Osmosis: The Bane of Liquid Applied Waterproofing Membranes

WESTFORD SYMPOSIUM SUMMER CAMP 2014:

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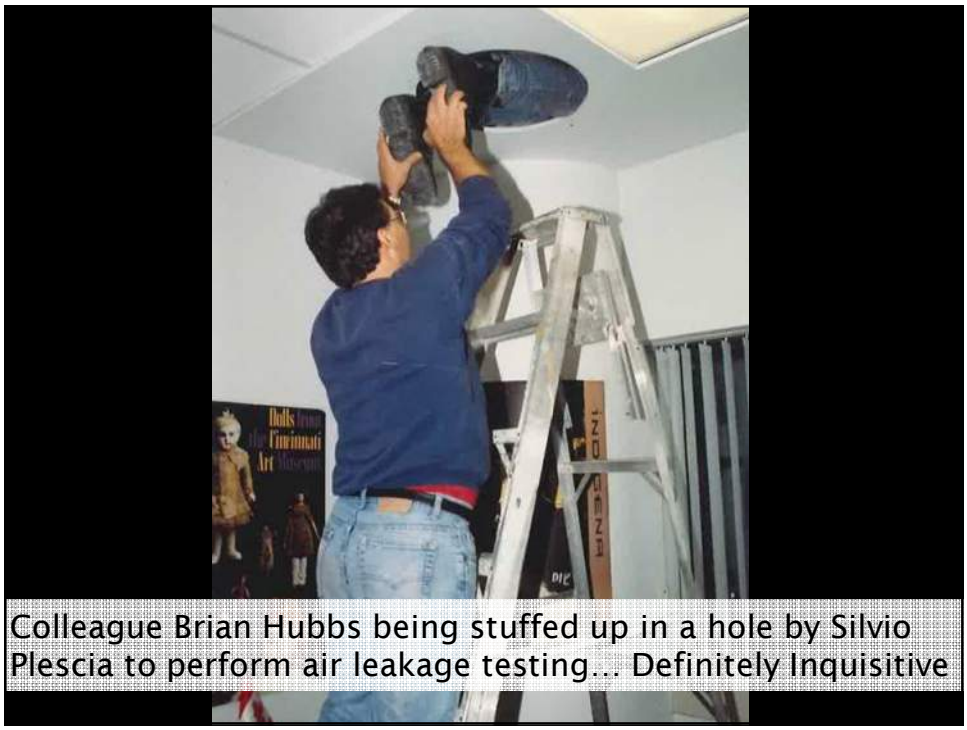
Outline

- → The Waterproofing Conundrum
- → Proving It
- → Testing It
- → Measuring It
- → Findings to Date
- → What to Look for?
- → What Next?

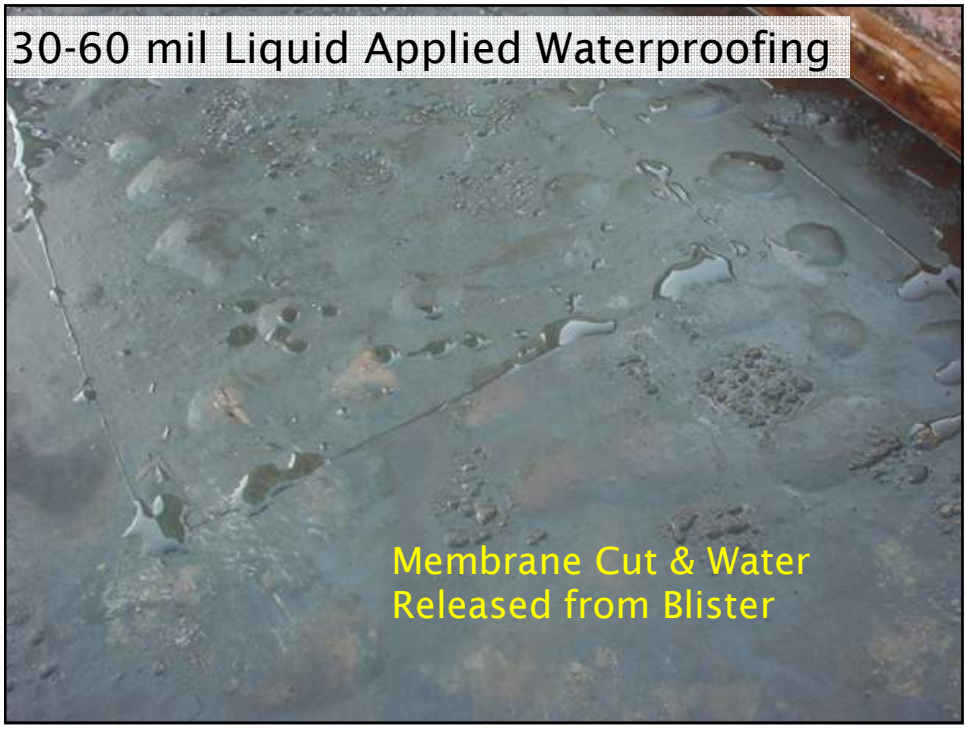
Inquisitive:

definition: eager to learn or learn more, to be curious, desire to solve problems….engineers!


Inquisitive & Loaded with
Cool Tools at Career Age

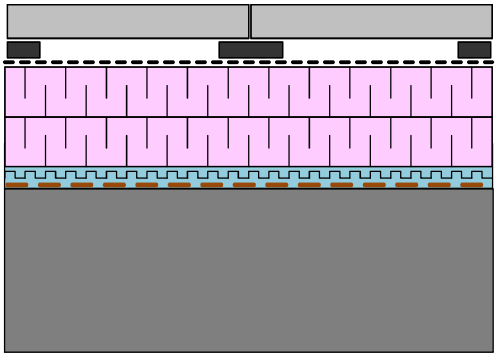

Colleague Brian Hubbs being stuffed up in a hole by Silvio
Plescia to perform air leakage testing… Definitely Inquisitive

The Waterproofing Conundrum


30-60 mil Liquid Applied Waterproofing
Membrane Cut & Water
Released from Blister


Liquid Water Below Membrane &
Reported Intermittent Leaks
Lots of water below
the membrane

Problematic Roof Assemblies Affected



- Concrete Pavers, Ballast, or Dirt/Green Roof
- Pedestals (optional)
- Filter Fabric
- XPS Insulation (over heated space)
- Drainage Mat (optional)
- **Liquid membrane**
- Concrete roof slab

Blistering observed over both conditioned (interior) and unconditioned space (parking garages), within planters, green roofs, and water features

2004 - Evaluating the Problem

- Systemic failure of 5 year old waterproofing membrane throughout massive 4 tower residential complex
  - Just one of many buildings affected that we were aware of
- Cause of the blistering unknown at the time
  - Apparent correlation with membrane thickness
  - Initial monitoring & research started

2004 – Membrane "Blistering Index"

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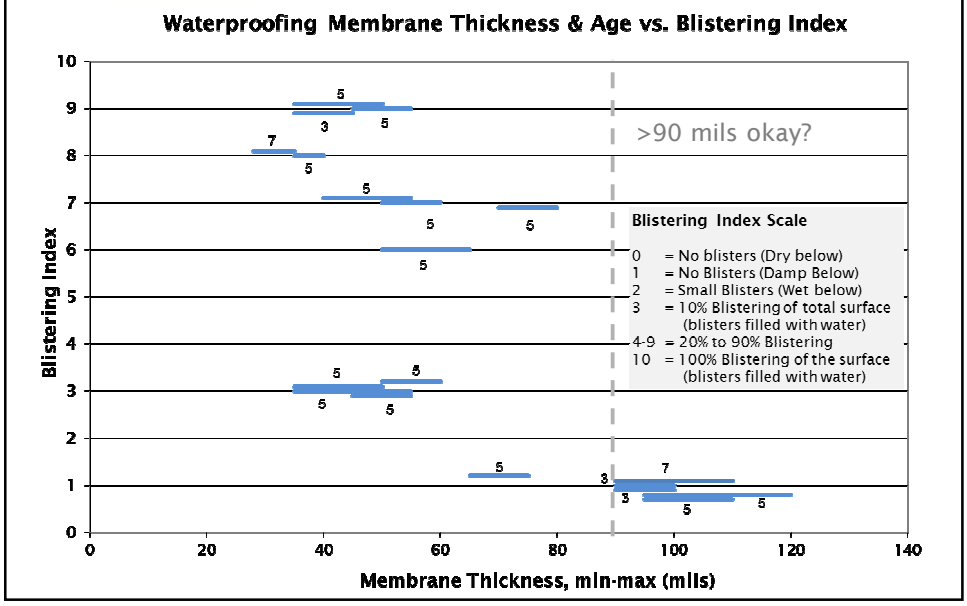



Blisters Everywhere you Dig!

