Osmosis and Blistering of Liquid Applied Waterproofing Membranes – What We Have Learned in the Past Decade

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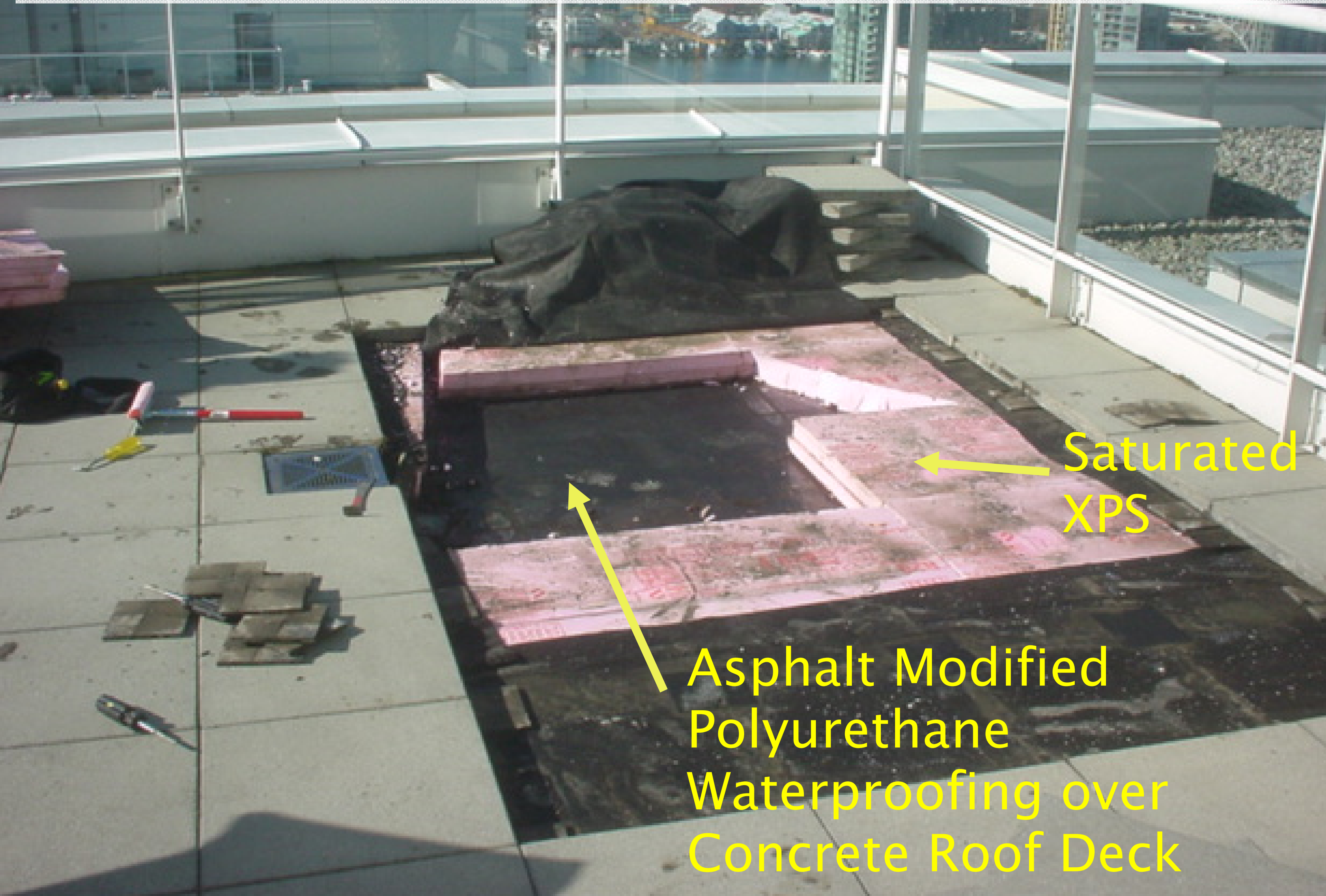
RDH BUILDING SCIENCE

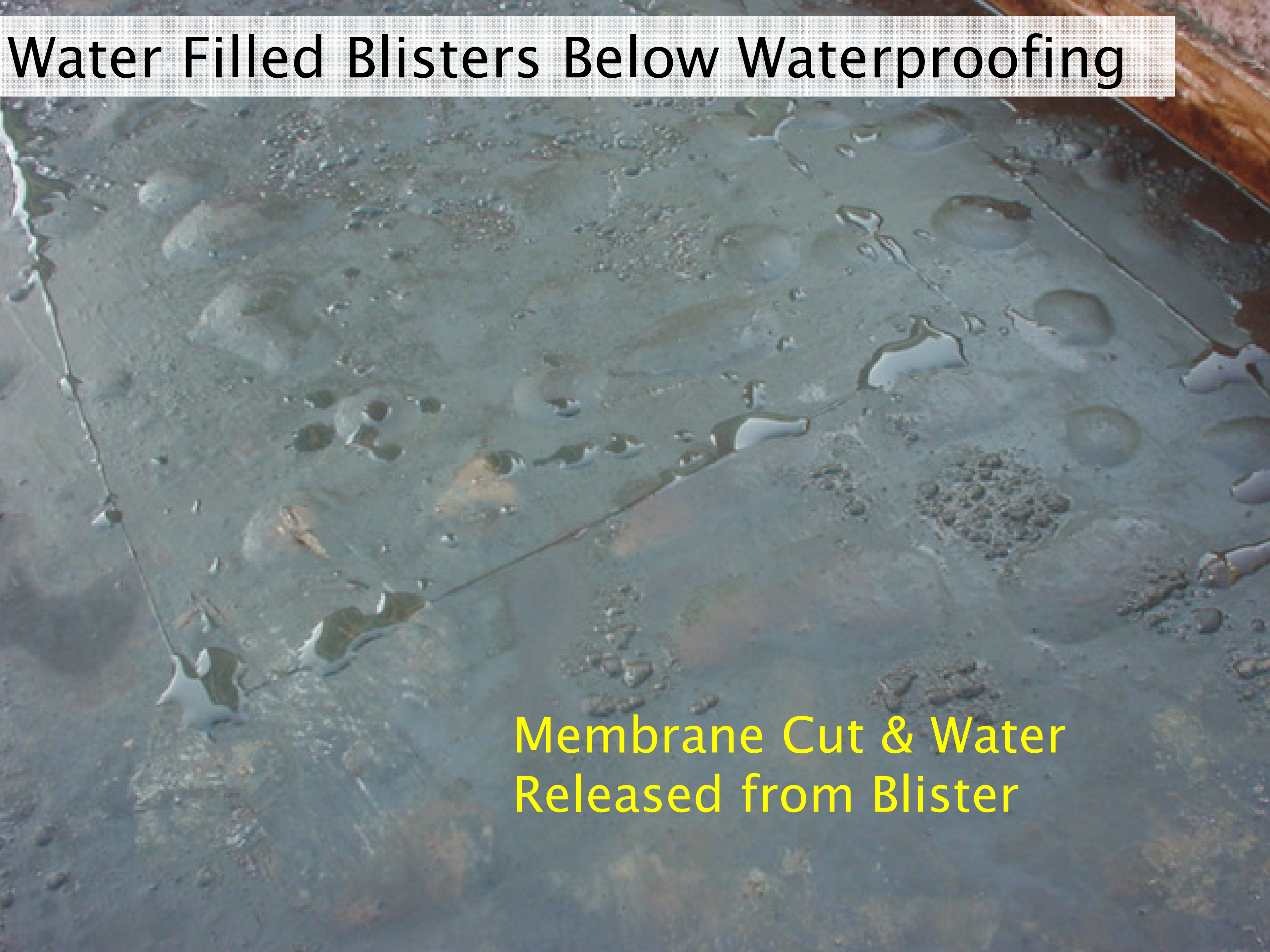
Outline

- → Background & History of Blistering Membranes
- → Review of Theories and Proving the Failure Mechanism
- → Ongoing Membrane Evaluations and What to Look for

