

Whitepaper

The Myth of Vapor Permeation and Thermal Insulation

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ABSTRACT

Glass Fiber Reinforced Polypropylene (GFPP) composite is a light weight material with high impact resistance and very low moisture intake suitable for reefer liners over the traditional thermoset FRP panels. Polypropylene is one of the lowest moisture absorbing polymer available worldwide, which makes it ideal for interior panels for refrigerated trailers and truck bodies. Approximately five years ago, US Liner formally introduced Versitex, a continuous glass fiber reinforced polypropylene composite panel to answer the market demand.

There have been many myths surrounding how vapor permeation through the reefer liners would affect the insulation performance of the urethane foam behind the liners. Specifically, Great Dane's ThermoGuard has claimed that it can improve thermal efficiency by simply putting a thin foil layer within its panel. This paper reports that water absorption is the major rate limiting mechanism of water vapor permeation through the composite liners instead of the diffusion mechanism that aluminum foil is trying to block. The paper has found that US Liner's Versitex product, generically known as GFPP has similar vapor barrier properties compared to a foiled product such as ThermoGuard. In addition, this paper will illustrate that GFPP's have significant benefit over thermoset FRP. Among GFPPs, there is little difference between foiled and non-foiled.

While claims have been made that having a barrier layer in the wall panel may be the answer to a thermally efficient unit, there are several other factors that play equally meaningful a role. These include: type of insulation foam and blowing agents used during trailer manufacturing (no voids in wall, foam thickness), injection method, seal between scuff and wall, seal at all joints, no wall damage during use, door seal leakage, subpan leakage, and a variety of other issues. Insulation specifications and manufacturing method play a much greater role in efficiencies than does foil. This paper will show that when Versitex non-foiled GFPP is chosen as reefer liner material, there shall be no discernible difference between foiled and non-foiled ThermoGuard type panels in regards to loss of insulation efficiency. It is not recommended to pay the extra foil cost and hope for a payback.



WHO IS US LINER COMPANY

US Liner Company (USLCO), a division of American Made LLC, located in Cranberry Township Pennsylvania, was founded in 1983 to develop unique materials that had never been used in the refrigerated truck/trailer market before. Traditional materials such as wood, fiberglass, steel, and aluminum had been used for over 40 years in these applications. USLCO was the first Company in North America to introduce reinforced thermoplastic materials into the refrigerated trailer market. Bulitex was the first high impact reefer panel introduced, followed by Versitex. Bulitex was designed to be the most impact resistance panel on the market and outperform any other product. USLCO developed and manufactured a continuous glass-reinforced woven thermoplastic material under the brand name of Bulitex® in the late 1990s and now the company's next generation material called Versitex®, these two materials have become the gold standard for toughness and durability in applications throughout many industries worldwide.

Combining continuous glass fibers with tough, corrosion and moisture resistant polypropylene, in multilayer laminated structures, U.S. Liner has perfected a new class of versatile sheet materials. Utilizing this technology, we're helping our customers rethink even their most basic assumptions about sheet applications. And we're backing these technical developments with manufacturing capacity and signature service and support.

The company's sales over the past several years have shifted from Bulitex "Ballistic Textile" to almost exclusively to Versitex whose name is derived as a versatile "Textile" product has displaced fiberglass, wood, steel and aluminum in numerous market applications by offering a stronger, lighter and low cost alternative to these traditionally used materials. Additionally, with today's environmental focus, virtually all of USLCO's products are 100% recyclable as it is manufactured from the two most common recycled materials, glass and polypropylene.

Versitex literally ships around the corner and around the world! In fact, U.S. Liner products bring so many advantages to so many different applications.