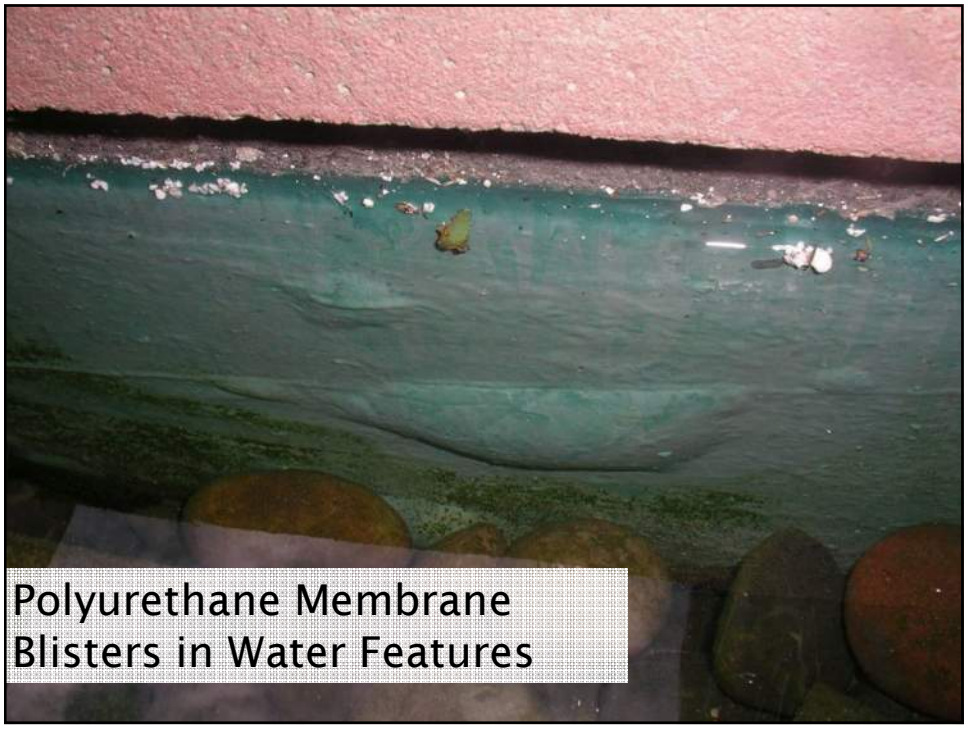

Gallons of Water Beneath Membranes

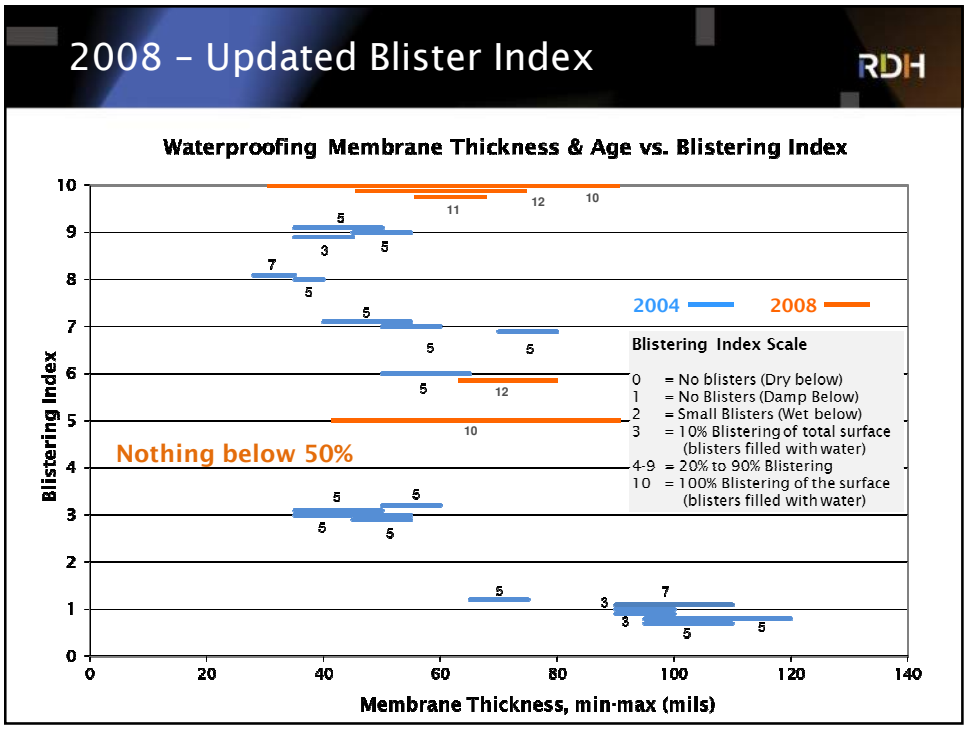

Leaks, Lawsuits &
Membrane Renewals


Membrane Blisters Lifting Pavers & Leaks


Membrane Blisters Lifting Pavers & Leaks


Paver Water Beds!


Polyurethane Membrane
Blisters in Water Features


2008 – Updated Blister Index
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Waterproofing Membrane Thickness & Age vs. Blistering Index
Blistering Index
Membrane Thickness, min-max (mils)
2004
2008
Nothing below 50%
Blistering Index Scale
0 = No blisters (Dry below)
1 = No Blisters (Damp Below)
2 = Small Blisters (Wet below)
3 = 10% Blistering of total surface (blisters filled with water)
4-9 = 20% to 90% Blistering
10 = 100% Blistering of the surface (blisters filled with water)

2008 – State of Affairs

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- Systemic issue affecting mostly asphalt modified polyurethane membranes in protected membrane roofs over concrete decks
  - 2 similar membranes from 2 major manufacturers
- Findings – Water Filled Blisters
  - Membranes 3 to 15 years old with blisters
  - Membranes 30-60 mils, some up to 120 mils
  - Blisters filled with water under pressure
  - Blisters range from penny size to entire roof deck areas
  - No obvious detail or discontinuity
  - Top of membrane almost always wet
  - Ability to lift pavers, expand/grow over time

Industry Perception Pre 2008

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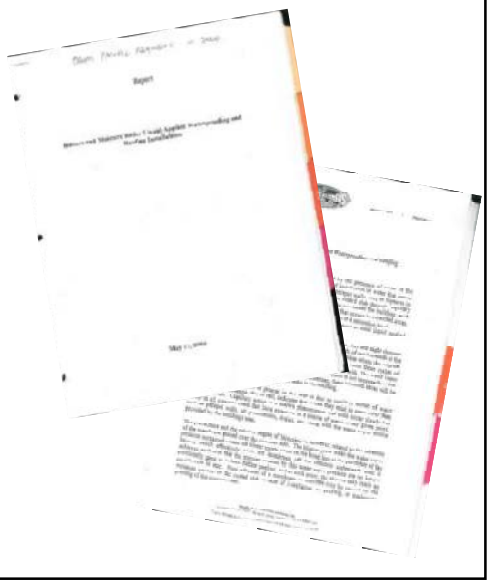
- Many hypotheses and strong opinions as to the blistering mechanisms
- Little building science understanding or research – lots of speculation
- Blame fell to many roofers and the liquid membrane manufacturers
- Reports of problems worldwide



Theory #1: Pinholes in Thin Membrane

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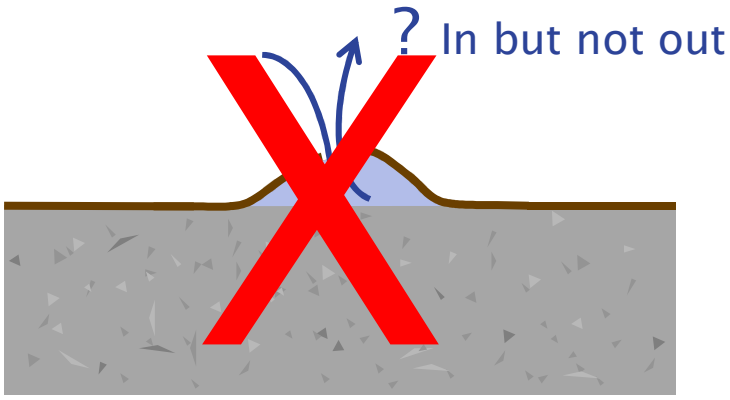

Theory #2: Hydrostatic Head from Details

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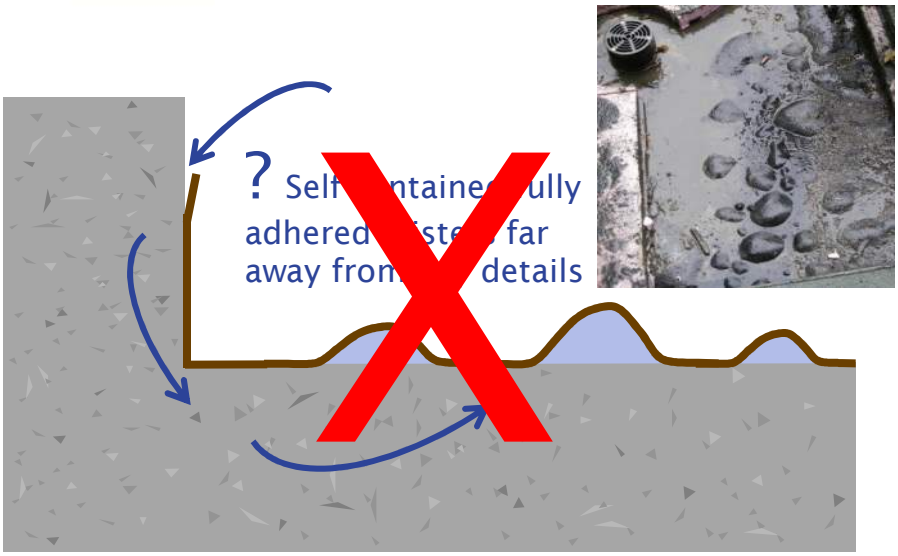

Theory #3: Vapor Diffusion from Inside

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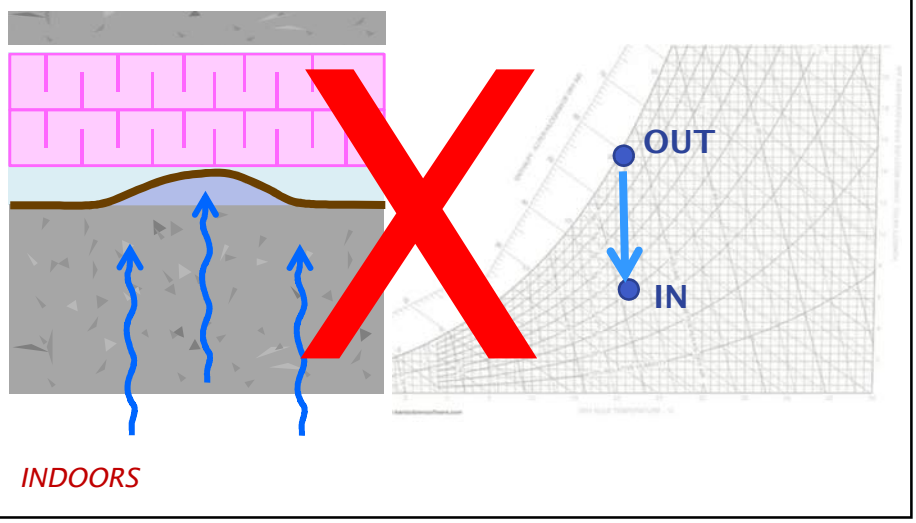