2004 - Tip of the Iceberg & Roof Warranty Reviews

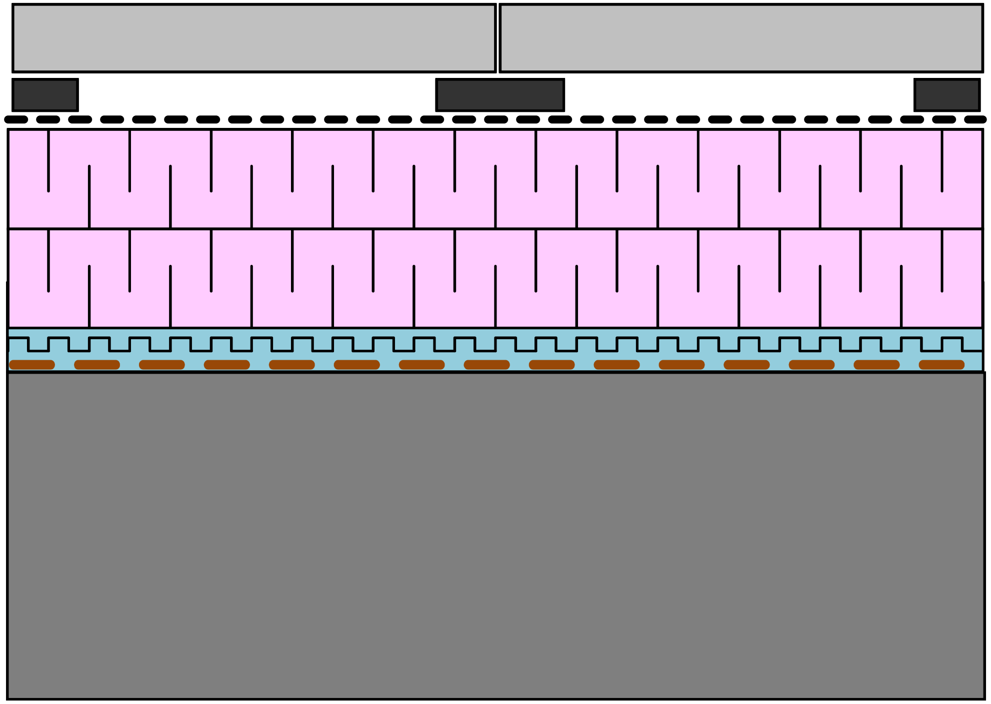


Water Filled Blisters Below Waterproofing



Water Below Roof Membrane & Reported Intermittent Leaks

Problematic Roof Assemblies Affected



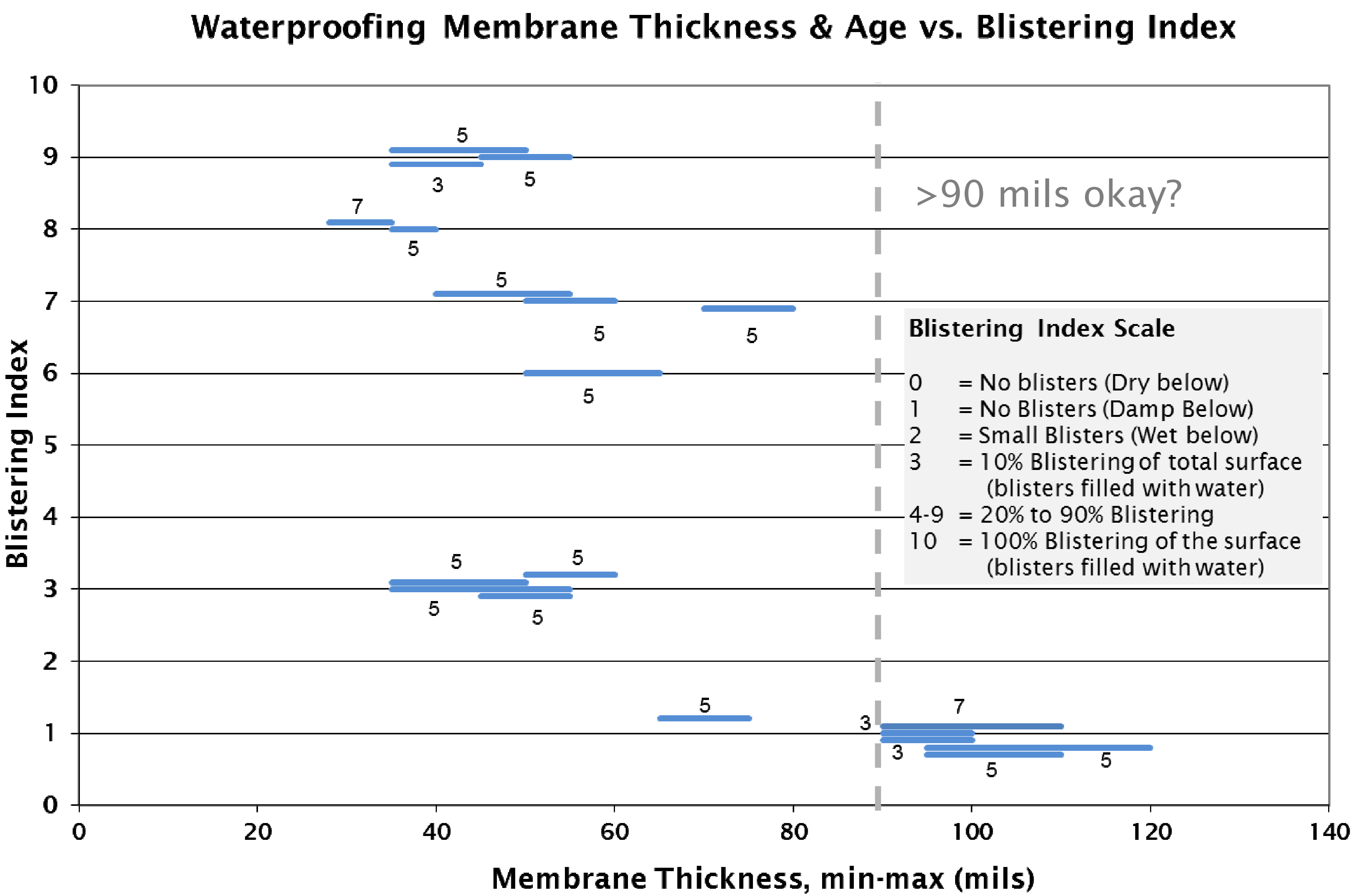
- → Concrete Pavers, Ballast, or Dirt/Green Roof
- → Pedestals (optional)
- → Filter Fabric
- → XPS Insulation (optional, only over heated space)
- → Drainage Mat (optional)
- → **Liquid membrane**
- → Concrete roof slab

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

2004 – Digging into the Problem

- → Failures uncovered during regular reviews at many local building projects – all similar membranes and assemblies over concrete podium or roof/deck slabs
- → Cause of the blistering unknown at the time
  - → Apparent correlation with membrane thickness
  - → Initial monitoring & research started

2004 – Membrane "Blistering Index"




2008 - The Problem Grows…


Blisters Everywhere you Dig!

Gallons of Water Beneath Membranes

Leaks & Membrane Renewals

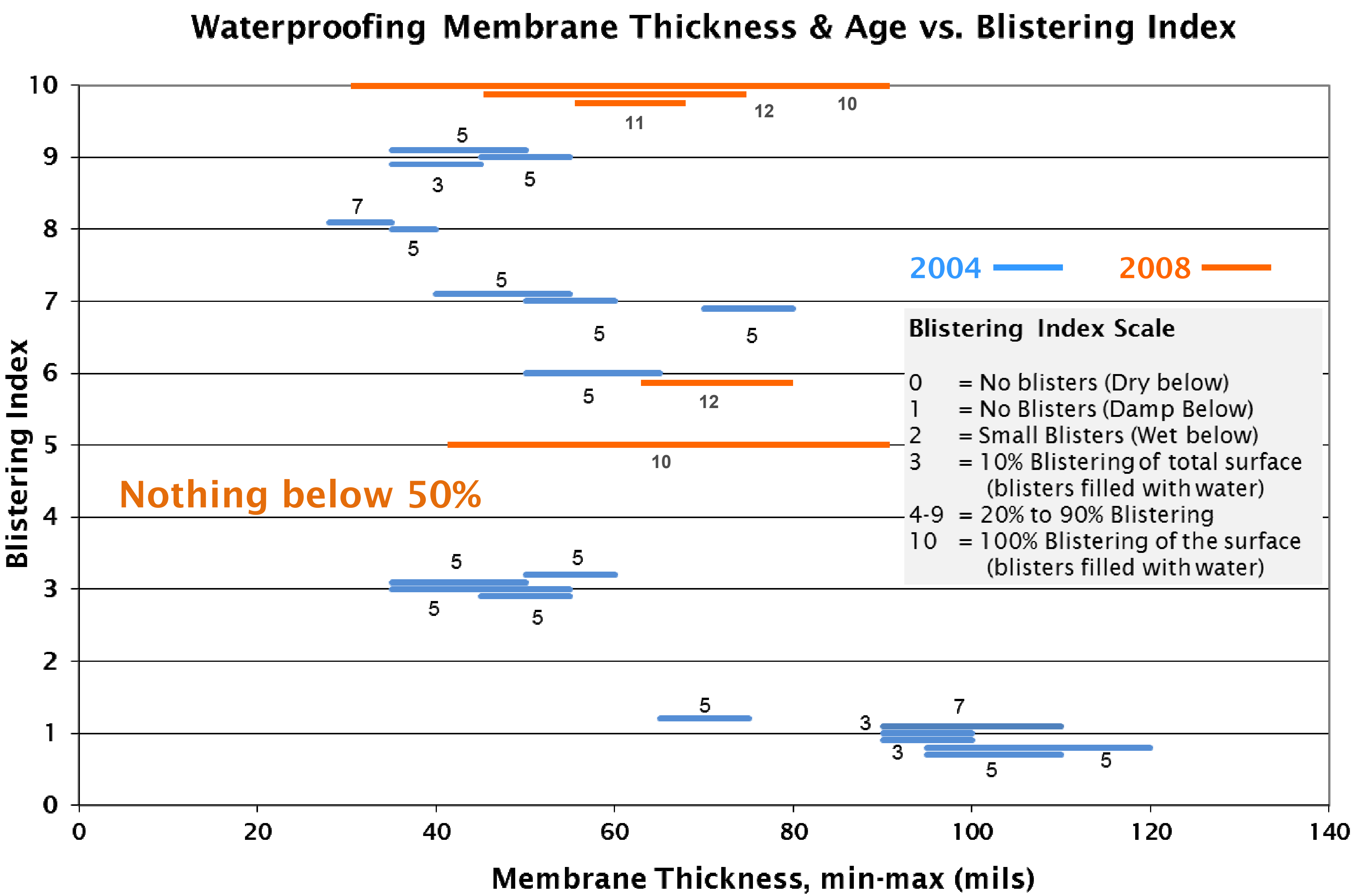
Membrane Blisters Lifting Pavers & Leaks