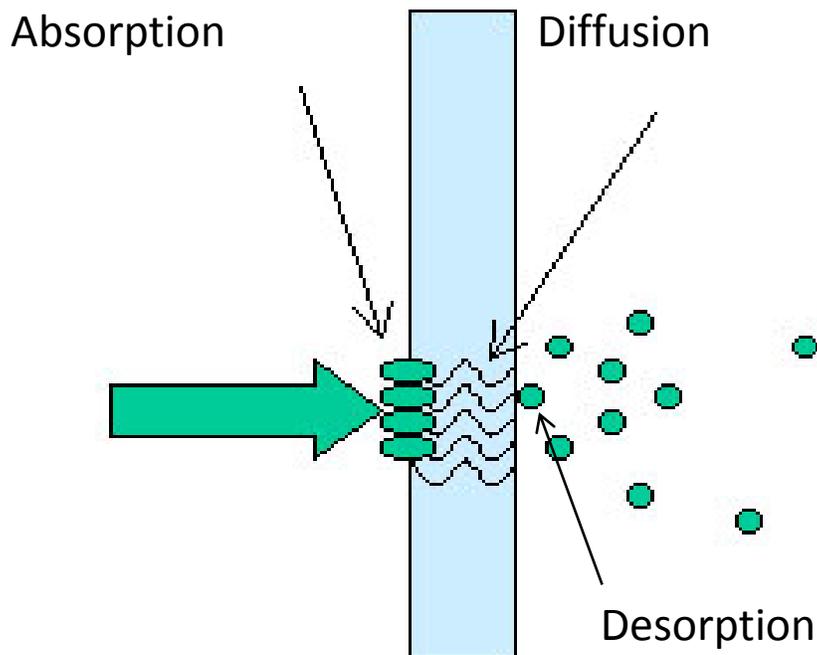


HOW PERMEATION WORKS

Permeation is the transfer of vapor or gasses through a barrier material such as polymer or composite to the other side. As illustrated in the figure below, the process involves three steps.

1. **Absorption** - The vapor molecules are absorbed onto the surface of the barrier material.
2. **Diffusion** - The absorbed molecules migrate through the medium to the opposite side due to concentration differential.
3. **Desorption** - The migrated molecules evaporate from the second surface of the barrier material.

The entire process is driven by permeant (i.e. vapor/gas) concentration gradient. Vapor molecules from the high concentration side pass through the barrier material to the low concentration side until the partial pressures reach an equilibrium.



FACTORS AFFECTING PERMEATION RATES

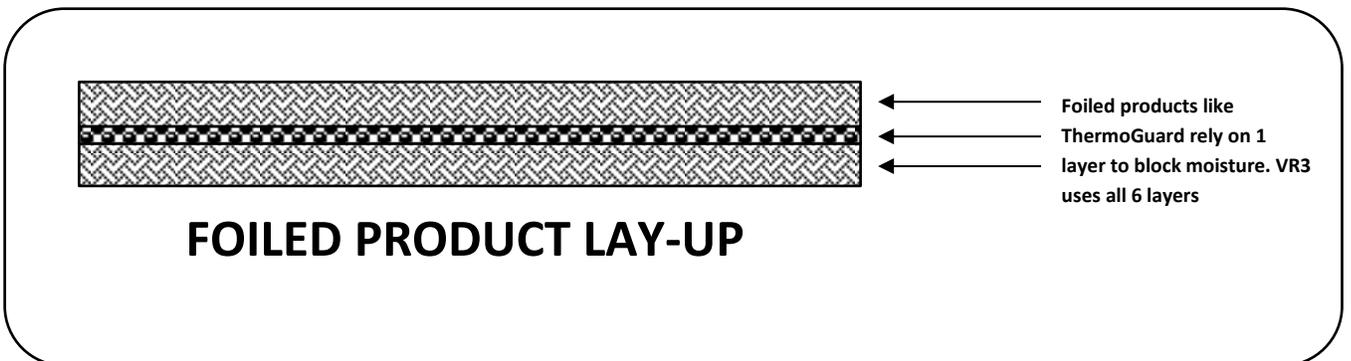
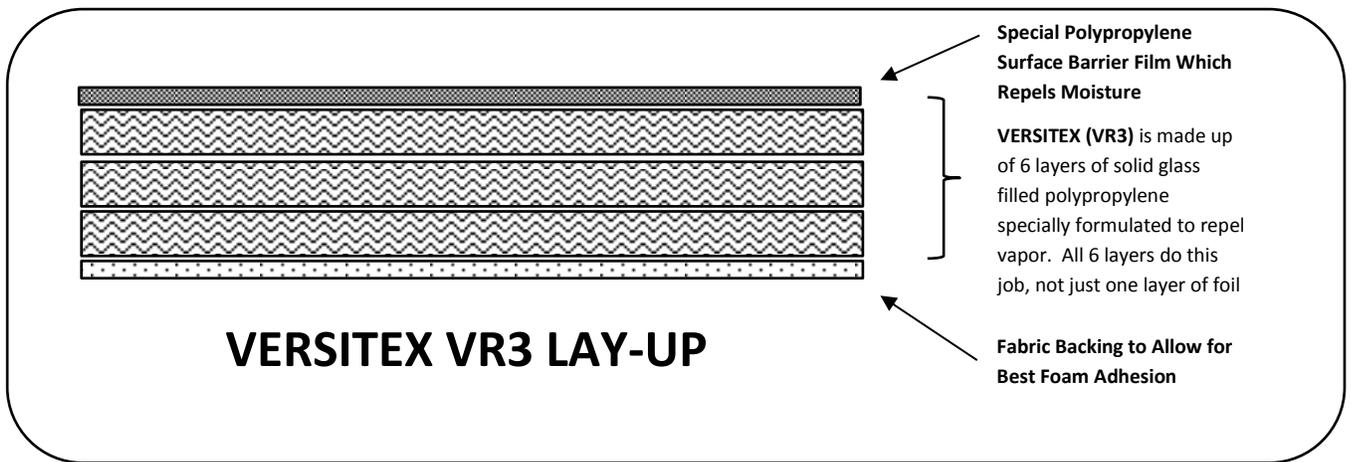
All polymers are permeable to some degree. The permeability is affected mainly by the follow physical and chemical variables of vapor, barrier material, and environmental conditions.