Theory #4: Diffusion & Capillary from Outside

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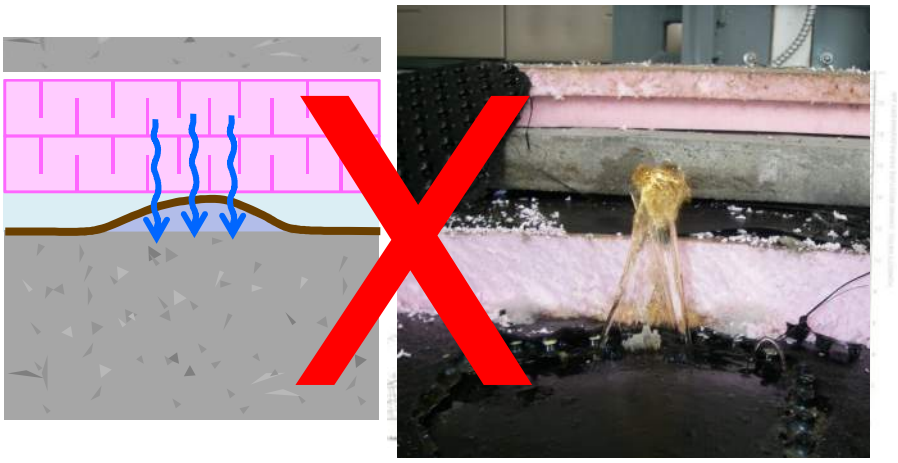
OUTDOORS



INDOORS

Hypothesis: Osmosis

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→ **Osmosis** developed as a possible hypothesis after debunking all other options

→ Osmosis is the flow of water across a **semi-permeable membrane** from the side of **low to high salt (solute) concentration**

→ **Requires 2 things**:
- → Difference in salt (solute, metal ion) concentration
- → A membrane permeable to water molecules, but with pore structure too small for dissolved ions to pass

What is Osmosis?

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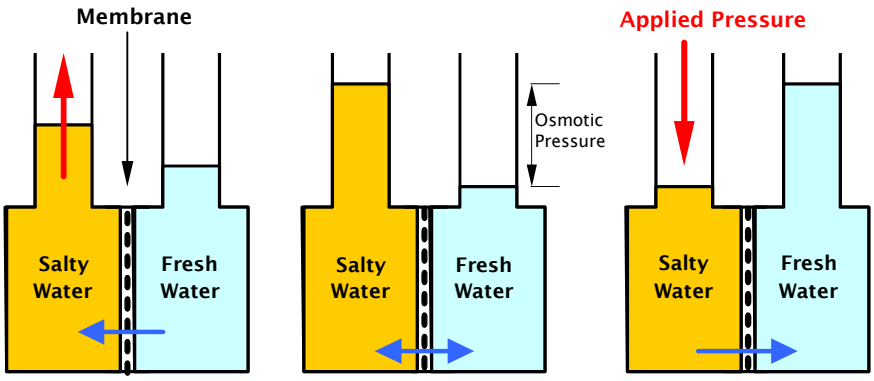

Osmosis:
Water flows through membrane from lower to higher dissolved salt Ion concentration

Equilibrium:
Osmotic pressure is the pressure required to stop water flow and reach equilibrium across membrane

Reverse Osmosis:
Mechanical pressure greater than the natural osmotic pressure is applied to filter dissolved salt ions out and create fresh water

Osmosis in Other Applications

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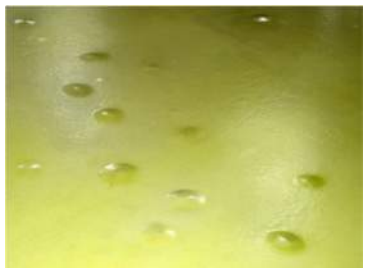
- Not well documented by building/roofing industry
  - Either rare or unreported
- Other industries:
  - Fiberglass boat hulls
    - Uncured resins create chemical osmotic cell
  - Epoxy Floor Coatings
    - Moisture from slabs on grade create blisters beneath certain membranes
  - Bridge decks
    - De-icing salts cause blistering of coatings



Could it Be Osmosis?

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- Questions to answer:
  - Is the blister water salty?
  - What is the osmotic pressure difference between rainwater and blister water?
  - Is the waterproofing membrane semi-permeable?
- Industry resources available
  - Reverse Osmosis filter industry – formulas/calculators for reverse osmosis system pressures based on dissolved salt concentrations
  - Visual/ microscope & vapor permeance testing (ASTM E96) for relative permeability of membrane

Is the Blister Water Salty?

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- Blister water extracted from several roofs & sent to 3rd party water lab
- Blister water found to contains high concentrations of dissolved metals:
  - **Sodium:** naturally occurring within cement and aggregates
  - **Potassium:** potash used within concrete additive
  - **Silicon:** naturally occurring within cement and aggregates
- Rainwater from ponding water - no relevant concentration of minerals

What is the Osmotic Pressure Potential?

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- Blister water contains: Sodium, Potassium, Silicon and traces of other dissolved minerals including Boron, Magnesium, Tin and other stuff!
- Calculated osmotic suction pressures for different blister water samples found to range from **300 to 400 kPa (43 to 58 psi)!**
  - Reinforces finding that water extracted from membrane blister tended to be under some positive pressure
  - As blisters form and grow, the membrane delaminates – so full pressures are never realized
  - For reference – brackish water = 25 kPa (3.6 psi), seawater 2500 kPa (363 psi)

Is the Membrane Permeable?

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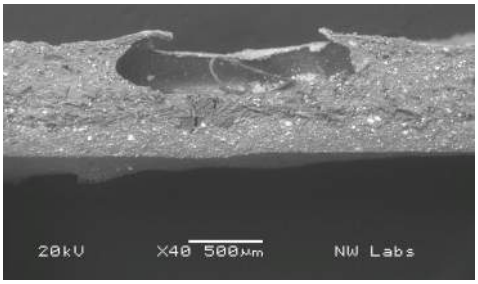
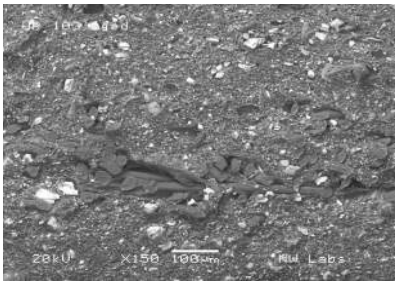
Membrane #1 – Aged 30 mil moisture cure chemistry, removed from roof





Is the Membrane Permeable?

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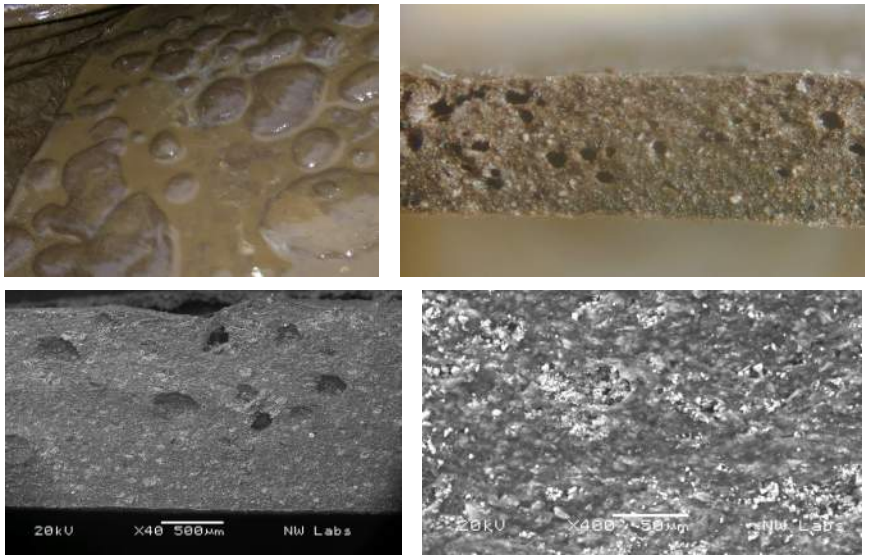
Membrane #2 – Aged 60 mil moisture cure chemistry, removed from roof



Is the Membrane Permeable?

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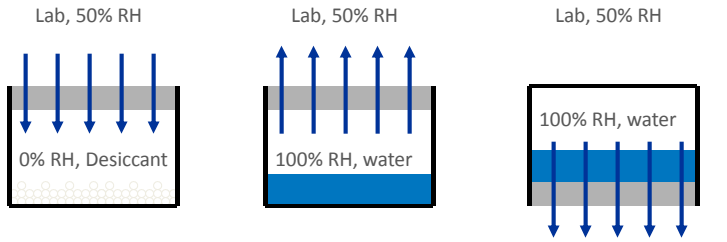
- Many manufacturers were in 2008 and still are today reporting ASTM E96 vapor permeance 'dry-cup' values
- Tested both aged (removed from site) and new (laboratory made) membrane samples for each
- Tested: dry, wet, and inverted wet cup



DRY CUP – Average RH = 25%

WET CUP – Average RH = 75%

Inverted WET CUP – Average RH = 75% + H_20

Are These Membranes Permeable?