Membrane Blisters Lifting Pavers & Leaks

Membrane Water Beds!


Water Filled Blisters in Water Features

2008 – Updated Blister Index



2008 – State of Affairs

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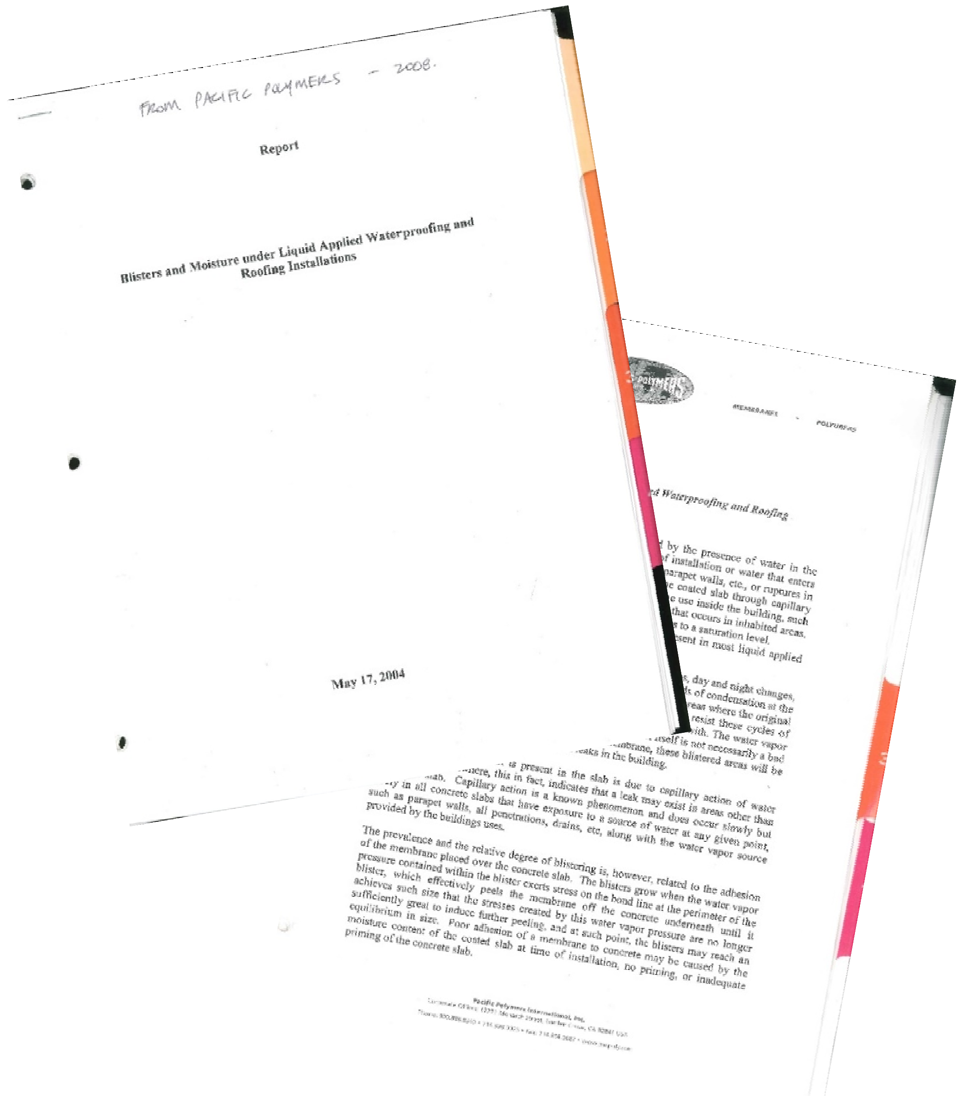
- Systemic issue affecting asphalt modified polyurethane waterproofing membranes in protected membrane roofs over concrete decks
  - 2 similar asphalt modified membranes from 2 major manufacturers identified in majority of cases (plus few others)
- Findings – Water Filled Blisters
  - Membranes 3 to 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

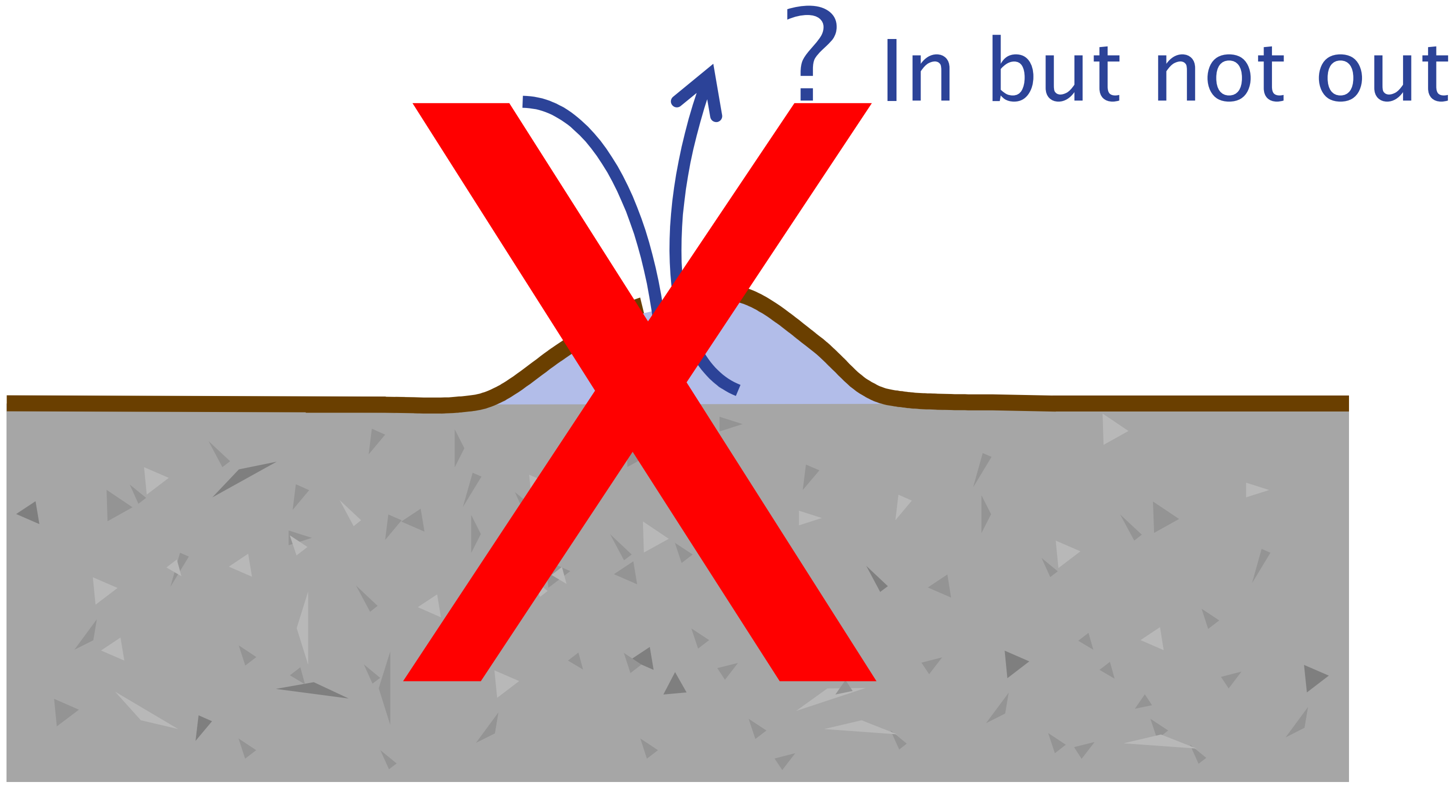
Theories & Urban Legends

Industry Perception Pre 2008

- 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 outside of the Lower Mainland & beyond North America