1. **Chemical Affinity between the Vapor and Barrier.** If the vapor molecules and barrier material are more chemically compatible or contain similar polarity or functional groups, the vapor can be absorbed more easily onto the surface. In addition, this can cause the polymer chains in the barrier more likely to swell, allowing easier penetration of the vapor molecules. An example of polymer chains that would be most likely to swell from moisture penetration /absorption is Nylon and FRP. Whereas, water vapor absorption into GFPP Versitex Polypropylene or Polyethylene are repelling, thereby resulting in almost no absorption at all
2. **Vapor Concentration.** Both absorption and diffusion rates are proportional to the concentration gradients of the permeant. For example, in water vapor transmission test, relative humidity is one of the key driving forces.
3. **Temperature.** Higher temperature increases molecule mobility and hence faster diffusion. In a refrigerated condition, water molecules are less mobile or even freeze to solid if below freezing point. *Note: This is critical as the foiled product propaganda indicates the use of TTMA RP No. 38 testing method to arrive at the graphs displayed in the literature. However, the test requires the use of heating the inside of the unit and not cooling. Thereby making the results ambiguous and unreliable*
4. **Pressure.** Vapor pressure of the permeant serves as another driving force of transmission. The higher the pressure the greater the permeation rates.
5. **Void in the Barrier.** Physical voids, cracks or pinholes created path without resistance, immediately compromising the barrier integrity. Thin foils do not provide the same characteristics as sheet. An example would be why there is expiration date on foiled food packaging products that have to remain fresh and moisture free. The thin foils used to keep fresh and intact only last a finite period of time.
6. **Barrier thickness.** The thicker the barrier the lower the transmission rates
7. **Polymer Crystallinity.** The amorphous phase of the polymer medium, where the polymer chains are more mobile, allows the diffusion of vapor molecules passing through. The molecules in the crystalline phase are organized, making it difficult for foreign molecules to pass through. Therefore, high crystallinity increases barrier properties. Versitex (GFPP) has the highest crystallinity.