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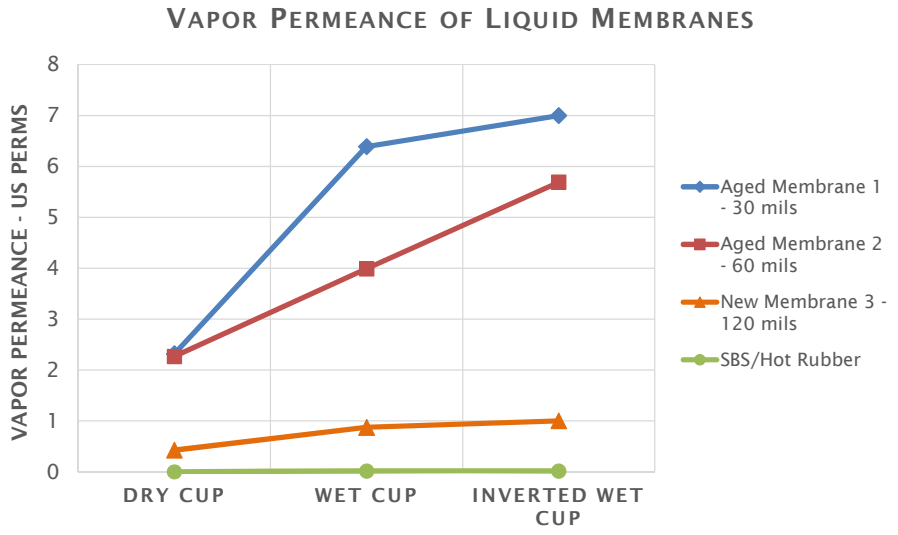

Impact of High Vapor Permeance

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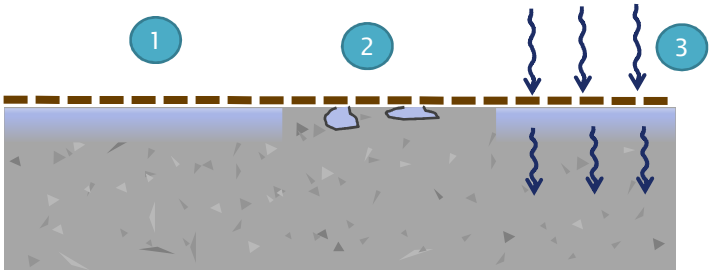
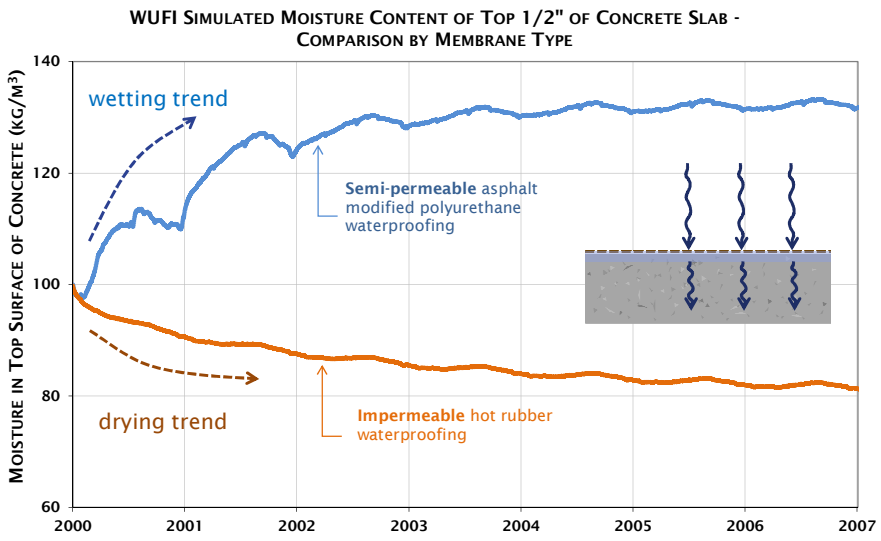
→ How does the concrete get wet or water initially get below the membrane to create the osmotic cell?

1. Fresh cast concrete is initially saturated or rained on
2. Condensation & liquid water within bug holes and unfilled surface voids below membrane
3. Vapor diffusion from topside of membrane – until water & equilibrium on both sides



Impact of High Vapour Permeance

RDH



How to Measure Osmotic Flow Rate?

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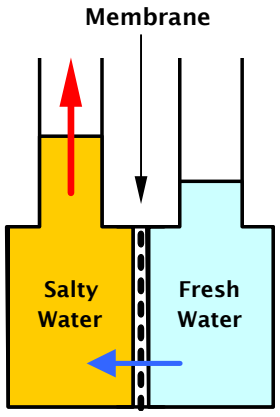
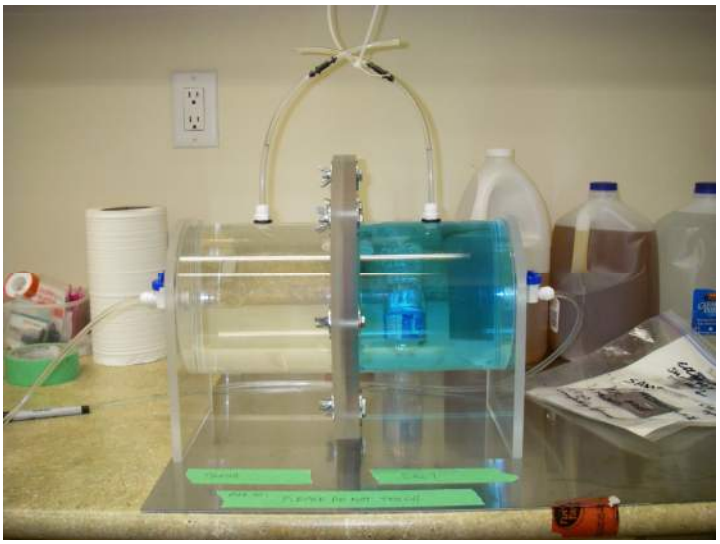
- → Dissolved salt/metal ion concentration difference across membrane? √
- → Membrane permeable to water? √
- → Mechanism of initial wetting? √
- → Measure osmotic flow rate directly ?



Measure movement of water across waterproofing membrane with salt water from site

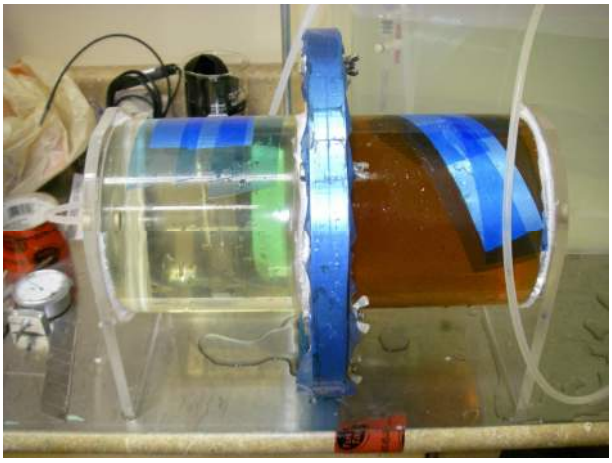
Chamber Concepts: Version 1.0

Chamber Concepts: Version 1.1



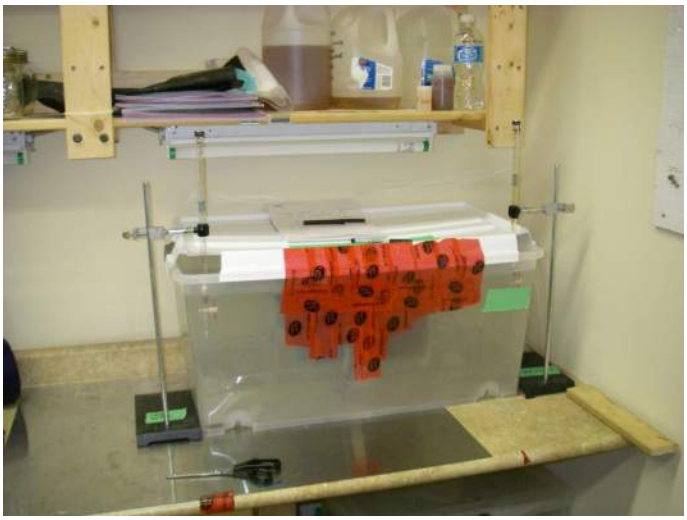
Chamber Concepts: Version 1.2

RDH



Chamber Concepts: Version 1.3

RDH



Chamber Concepts: Versions 2.0 & 2.1

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Chamber Concepts: Version 3.0

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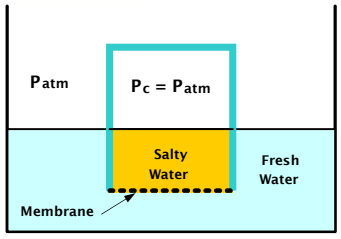
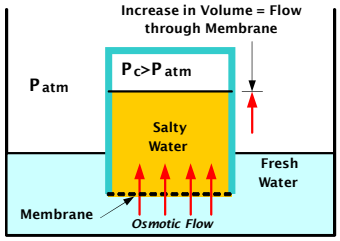
Sometimes simpler is better…

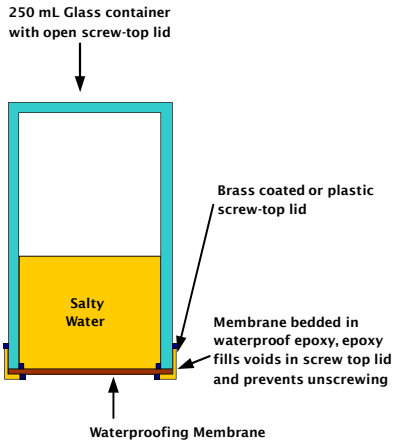
Osmotic Flow Laboratory Apparatus



Initial Setup, Pressure within Container is equal to atmospheric.