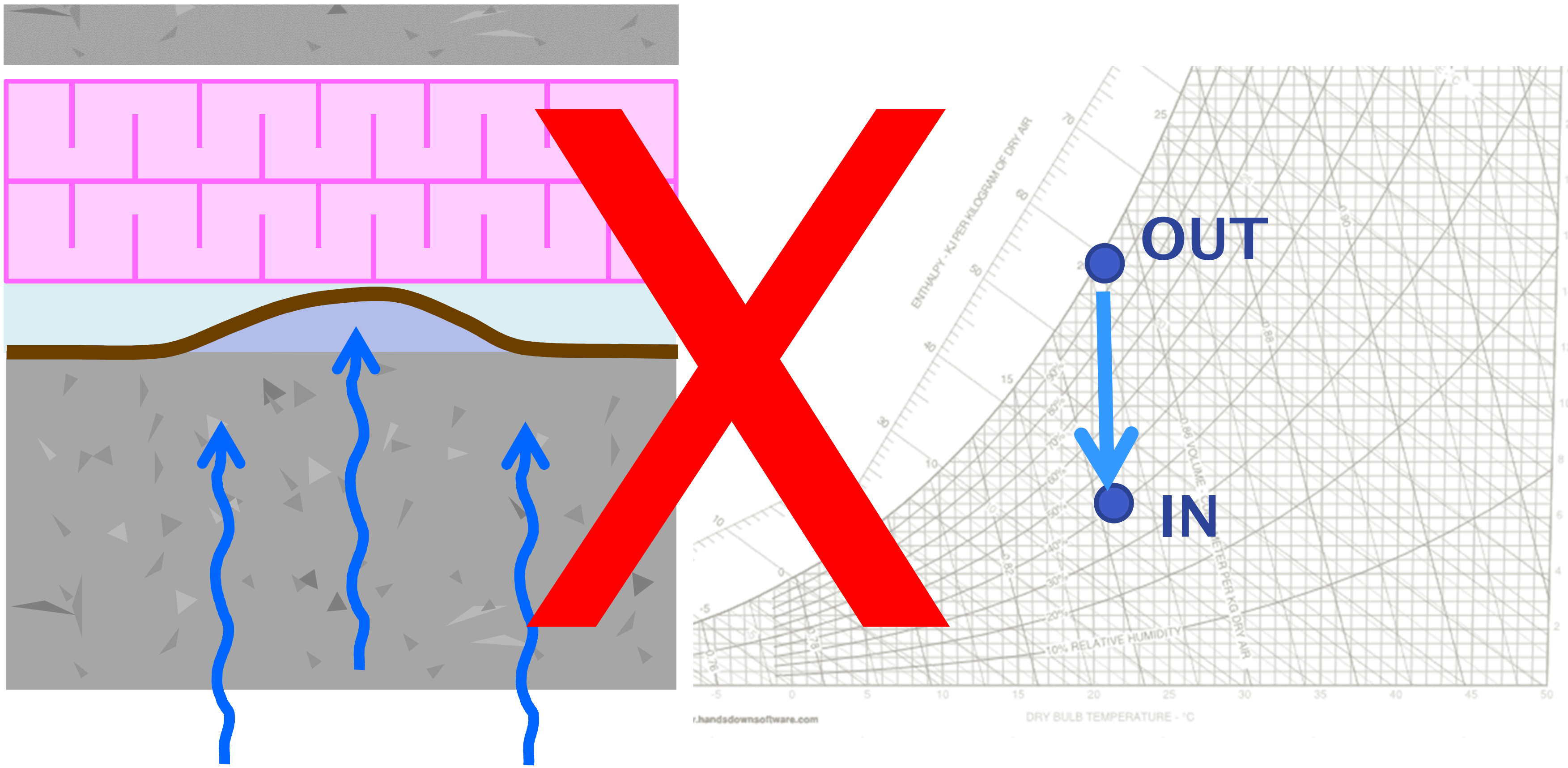
Theory #1: Pinholes in Thin Membrane



Theory #2: Hydrostatic Head from Details

Theory #3: Vapor Diffusion from Inside

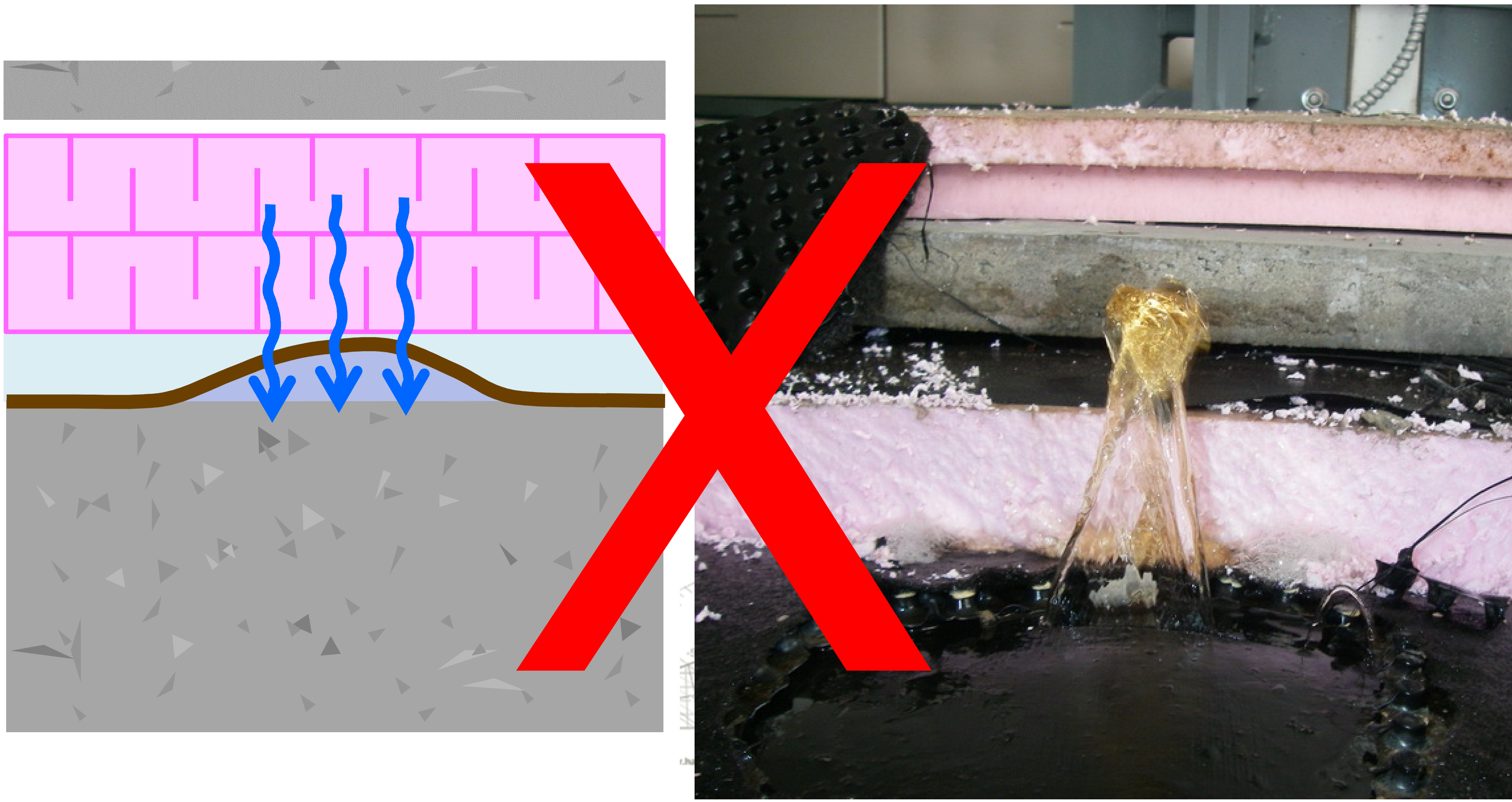
OUTDOORS



INDOORS

Theory #4: Diffusion & Capillary from Outside

OUTDOORS

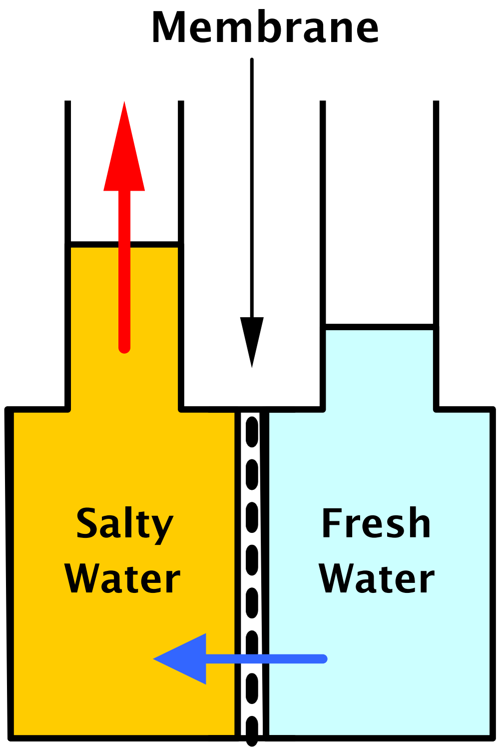


INDOORS

Hypothesis: Osmosis

- **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 concentration (i.e. solute, dissolved metals)
  - A membrane permeable to water molecules, with a pore structure too small for most dissolved solids to pass

What is Osmosis?

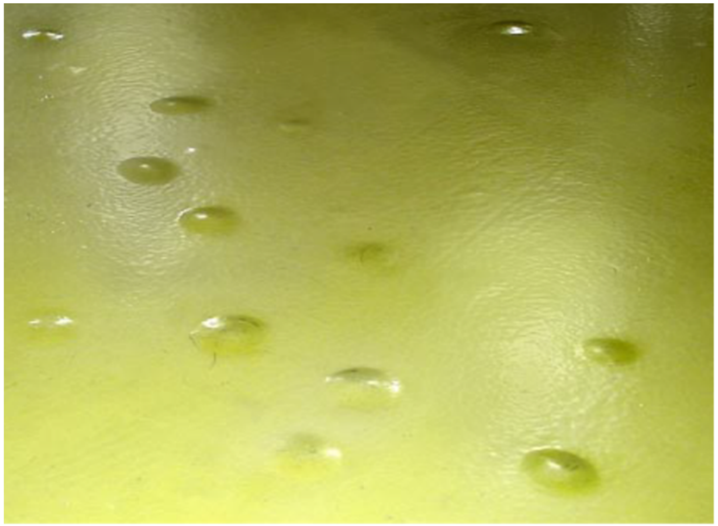


Osmosis:

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

Osmosis in Other Applications

- → 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 flooring systems
  - → Bridge decks
    - De-icing salts cause blistering of coatings



Could it Be Osmosis?

- Research Questions to Answer:
  - Is the blister water salty/contain dissolved solids?
  - 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


Water Extraction For Testing

Is the Blister Water Salty?

- Blister water extracted from blisters of several roofs & sent to 3rd party water testing lab