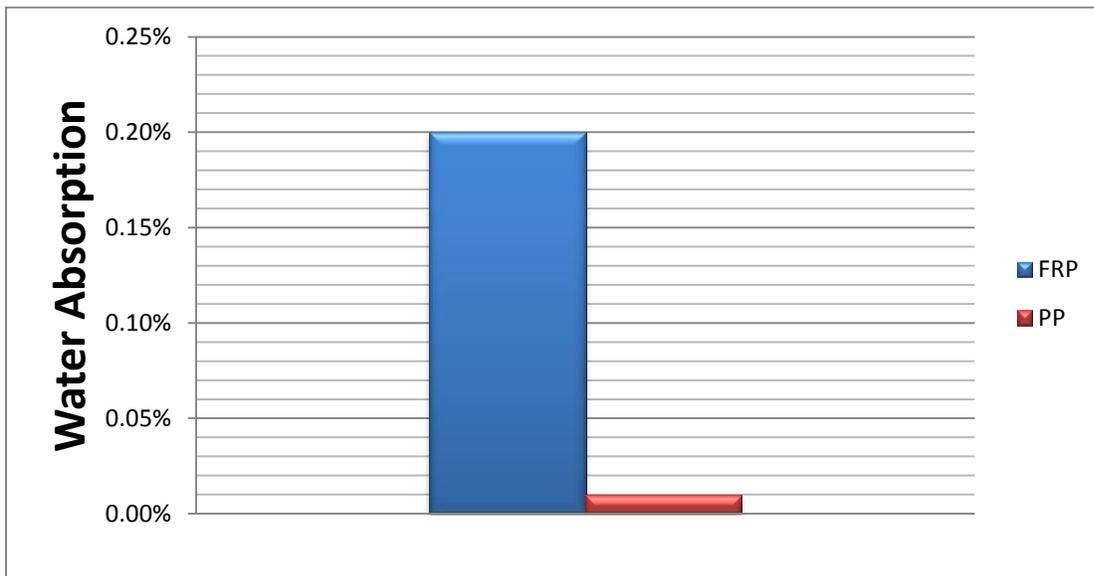
8. **Additives in Polymer.** Platelet-like additives in polymer matrix results in torturous path for permeant to diffuse through, effectively increasing the barrier properties. USLCO uses very specific additives to improve even greater the barrier properties of its products. ***IT IS MORE RELIABLE THAN FOIL SINCE THE WHOLE PRODUCT ACTS AS BARRIER, NOT JUST THE FOILS.***

***** See Lay-Up Illustrations Below *****



WATER ABSORPTION EFFECT ON WVTR (Water Vapor Transmission Rate)

The first step of permeation is absorption of the permeant (i.e. vapor) into the medium. The graph below shows water absorption rate of two typical liner panel substrates, Polypropylene (PP) and Fiberglass (FRP) for 24 hours at 25 C per ASTM D-570. It's shown that FRP absorbs 20X more water than Polypropylene. This is consistent with the WVTR results and the permeation factors described in the next section. Typical FRP resins, vinyl ester or epoxy ester, are hygroscopic and thus have high affinity to water vapor molecules. On the other hand, Polypropylene (PP) is hydrophobic and repels water molecules, resulting in very little absorption and subsequent transmission.

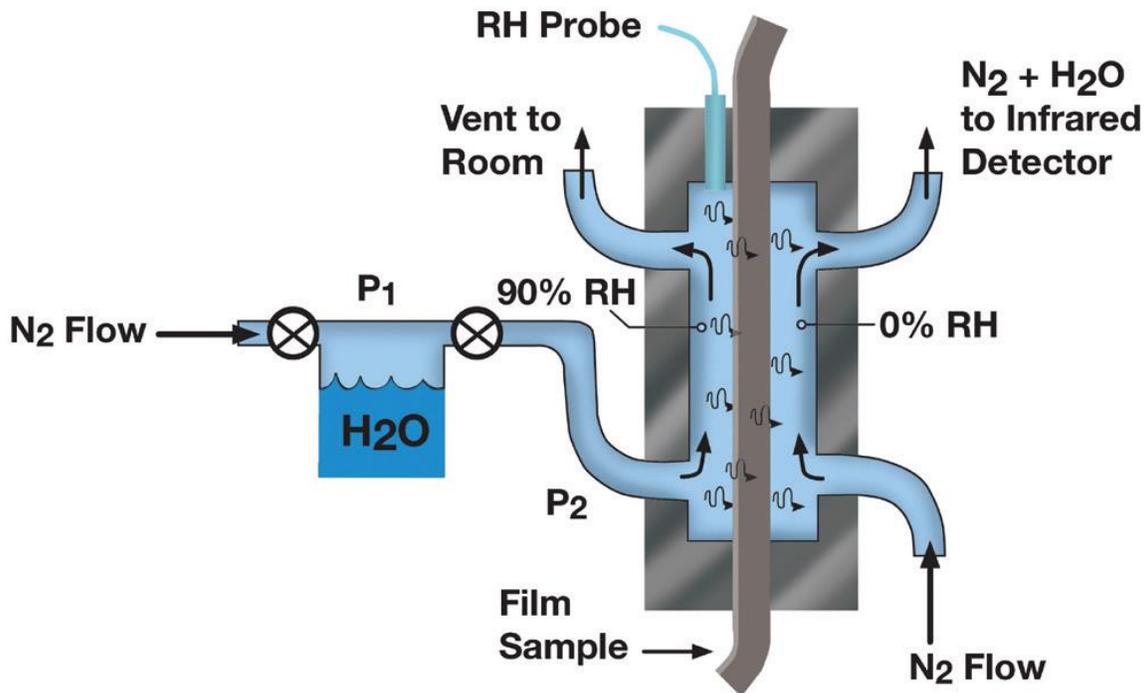


Source: Crane ArmorTuf 65115 Technical Data Sheet, Generic PP Technical Data Sheet