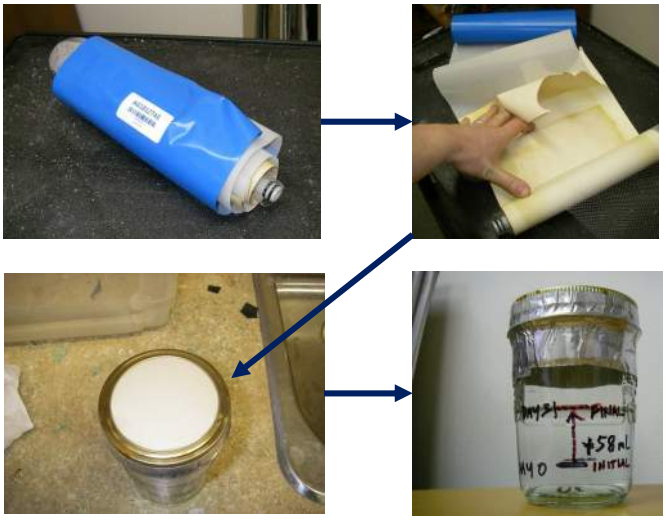


Osmosis occurs until Pressure within container reaches the Osmotic Pressure



Proof of Concept Testing

Commercial reverse osmosis filter

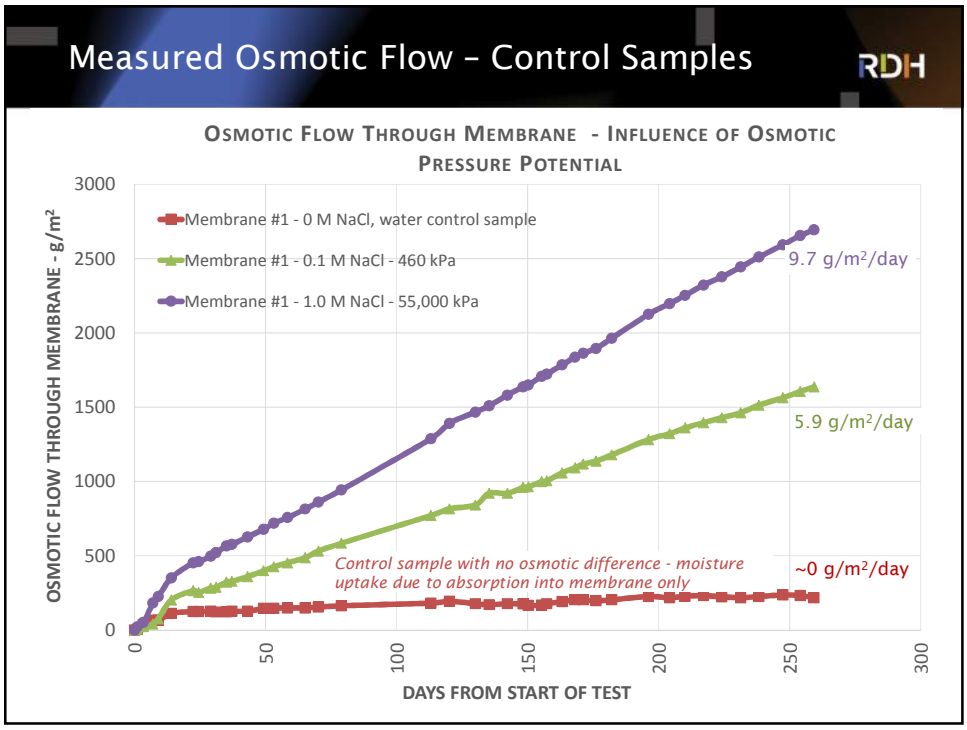


Measured volume/mass rates up to

15 L/m²/day

per manufacturers specs


1
2
3
4
5
6
7
8
9
10
At Last… Some Results


Measured Osmotic Flow – Control Samples
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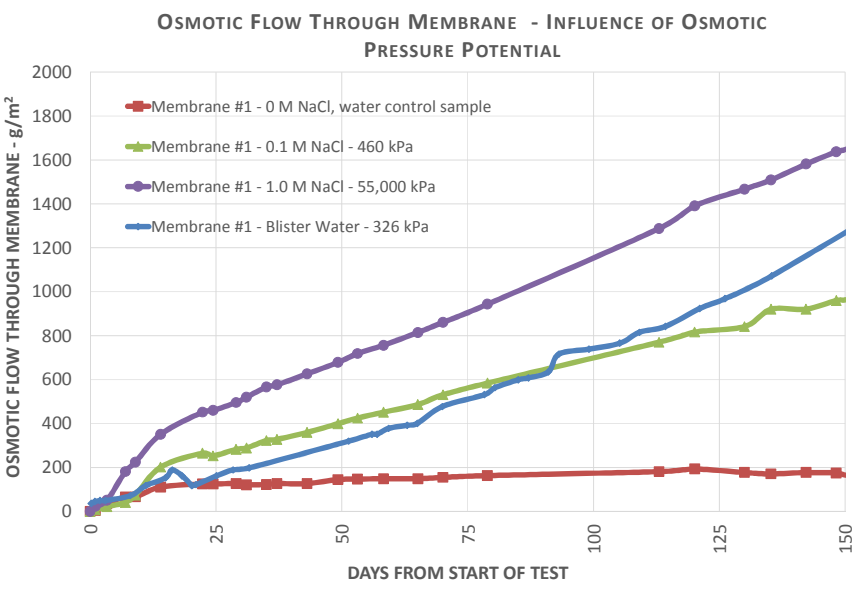
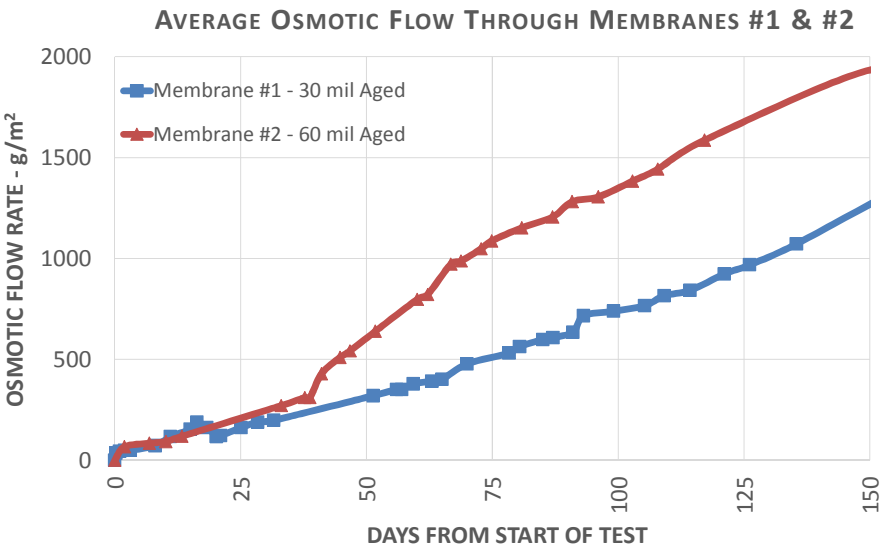
OSMOTIC FLOW THROUGH MEMBRANE - PRESSURE POTENTIAL
OSMOTIC FLOW THROUGH MEMBRANE - g/m²
Membrane #1 - 0 M NaCl, water control sample
Membrane #1 - 0.1 M NaCl - 460 kPa
Membrane #1 - 1.0 M NaCl - 55,000 kPa
9.7 g/m²/day
5.9 g/m²/day
~0 g/m²/day
Control sample with no osmotic difference - moisture uptake due to absorption into membrane only
3000
2500
2000
1500
1000
500
0
0
50
100
150
200
250
300
DAYS FROM START OF TEST

Measured Osmotic Flow – Blister Water



Aged Membrane Testing



New vs Aged Membrane Testing

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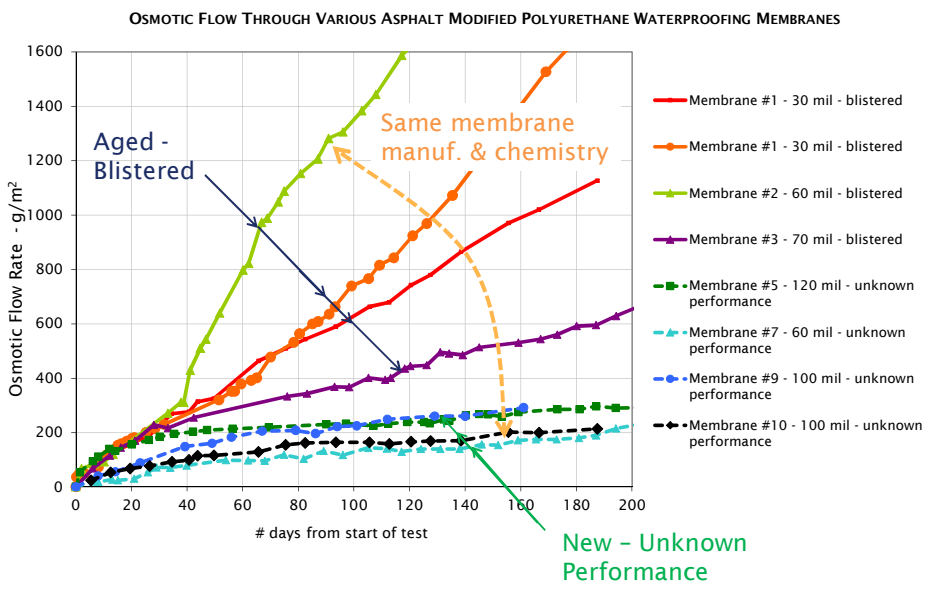

Impacts of Primers?