- Blister water below membrane above concrete found to contains high concentrations of dissolved minerals
  - Primarily **Sodium** and **Potassium** and traces of Silicon, Boron, Magnesium, Tin, Iron, Calcium, Sulphur and other trace elements (even Uranium!)
  - From cement, aggregates and admixtures of concrete (and leaching from membrane)
- Rainwater from ponding water on top of membrane - no relevant concentration of minerals

What is the Osmotic Pressure Potential?

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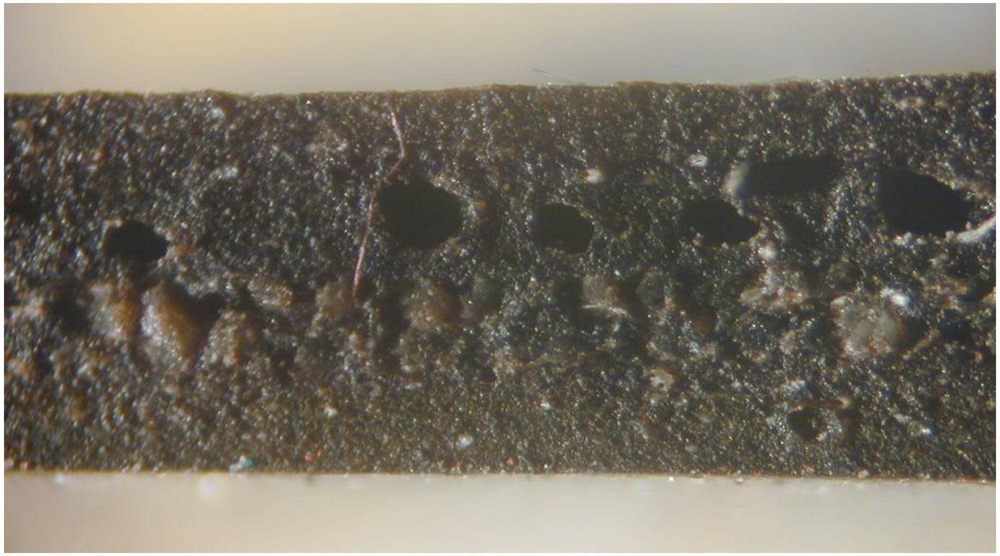
- The Osmotic potential is dependant on the Total Dissolved Solids (TDS) not the individual solutes
- Calculated osmotic suction pressures for various blister water samples extracted in past decade ranges from **300 to over 1400 kPa (44 to 203+ psi)!**
  - Explains why membrane blisters tend to be under some positive pressure
  - As blisters form and grow, the membrane delaminates – so full pressures are never realized in service

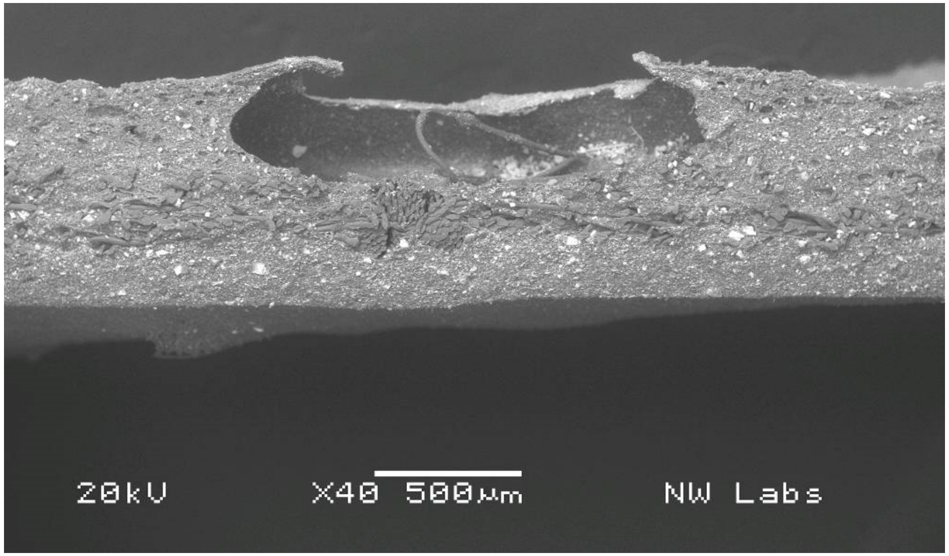
  - For reference – brackish water = 25 kPa (3.6 psi), seawater 2500 kPa (363 psi)

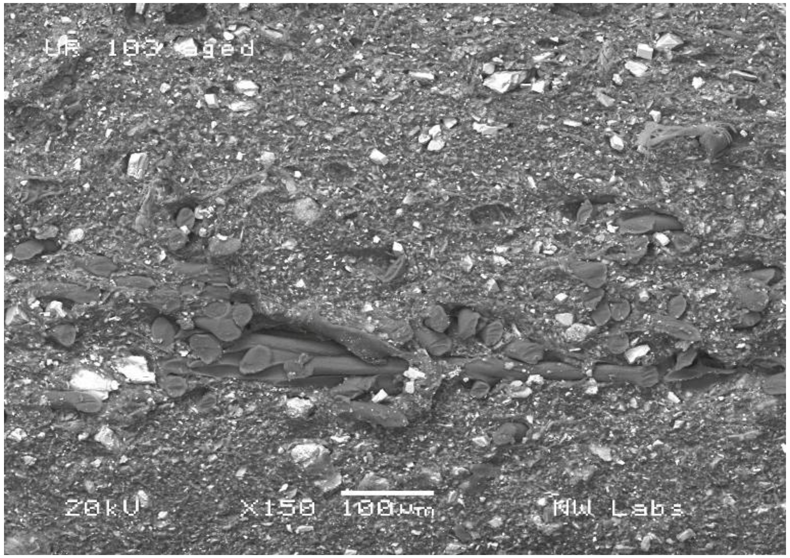

Membrane Removal

Is the Membrane Permeable?