PERMEATION MEASUREMENT

The Diagram below illustrates a schematic of how the water vapor transmission rate (WVTR) test per ASTM F-1249 is conducted. The barrier material is placed and sealed in the test apparatus, separating it into two chambers. One chamber is filled with the permeant of interest, in this case water vapor, at a controlled temperature and relative humidity. The other chamber is flushed with nitrogen carrier gas, carrying the permeated water molecules to the detector. The infrared sensor detects the concentration of water molecules or gas in the carrier gas and converts the signal to transmission rate, presented in amount of permeant per unit area per time. The units for transmission rates are commonly presented as $\text{g}/\text{m}^2/\text{day}$ or $\text{g}/100\text{in}^2/\text{day}$ for water vapor, and $\text{cc}/\text{m}^2/\text{day}$ for other gases. Transmission rate is specific to the specimen measured at a given thickness. Test conditions of temperature and relative humidity all affects the results and have to be specified in the test. A more generic material property is presented as permeation rate, which takes into account of the barrier thickness and partial pressure. It is calculated from measured transmission rate multiplied by the thickness of the barrier material and divided by the partial pressure gradient of the permeant. Typical unit is $\text{g}\cdot\text{mm}/\text{m}^2/\text{day}/\text{mmHg}$.



To understand the effect of those permeation factors described above to the composite liner materials, US Liner Company contracted an independent third party laboratory to perform water vapor transmission rate (WVTR) test per ASTM F-1249. The test specimens consisted of VERSITEX glass fiber reinforced PP panels, a panel which had a foil barrier layer along, and a traditional thermoset FRP panels. Data below show significant differences of WVTR between the hygroscopic FRP and the two intrinsically water repellent PP composites.

WATER VAPOR TRANSMISSION RATE TEST RESULTS

Company: US Liner
Date: August 31, 2007

Sample Description	Composite plaques
Test Temperature	100°F ± 0.5°F
Test R.H.	100%
Sample Test Area	50 cm ² masked
Sample Orientation	As marked
Test Results Accuracy	± 3%
Test Procedure	In order to report results as tested to the ASTM F-1249 (WVTR) standard test method, a minimum of triplicate testing of each sample is required.
Notes	· Test results were corrected to sea level pressure (760mmHg). · Average thickness is based on a minimum of five points distributed over the entire test area.

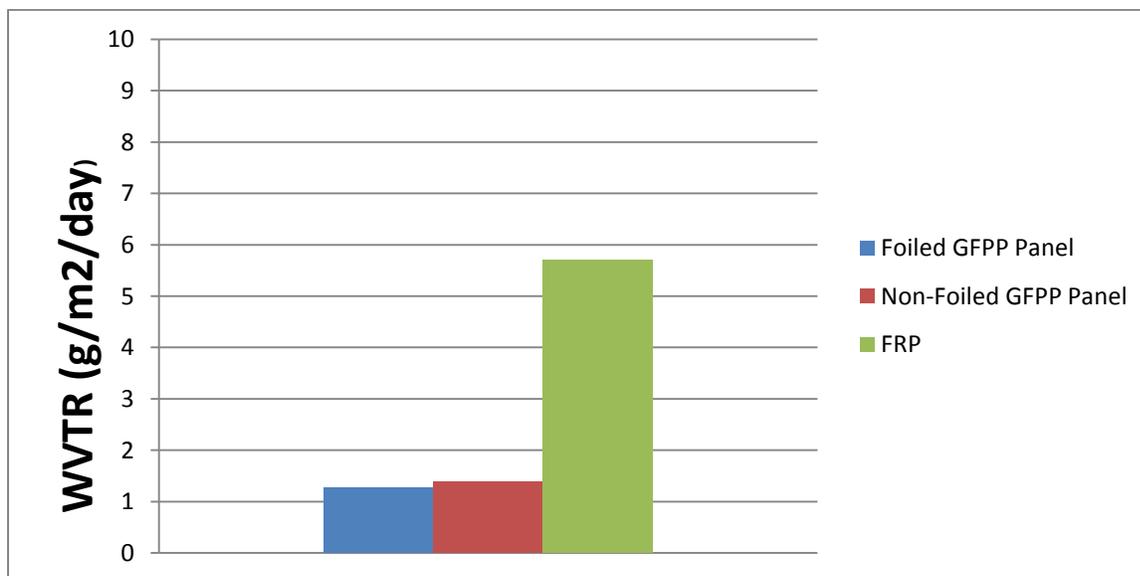
Sample Designation	Average Thickness (mils) ± .05	WVTR (WV Transmission Rate) The time rate of water vapor flow normal to the surfaces, under steady-state conditions, per unit area.	
		gm/M ² /day	gm/100 Inch ² /day
VR3	78.81	1.06	0.068
VR2	56.63	1.38	0.089



