to the orifice flow where there is a completely free discharge, allowing a calculation as follows:

<u>Orifice Equation</u>

$$Q = Cd\left(\frac{\pi D^2}{4}\right)\sqrt{2gh}$$

for a circular orifice, where:

Q = flow *(ft³/sec)*

Cd = coefficient of discharge
(Typical Values: Sharp Orifice = 0.62, Tube = 0.80)

D = area of orifice *(ft²)*

g = acceleration of gravity *(32.2 ft/sec²)*

h = head acting on centerline *(ft)*

So, for this example:

Cd = 0.62

D = 0.1" = 0.00833 ft

h= 2" = 0.166 ft

$$Q = 0.62\left(\frac{\pi \times 0.00833^2}{4}\right)\sqrt{2 \times 32.2 \times 0.166}$$

$$Q = 1.104 \times 10^{-4} cfs = 9.53\ cu\,ft/day$$

This calculation assumes no restrictions at the discharge point.

Studies[3] performed regarding the amount of leakage in primary liners have placed emphasis on the influencing parameters shown above. The effect of the degree of intimate contact between the underlying soil or aggregate has been indicated to be an extremely important item in determining the amount of leakage. Giroud and Bonaparte, through a combination of theoretical and laboratory methods, quantified the amount of leakage from a 0.16 in² (1 cm²) penetration, under 1.2 inches of hydraulic head, based on differing subgrade-geomembrane contact conditions which are summarized in Table 3.

Field Condition	Description
Best	Soil is well compacted, flat and smooth, has not been deformed by rutting during construction, and has no clods or cracks; the geomembrane is flexible and has no wrinkles; the geomembrane and soil are in close contact.
Worst	Soil is poorly compacted, has an irregular surface and is cracked; the geomembrane is stiff and exhibits a pattern of large, connected wrinkles.

Table 3. Description of Best and Worst Field Conditions for Subgrade-Geomembrane Contact

Figure 8 shows the amount of theoretical leakage through a single geomembrane puncture based on subgrade conditions, assuming a tightly compacted, low permeability subgrade. Figure 8 illustrates the amount of leakage under each condition, with “Good” and “Poor” indicating intermediate situations between the extremes.

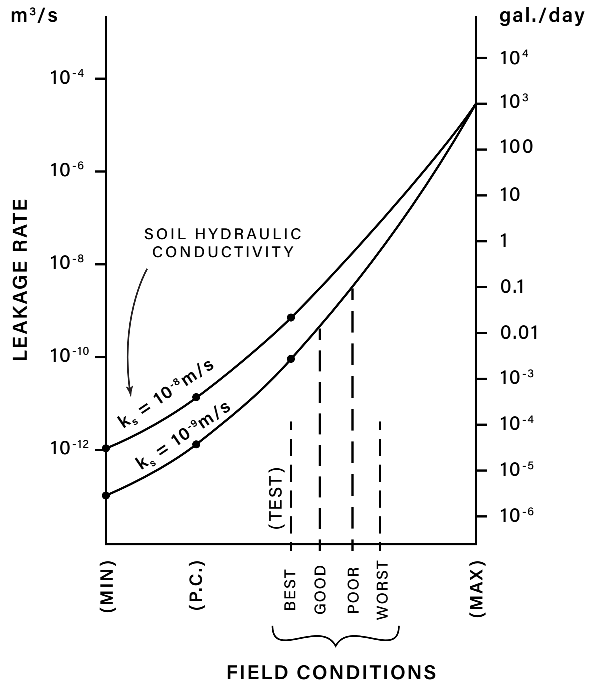


Figure 8. Flow Through a Single Puncture vs. Contact With Subgrade *(Giroud 1989)*

At the extreme amount of flow (MAX) it is assumed this is a near free-flow condition, similar to the orifice analysis given previously. However, the hole diameter for the analysis shown in Figure 8 is 0.45-inch as opposed to 0.1-inch in the orifice example. Using a 0.45-inch diameter in the orifice calculation yields a leakage value within the same order of magnitude as that shown in Figure 8.

Based on leakage estimate from Figure 8, the leakage vs. subgrade condition on a unit basis is shown in Table 4.

Max	Poor	Good	Best
10^3	0.01	0.03	1×10^{-5}

Table 4. Discharge Per Puncture Based on Subgrade Contact, Gallons/Puncture/Day[3]

As can be seen, a small hole created during installation, under minimal head, can create a large leak and destroy the credibility of the low permeability of the geomembrane. In fact, combining leakage due to vapor transmission as calculated by Fick’s Law, with orifice flow from construction damage shows the former is insignificant, as seen in Table 5.

Geomembrane	Theoretical Vapor Leakage -Gasoline, *gall/sf/day*	Number of punctures in field test /SF	Number of punctures in field test - assumes good subgrade contact, *gall/sf/day*	TOTAL Flow/SF based on Theoretical Vapor Leakage plus subgrade contact condition, *gall/sf/day*
9832 XR-5 G	5.3×10^{-7}	0	0	0.00000053
LLDPE-EVOH	4.1×10^{-9}	26	0.39	0.39

Geomembrane	Theoretical Vapor Leakage -Diesel, *gall/sf/day*	Number of punctures in field test /SF	Number of punctures in field test - assumes good subgrade contact, *gall/sf/day*	TOTAL Flow/SF based on Theoretical Vapor Leakage plus subgrade contact condition, *gall/sf/day*
9832 XR-5 G	4.1×10^{-9}	0	0	0.0000000041
LLDPE-EVOH	4.1×10^{-9}	26	0.39	0.39

Table 5. Analysis of Field Puncture Simulation Results, Under the Following Assumptions:

1. Theoretical vapor leakage based on hydraulic equivalent calculation shown in Table 1.
2. Leakage due to punctures is assumed at ½ the value from Figure 8 using “Good” subgrade contact conditions; corrected to assume smaller than 0.45-inch diameter average hole size, based on field puncture simulation.
3. TOTAL Flow/SF/Day is sum of columns 2 and 4.

SUMMARY AND CONCLUSIONS

Geomembrane polymer barriers offer excellent resistance to the transmission of fluids. The passage of chemically compatible materials is essentially zero and must pass through in a vapor state that is influenced by differential pressure across the membrane. Again, if chemically compatible, that passage is essentially zero.

Geomembranes are construction products. They are used as a component of an overall build to provide a reliable, lightweight, cost-effective alternative to thicker, heavier natural materials. Construction is an activity that lends itself to consideration of the term survivability (i.e., materials used in construction must be resilient and tough enough to be installed within the project to impart their desired function). Fragile materials can offer some advantages but seldom are the advantages worth the likelihood of damage during the construction activity.

In conclusion, the designer should consider the tradeoff for a slight advantage in one property for a much higher overall survivability in the other.

REFERENCES

1. **Koerner, Robert**, *Designing with Geosynthetics*, 6th Edition, 2012, Section 5.1.
2. **McWatters, R.S.; Rowe, K.R.**; "Permeation of Volatile Organic Compounds through EVOH Thin Film Membranes and Coextruded LLDPE/EVOH/LLDPE Geomembranes"; *Journal of Geotechnical and Geoenvironmental Engineering*; ASCE, February 2015.
3. **Giroud, J.P.; Bonaparte, R.**; "Leakage through liners constructed with geomembranes—Part II. Composite liners"; *Geotextiles and Geomembranes* 8 (1989) pp. 71-111.

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