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

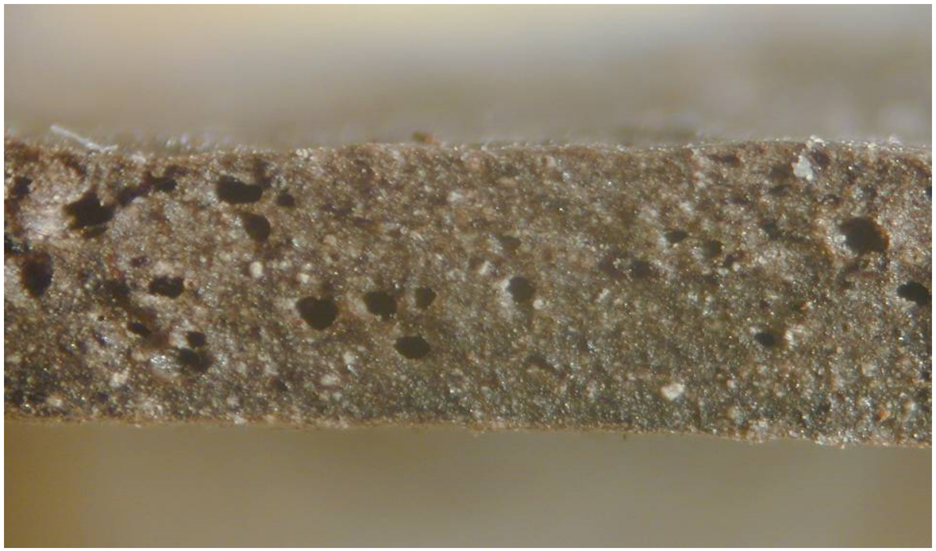


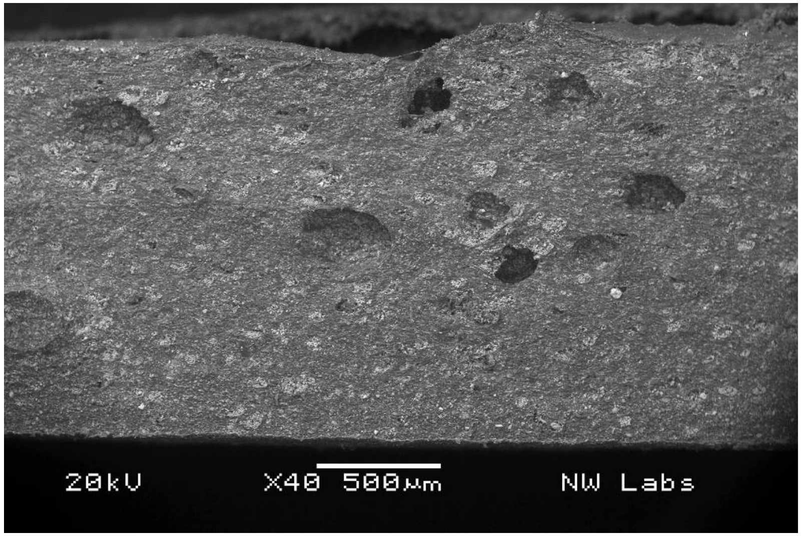


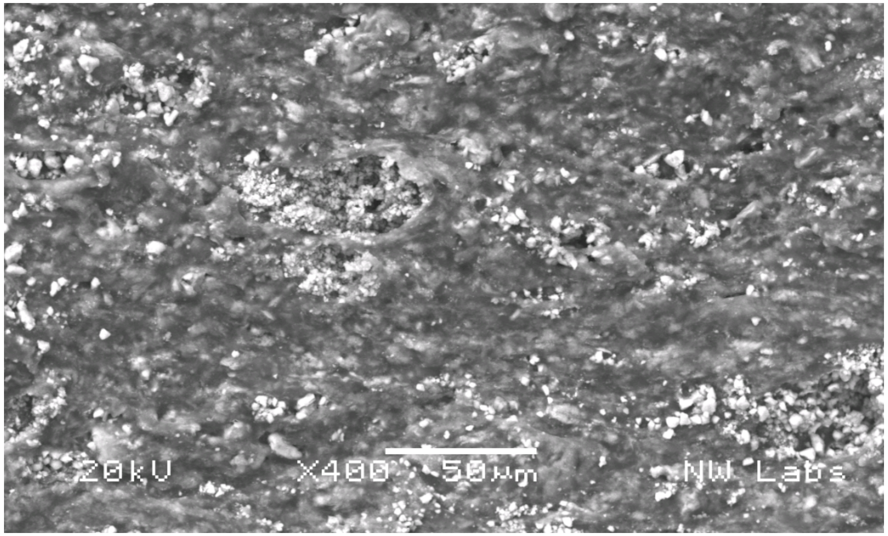


Is the Membrane Permeable?

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





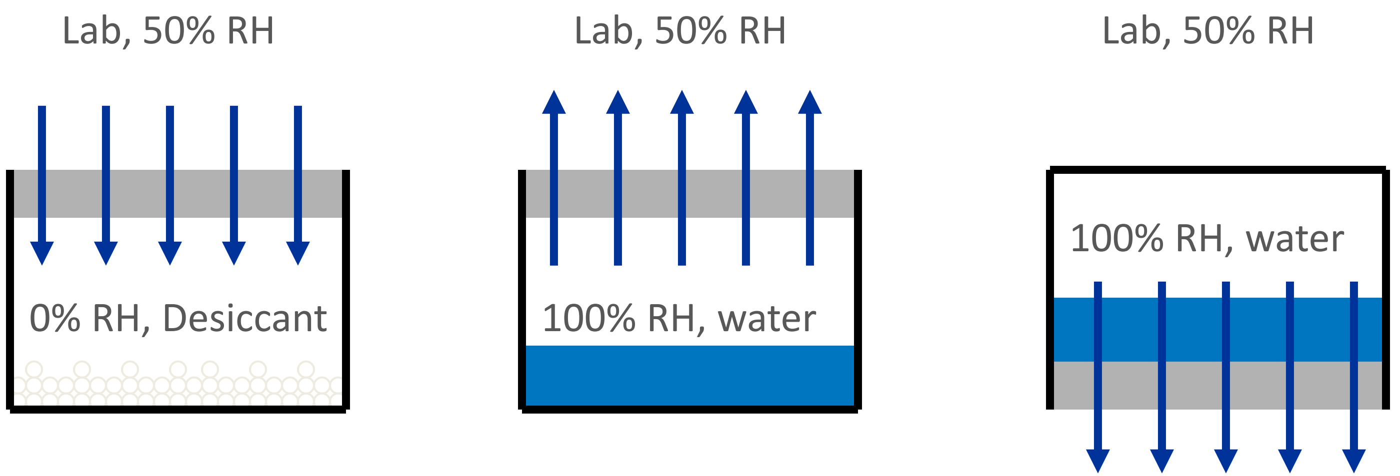


Is the Membrane Permeable?