WATER VAPOR TRANSMISSION RATE (WVTR)

Date Compiled	October 03, 2012
Test Procedure	ASTM F-1249 (WVTR)
Test Temperature	38C +/- 0.3C
Test R.H.	100%
Sample Test Area	50 cm ² masked
Sample Orientation	Smooth side to water vapor
Test Results Accuracy	+/- 5%
Notes	<ul style="list-style-type: none"> a. Test Results were corrected to sea level pressure (760 mmHg). b. Average thickness is based on a minimum of five points distributed over the entire test area c. Test accuracy is tighter on specimens with smooth surface to seal in the test apparatus.

Sample Designation	Average Thickness (mils)	WVTR The time rate of water vapor flow normal to the surface per unit area, under steady state conditions	
		g/sq.m/day	g/100 sq. inch /day
Foiled GFPP	90.90	1.28	0.083
Non-foiled GFPP	56.63	1.38	0.089
FRP	60	5.70	0.368



RESULTS - the results yielded that although the foil product was slightly better, it was well within the test specifications margin of error of +/- 3%, thereby establishing no discernable difference between the foiled and non-foiled GFPP panels. It was also noticed that in some tests of foiled GFPP there were pinholes present in some of the samples, as shown in the photo below Fig 1. These holes may be a result of the aluminum foil which is fragile and prone to tear and puncture. In addition, there is much evidence in the foils industry that if a foil is too thin, then the product can have pinholes. We believe this to be the case in the foiled (ThermoGuard) type products.

It seems that the diffusion mechanism the foil trying to block does not determine rate factor. **The effect of the thin foil barrier is trivial or negligible.** This might not be true for foiled food packaging because the multi-layered films are only a few mils thickness and the foil thickness is significant to the total thickness. In the case of liner panels the thickness is in tens or hundreds mils, the contribution of the thin foil, about 0.35 mils, diminishes. In this case, the absorption mechanism dominates the permeation process.

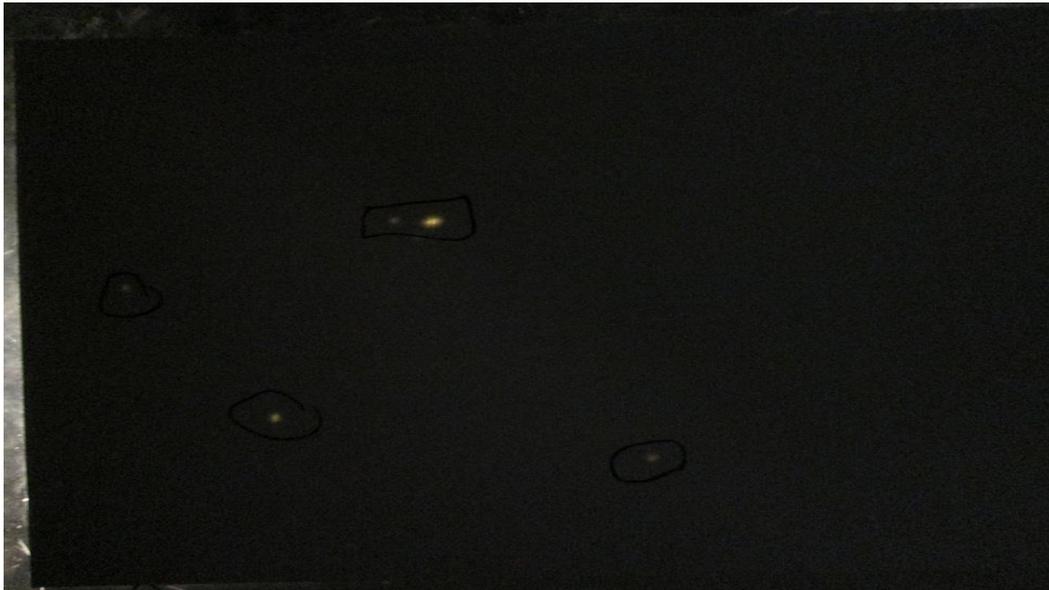


FIG 1. Holes 1mm-8 mm wide are seen in foiled GFPP through backlight. Magnification 37x's