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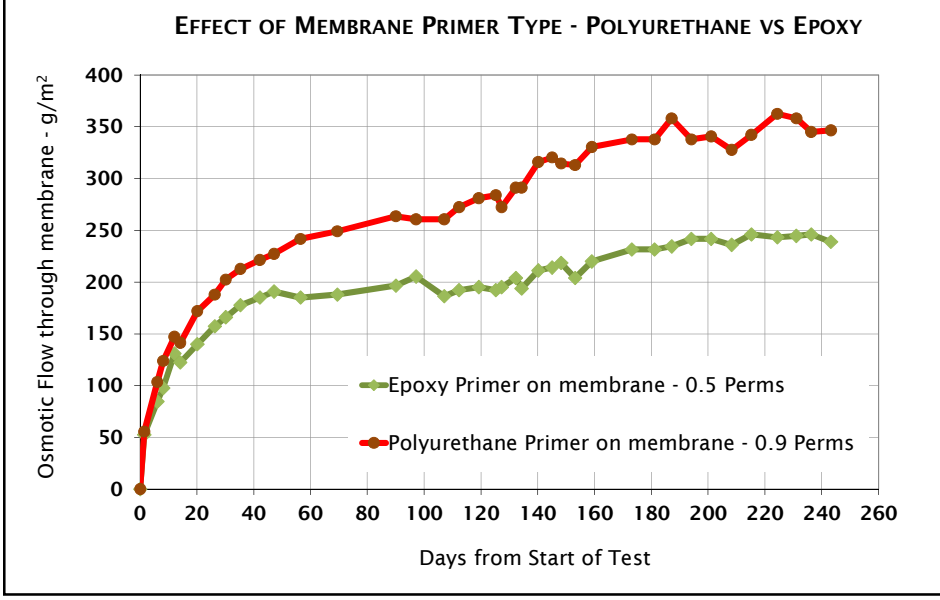

Findings – Original Membranes

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- Asphalt modified polyurethane membranes have serious shortcomings as waterproofing
  - Vapor permeance typically >5 US Perms after aging, even if initially <1 US perms
  - Osmotic Flow Rates of 5-12 g/m^2/day, (up to 20+ g/m^2/day with some 10-15 year old membranes)
  - Aged values much worse than initial
    - Impacts of alkaline environment and constant wetting?
  - Some primers effective at reducing flow rate, but difficult to apply to sufficient thickness in field
- Conclusion – if we could reduce osmotic flow rate to less than the vapor diffusion rate through concrete slab then could we be okay?

Summary: Osmotic Blistering Process

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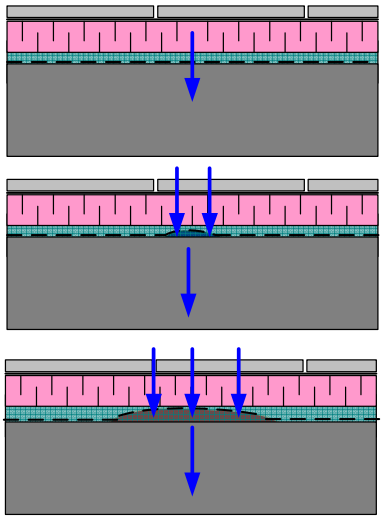

- Top surface of the membrane wet all year (insulation/dirt/water feature)
- Moisture moves though the membrane via vapor diffusion
- Concrete less permeable than the membrane = moisture accumulation
- Moisture dissolves minerals from concrete
- Osmosis forms small blisters at localized voids or de-bonded areas of membrane
- Osmotic pressure grows and continues expanding blisters over time

Worldwide Findings

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- RDH observations
  - Pacific Northwest to California
- Reported Osmotic Blistering issues by others through discussions and by our project involvement
  - Florida & Southern US
  - Hawaii
  - New Zealand
  - Europe & Asia
- Appears more prevalent in temperate, humid climates – where water is able to sit on membrane year-round
  - Or in ponds, planters and other wet places

Added to Hartwig Kuenzel's Roofing Book

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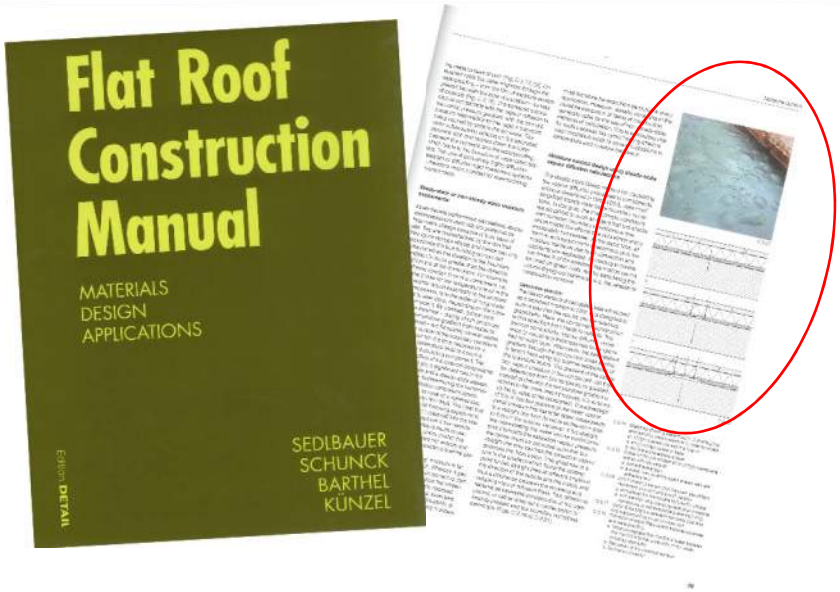

Many Blistered Membrane Renewals Projects

A Little Caution About Roofers & Tie-ins…

New and Ongoing Research

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- Between 2008 and 2014 we have worked with numerous liquid applied membrane manufacturers to address osmosis
  - Measure osmotic flow rate, vapor permeance, absorption
  - Assess impacts of thickness, reinforcing, primers, fillers, cure method, different chemistries, etc.
  - Looked at alternate membrane chemistries & membrane types
    - 2 component & single component chemistries
    - Polyurethanes (asphalt and non-asphalt modified)
    - Polyureas
    - Polyesters
    - PMMAs
    - Asphalt Emulsions
  - Continued testing of original two membrane offenders & other membranes applied in past decade (litigation and R&D)

Laboratory Apparatus Revisions

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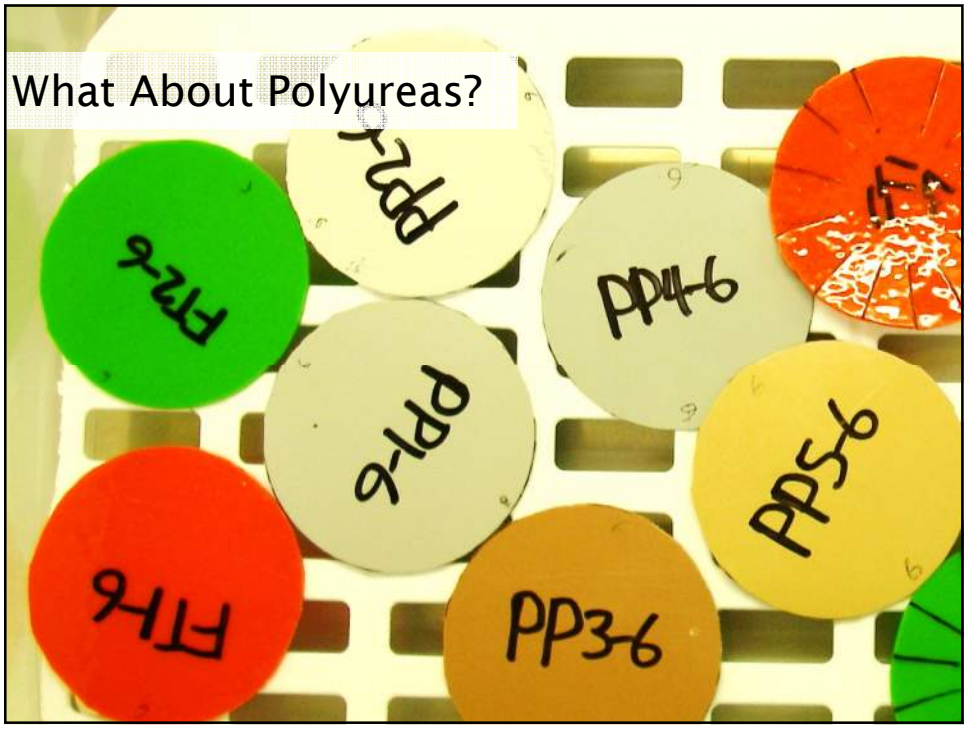
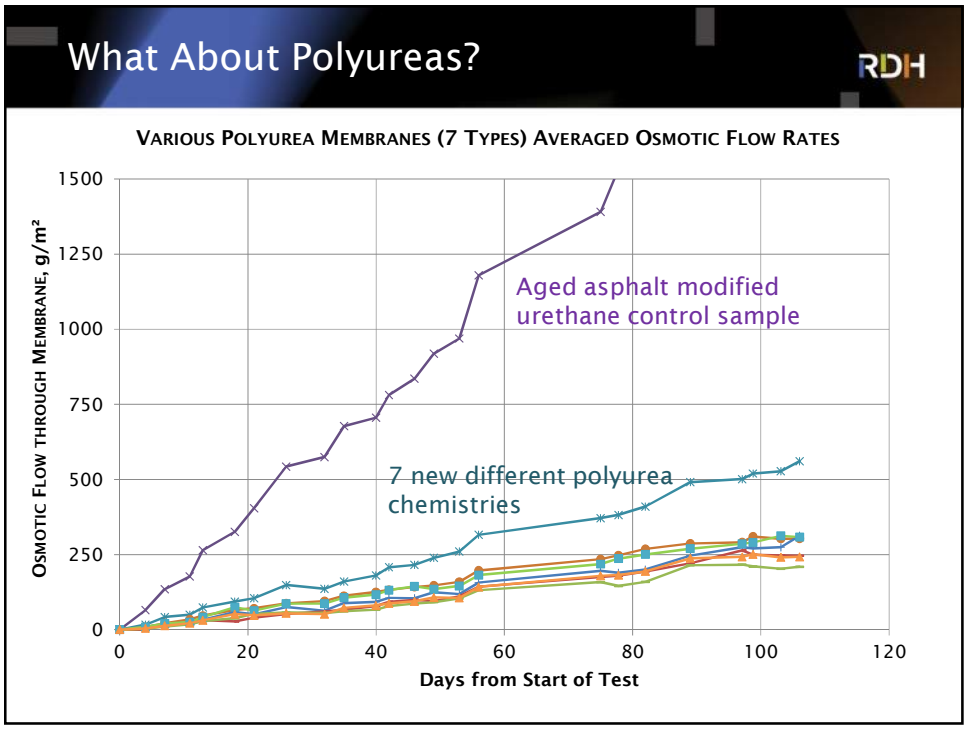
Improved lid with powder-coated corrosion proof finish & improved epoxy seal to keep water out of gap & consistent measurement