→ Many manufacturers were in the mid 2000s 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

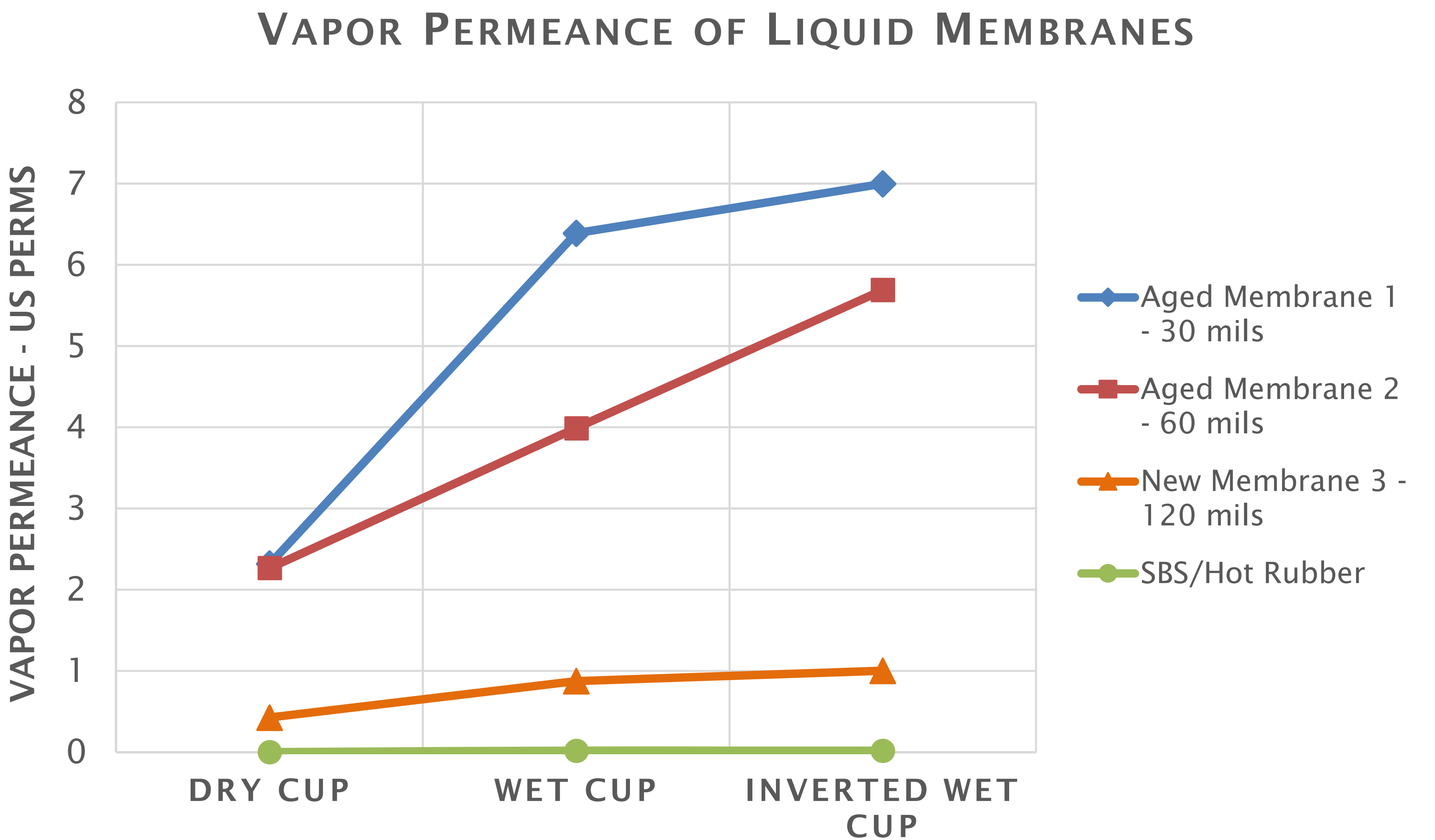


DRY CUP –
Average RH = 25%

WET CUP –
Average RH = 75%

Inverted WET CUP –
Average RH = 75% + H_20

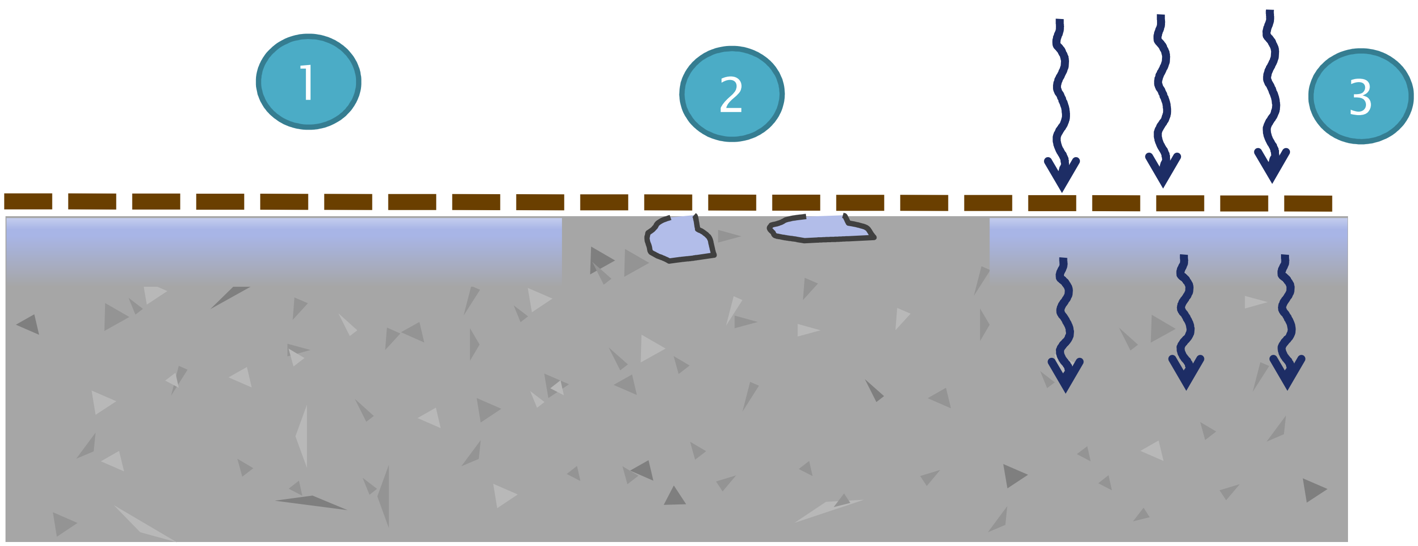
Are These Membranes Permeable?