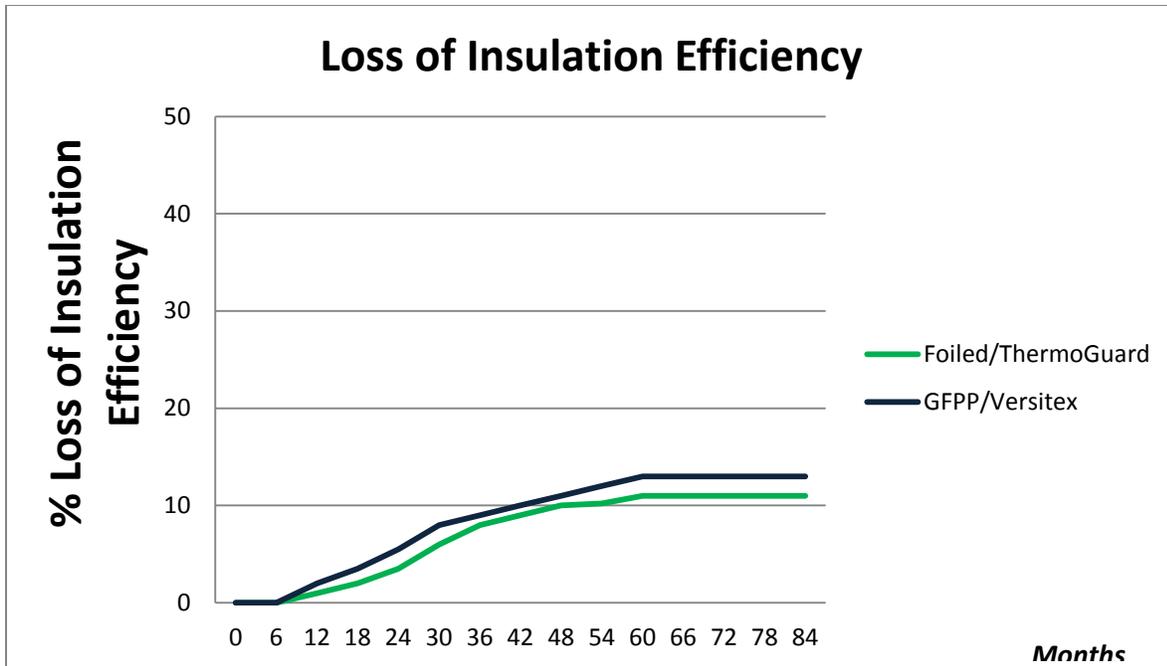
In the real world situation of a reefer, there are many other leak paths through edges or joints between doors, floor, walls, ceiling, and the refrigeration unit, more than merely through the wall surface. The entire system has to be tested as suggested by TTMA in the Appendix.



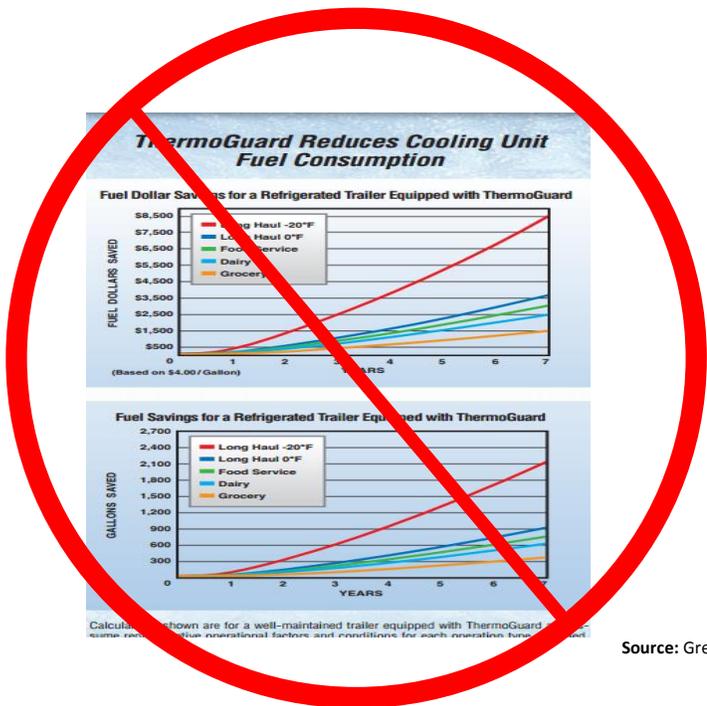
CONCLUSIONS:

- 1) In looking at the thermal permeability of Versitex (VR2 & VR3) panels compared to foiled ThermoGuard type panels, **there is no difference between the permeability of these panels and thus the thermal efficiency of these panels when put side by side in to a trailer.**
- 2) Considering the significant amount of factors that can affect the thermal efficiency of the trailer, there is no evidence given the results shown in this report that would suggest that a foiled panel provides any better thermal insulating properties than using a USLCO panel.
- 3) Spending extra money for a foil laminate panel assuming there will be savings down the road is not prudent.
- 4) Versitex is not the “Traditional Liners” that are highlighted in Great Dane ThermoGuard Literature and their White Paper. We believe it was FRP that was studied as Versitex has only been commercially available in its present for about 5 years now. Comparisons are misleading.
- 5) There are marginal to no additional fuel saving by using a foiled ThermoGuard type product (See Chart Below). There are many other factors that contribute to thermal efficiency of the trailer. The interior panel is just one.





Note: Loss of Efficiency is Negligible – Based on WVTR (ASTM F-1249) conducted by independent lab and extrapolation of data from Great Dane Whitepaper 2012



No Fuel Savings Based on Permeation Data Comparisons

Source: Great Dane ThermoGuard Brochure640 DMD 1012

Appendix 1

Testing and Rating Heat Transmission of Controlled Temperature Vehicles

Thermal insulation and air leakage performances of reefers may be tested per TTMA RP No. 38. In both tests, the vehicle shall be situated inside a test chamber within specific temperature ranges. The test cannot be conducted in the field since the control parameters are critical to establishing relevant data points.

The TTMA RP No. 38 Test is twofold. First there is an air leakage test which basically pressurizes the trailer and determines the amount of leaks that are in the trailer. The second test is the Thermal Insulation Test which requires the use of heat, not cooling (as suggested by ThermoGuard Literature)

In the air leakage test, air is introduced into the vehicle to maintain a steady state of pressure differential of 0.5 inch water column. The air flow rate is then recorded as the measurement of air leakage. The air leakage rate shall be used to determine the appropriate heat transmission correction factor.

In the thermal insulation test, the energy required to maintain a steady state of interior-exterior temperature differential shall be measured with a watt-hour meter. The watt-hour and temperatures are then recorded for the calculation of heat transmission rate.



Appendix 2

Thermal Insulation Mechanism

Polyurethane foams are commonly used for providing excellent thermal insulation in refrigeration applications. When urethane mixture is injected into the space between exterior and interior walls, chemical reaction takes place and foaming agent in the mixture starts forming bubbles while the isocyanates and polyols react to form a thermoset network. The control of the rise of foam and the size of bubbles determine how good the insulation efficiency will be. Best insulation is achieved by closed-cell foam, in which the gas in the bubbles is trapped by the urethane matrix, preventing it from flowing from cell to cell. Finer bubbles results in better insulation. Overtime, the foaming gas might escape through the cell walls and be replaced by atmospheric gas.

Table below shows thermal conductivity values of the materials of interest. They can be divided into three categories. The thermal conductivity of solid polymers, including PU, are typically in the neighborhood of 200 mW/(m.K). Those of gases, including volatile foaming agents and air, are about an order of magnitude lower in the neighborhood of 20 mW/(m.K). Foams are mixtures of the above solid and a majority of gas. Their thermal conductivities fall on the vicinity of 30 mW/(m.K), following the rule-of-mixture.

MATERIAL	Thermal Conductivity mW/(m.K)
Vacuum	0
Air	24
Pentane	14
Freon	7
Water vapor	19
Styrofoam	33
PU foam	30
Plastics	200
Vinyl Ester	250

Source: engineersedge.com

Notes: *ThermoGuard* is a registered Trademark of Great Dane Limited Partners
ArmorTuf is a registered trademark of Crane Corporation