What About Polyureas?
PP4-6
PP1-6
PP3-6
PP5-6


What About Polyureas?
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VARIOUS POLYUREA MEMBRANES (7 TYPES) AVERAGED OSMOTIC FLOW RATES
OSMOTIC FLOW THROUGH MEMBRANE, g/m²
1500
1250
1000
750
500
250
0
0
20
40
60
80
100
120
Days from Start of Test
Aged asphalt modified urethane control sample
7 new different polyurea chemistries

What About Polyureas

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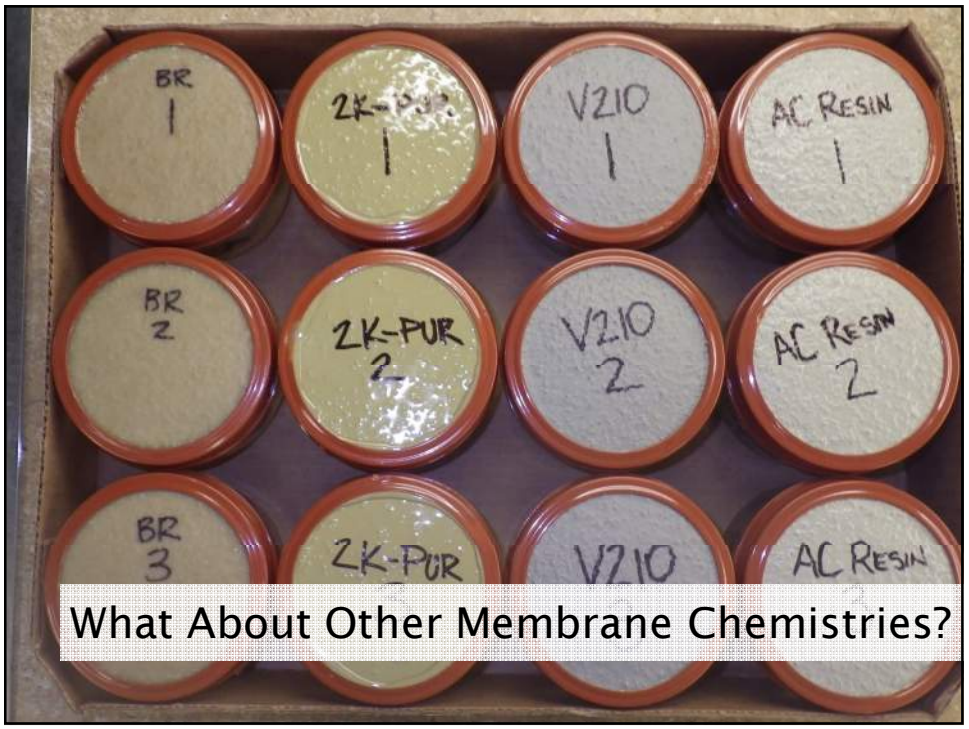
Membrane Sample Name	Membrane Thickness: Average, mils Range, mils	Osmotic Flow Rate Average, g/m²/day Range, g/m²/day	Water Absorption - % & Time to Reach Equilibrium	Inverted Vapour Permeance as Measured: US Perms
Grey	83	2.9	1.5%, <7 days	1.4 US Perms
Brown	78	2.0	2.0%, <7 days	2.2 US Perms
Beige	83	2.3	1.6%, <7 days	1.2 US Perms
Grey 2	135	2.9	0.6%, <7 days	1.9 US Perms
Grey 3	34	5.3	1.3%, <7 days	3.5 US Perms
Orange	106	2.3	1.2%, <7 days	1.2 US Perms
Green	74	2.9	1.6%, <7 days	2.1 US Perms

RED = BAD TRAIT, GREEN = DESIRABLE TRAIT



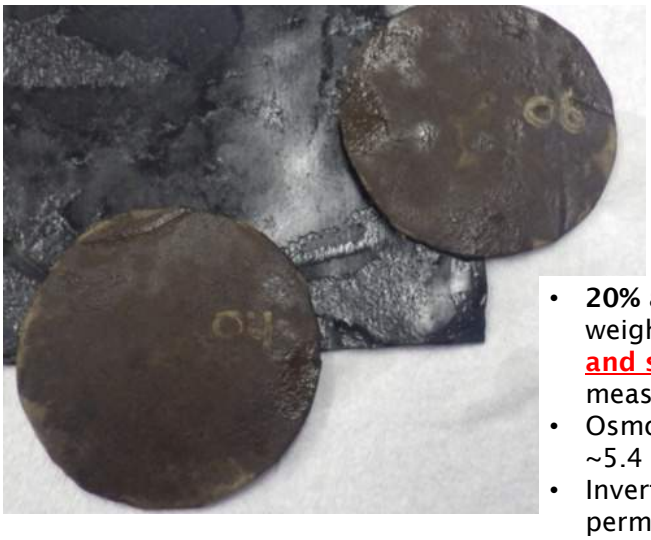
What About Other Membrane Chemistries?

What About Other Membrane Chemistries?

Membrane Sample Name	Vapour Permeance of 100 mil Standard Thickness: (US Perms)		Water Absorption: % by Mass		Osmotic Flow Rate, Thickness Average, g/m²/day
	Wet Cup	Inverted Wet Cup	At 20 days	At 250 days	
AFU-Asphalt Free Urethane Resin	0.08 US Perms	0.08 US Perms	1.6%	>4.5% (has not stopped)	~0.7 (87 mils)
PE – Polyester Based System	0.26 US Perms	0.27 US Perms	1.3%	0.2%	0.4 (55 mils)
PE2 Two component polyester system	0.31 US Perms	0.33 US Perms	1.7%	0.8%	0.5 (54 mils)
PMMA – Poly Methyl MethAcrlyate	0.27 US Perms	0.28 US Perms	1.7%	>4.4% (has not stopped)	~0.8 (65 mils)

RED = BAD TRAIT, GREEN = DESIRABLE TRAIT, ORANGE - BORDERLINE

What About Asphalt Emulsions?



- **20% absorption** by weight after 210 days **and still rising**, 20% measured swelling
- Osmostic flow rate: ~5.4 g/m²/day
- Inverted wet cup permeance 0.14 US perms for 121 mils

Comparison of Results to Date

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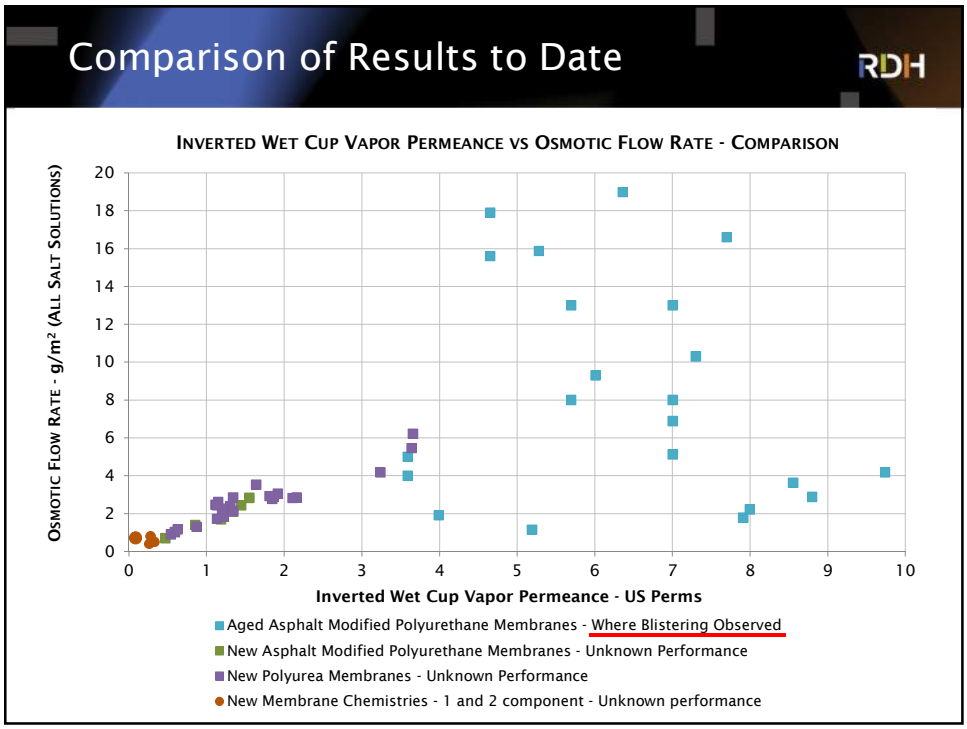
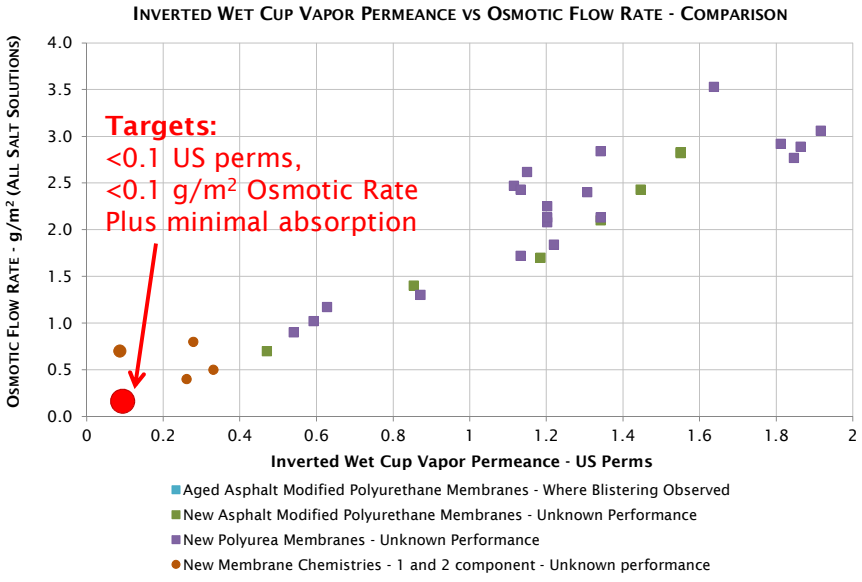


Comparison of Results to Date

RDH



Revised Test Procedure & Targets

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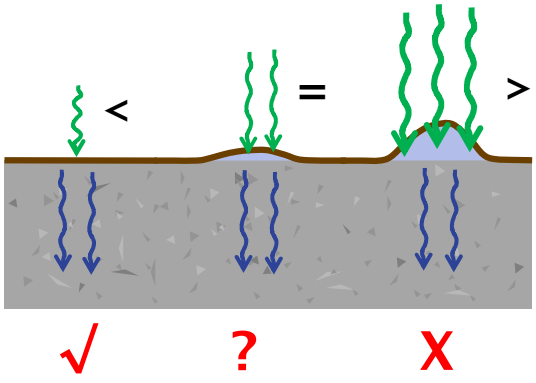
- Key Measurements:
  - Vapor Permeance – Inverted wet cup testing (<0.1 perms, want this to be less than the concrete slab)
  - Osmotic Flow Rate – measure by apparatus with control salt solution for 3-6 months (<0.1 g/m²/day)
  - Water Absorption – soak it until it stops (<1%)

Osmotic Flow Rate

VS.

Concrete Vapour Diffusion Rate



Recommendations

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- Avoid use of cold applied membrane chemistries over concrete in a protected roof or environment where top of membrane will be wet (roof, pond, split-slab, planter etc.)
  - Be very careful of membranes made for "green concrete" as tend to be worse (higher vapor permeance)
  - Not just a black asphalt modified membrane problem – affects all types – polyureas, polyurethanes, PMMAs etc.
- In meantime use a good tried and true fully adhered system – use hot rubber, 2 Ply SBS, built-up asphalt etc.
  - Where "hands-tied", keep water from getting down to liquid waterproofing (supplemental drainage above insulation)

Some Conversions

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- Desired Inverted Wet Cup Vapor permeance to be less than 0.1 US Perms (<6 ng/Pa s m^2)
- Few manufacturers report **inverted wet cup**, usually just wet cup (Procedure B) (or worse still dry cup, Procedure A)
  - *Inverted wet cup* values typically 10 to 50% higher than *wet cup* and can be many times higher than *dry cup* values
- Watch reporting units
  - 1 mil = 1/1000"
  - 1 mm = 25.4 mils
  - Permeability in *perm-in* : divide by thickness (inches)
  - WVT (grains/hr/ft^2) not same units or value as vapor permeance (grains/hr/ft^2 inHg)
  - Convert to US perms for quick check

Red Flags to Look Out For

RDH

TECHNICAL DATA

Property	Typical Value	Test Method
Solids Content By Weight	98%	ASTM D-1644
Solids Content By Volume	98%	ASTM D-2697
Tensile Strength	70 psi	ASTM D-2370
Elongation	440%	ASTM D-2370
Water Vapor Transmission	0.07 perm inches	ASTM E-96
Shore 00 Hardness	55	ASTM C-661
Low Temperature Flex	-20° F (-28.9° C) pass ¼" (6.4 mm) mandrel	ASTM D-816
Shrinkage	No visible shrinkage after 14 days	
Service Temperature	-40° F - 158° (-40° - 70° C) continuous service	
Minimum Application Temperature	Above 30° F (-1° C) and rising	

2.3 US Perms!

Red Flags to Look Out For

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Needs Updating!

Withdrawn standard

Physical Properties: Conforms to ASTM C836 CAN/CGSB 37.58

-Color	Brown	-Flash Point (open cup)	>232°C (450°F)
-Solvent Content	0 %	-Maximum V.O.C.	< 40 grams/liter
-Solid Content	97%	-Elongation(ASTM D412)	575%
-Rate of Application	High Build -Horizontal: 165 mils (4 mm) total fabric reinforced system -Vertical: 110 mils (2.6mm) Single Coat Horizontal: 110 mils (2.6mm) Vertical: 55 mils (1.3mm)	-Recovery (ASTM D412) -Shore 00 Hardness -Adhesion in peel after water immersion (ASTM C836) -Water Vapor Permeance (ASTM E96 Procedure B	95% Min 60 Pass 3 mm (125 mils) film 1.3 perms
-Coverage	Approx. 0.75 m²/l (30 ft²/ US Gal) at 55 mils 0.37 m²/l (15 ft²/ US Gal) at 110 mils		
-Min. Application temp.	3°C (35°F)	-Low Temp. Crack Bridging Capability	No cracking No splitting No loss of adhesion
-Setting Time Initial Set Set Through	@ 50% R.H. 72°F@ 60mils 1 Hours 3 Hours	-Flammability Wet	Non-Flammable
-Low Temperature Flexibility and Adhesion @ Minus 13°F	No cracking No loss of adhesion No delamination		

Red Flags to Look out For

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PROPERTY	RESULTS		TEST METHOD
	High-Build System	Standard System	
Tensile strength, psi (MPA)	200 (1.4)	150 (1.0)	ASTM D 412
Average elongation, %	300[1]	600	ASTM D 412
100% modulus, psi (Mpa)	80 (0.6)	80 (0.6)	ASTM D 412
Moisture-vapor permeability, dry perms	0.075	0.1	ASTM E 96
Crack bridging test, cycled 10 times per 24 hours at 15°F (-9°C)	Passed ¼"; no loss of bond or or cracking exhibited	Passed 1/16"; no loss of bond or cracking exhibited	ASTM C 836
Extensibility after heat aging		No cracking	ASTM C 836
Adhesion in peel, lbs/in (1 lb/in minimum)	5		ASTM C 836
Weight loss, % (20% max)		16	ASTM C 836

Results shown are typical but are not intended as performance criteria for on-site installed material.
[1]Tested in direction of greatest elongation of fabric

1.7 US Perms (DRY CUP)

bitumen-modified polyurethane.

Compliances

- ASTM C 836
- National standard of Canada 37.58 - M86 developed by CGSB

PROPERTY	VALUE
Minimum recovery, %	90
Swelling in water, 3 days at room temperature	Nil
Service temp. range, °F (°C)	
Minimum	-40 (-40)
Maximum	120 (49)

Red Flags to Look out for

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TYPICAL PHYSICAL PROPERTIES

ASTM C836 Standard Specification for High Solids Content, Cold Liquid-Applied Elastomeric Waterproofing Membrane for Use with Separate Wearing Course

Physical Property	Test Method/Requirement	Results
Material	Shall Cure and maintain seal against water	Pass
Stability (80°F/26.7°C)	Shelf Life 6 months	1 year
Hardness, Type 00	ASTM D 2240 as modified in section 5.5 of ASTM C 836; 50 minimum	70 -80
Vertical Hold*	60 mils	
Weight Loss	ASTM C 1250 20% Maximum Loss 80% Solids Minimum	
Low Temperature Flexibility and Crack Bridging	ASTM C 1305 No Cracking	
Adhesion-in-Peel after Water Immersion (Unprimed)	ASTM C 794 as modified in section 5.9 of ASTM C 836 1 lbf/in. (4.4N)	
Extensibility After Heat Aging	ASTM C 1522 Membrane must bridge 1/4" (6 mm) crack	Pass

*Roller and Trowel Grade only. Self-Leveling Grade is not designed to hold on a vertical.

No Permeance measurements anywhere

Features and Benefits

can be applied in as little as 24 hours following the removal of concrete forms to keep construction moving. It can also be applied to damp concrete, reducing the delays associated with rain or other sources of water. The unique ability to catalyze with water when desired will speed cure times, especially cold temperatures and low relative humidity, to further compress the construction schedule. can be applied at a rate of up to

Red Flags to Look out for

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PROPERTY	TEST METHOD	TYPE 1	TYPE 2
Consistency		Thixotropic	Thixotropic
Shore "A" Hardness:	ASTM D-2240	40 ± 5A	35 ± 5A
Tensile Strength (psi) (N/sq.m)	ASTM D-412	300 ± 10 (2.1 N/m²)	436 ± 10 (3.0 N/m²)
Percent elongation	ASTM D-412	700 ± 10% min	700 ± 10% min
Adhesion to concrete	ASTM D-903-98	14.9 lb./in (2.79kg/cm) No peel /film break	19 lb./in (3.38kg/cm) No peel /film break
Hydrostatic Pressure Resistance	ASTN D 751-00		94 PSI (0.65 N/sq.m)
Resistance to Decay	ASTM D-154	No surface defects	No surface defects
Moisture Vapor Transmission (grains/hr./sq.ft)	ASTM E-96-00 (procedure B) water method	0.72	0.72
Water Vapor Transmission (grains /hr/sq.ft.)		N.av.	1.563

Two measurements?

0.72 WVT works out to ~ 1.8 US Perms (Wet cup)
1.56 WVT ~ 4.0 US Perms (Wet cup)

Next Steps

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- Determine maximum safe vapor permeance threshold for waterproofing membranes over concrete
- Refine and develop ASTM osmotic flow test method and determine acceptable maximum flow rates for different applications.
- Revise Applicable Standards (ASTM C836 and/or withdrawn CAN/CGSB-37.58-M86) to specify:
  - Maximum allowable **inverted wet cup** permeance (<0.1 perms?)
  - Maximum absorption for **constant & prolonged immersion** (this is not the typical 24 hr/7day ASTM test)
  - Maximum allowable **osmotic flow rate** (<0.1 g/m², so less than concrete can dry through)
  - Consideration for aging and submersion within wet concrete environment (accelerated wet alkaline test?)

Next Steps

RDH

- Need a waterproofing industry champion to raise awareness and push revisions to ASTM standards and bring forth the osmosis test method
  - We gave been looking for a manufacturer with a cold applied liquid membrane that works! (market advantage)
- Testing and evaluation of all products currently on market
- Hopefully No More Problems!?

A Final Word of Warning

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Discussion + Questions
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