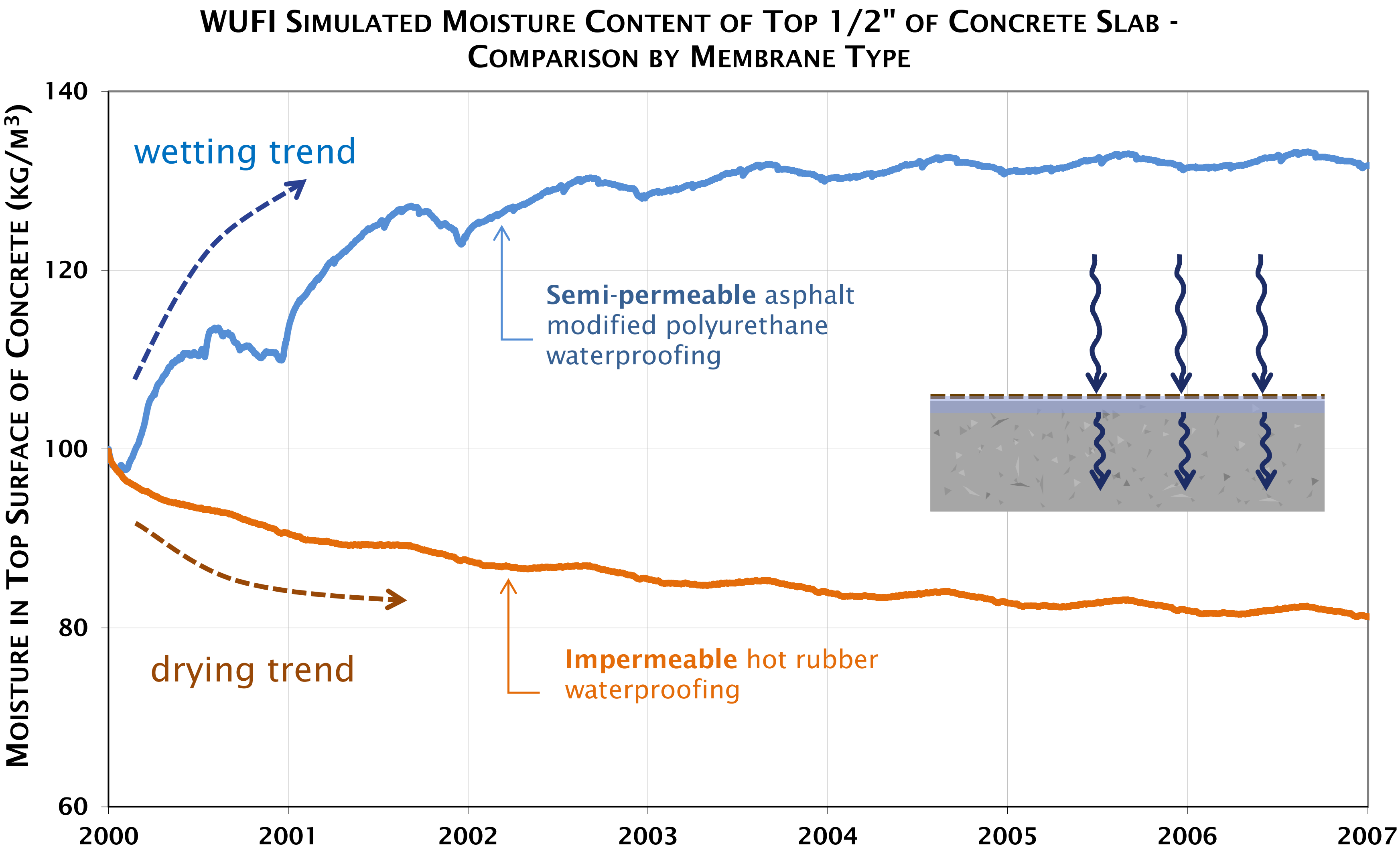
Impact of High Vapor Permeance

→ 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

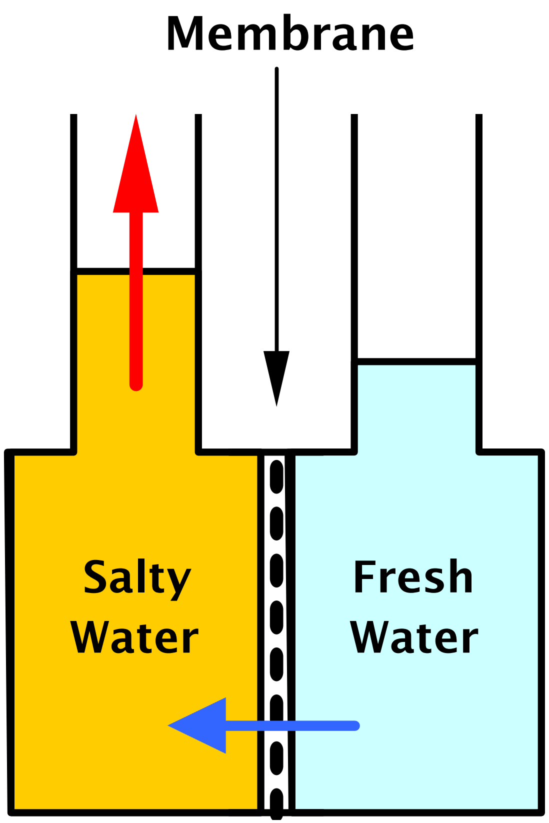


Impact of High Vapour Permeance



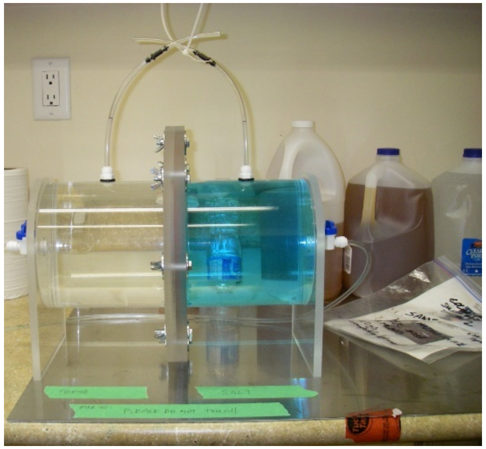
How to Measure Osmotic Flow Rate?

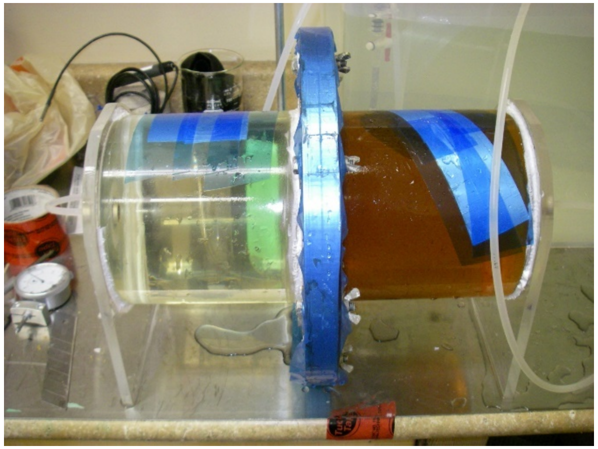
- Dissolved salt/metal ion concentration difference across membrane? ✓
- Membrane permeable to water? ✓
- Mechanism of initial wetting? ✓
- Measure osmotic flow rate directly ?



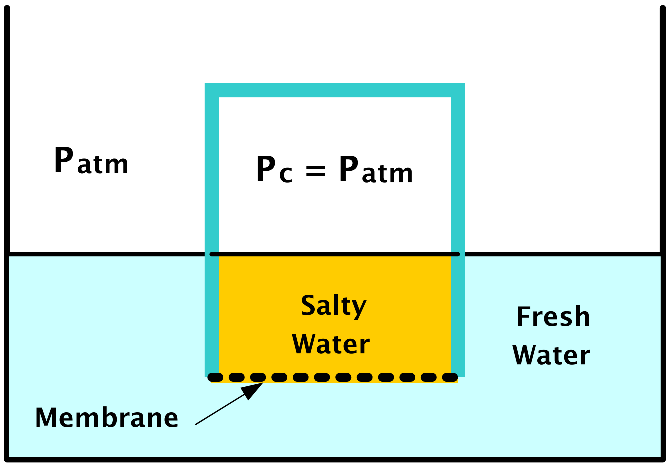
Measure movement of water across waterproofing membrane with salt water from site

Osmosis Test Chamber Concepts & Trials

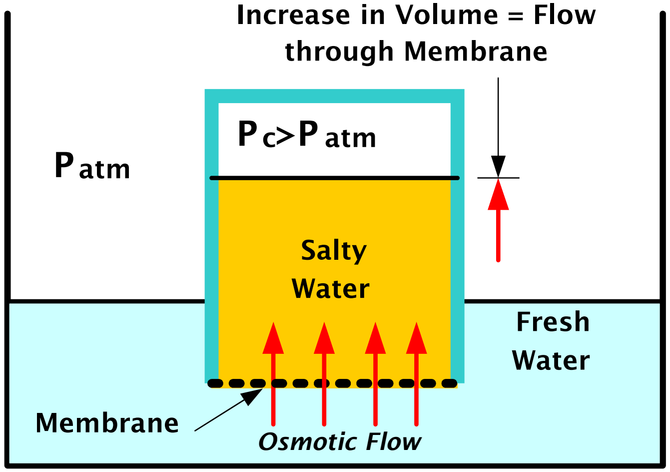




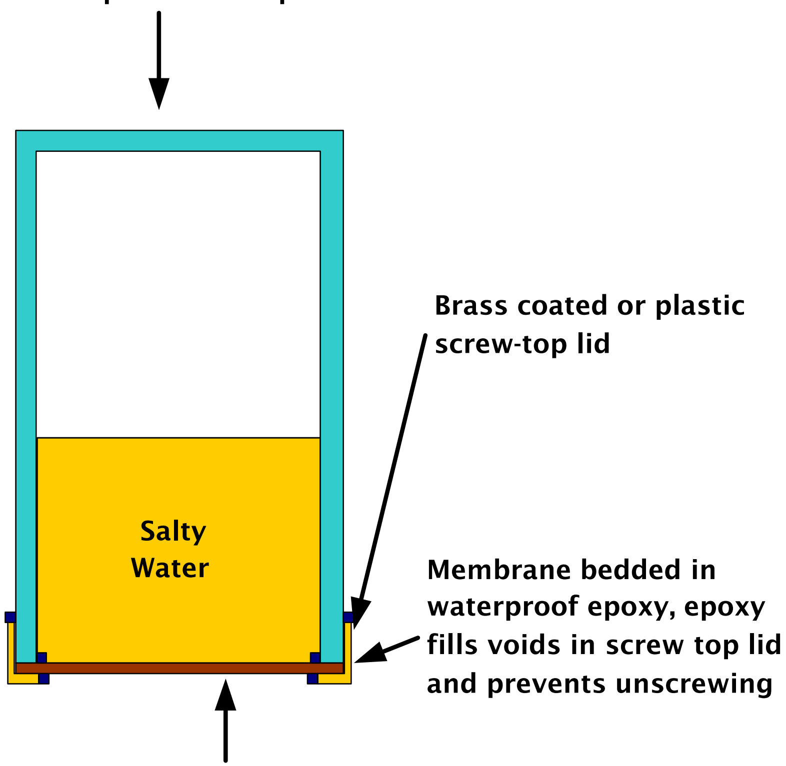
Osmotic Flow Laboratory Apparatus



Initial Setup, Pressure within Container is equal to atmospheric.

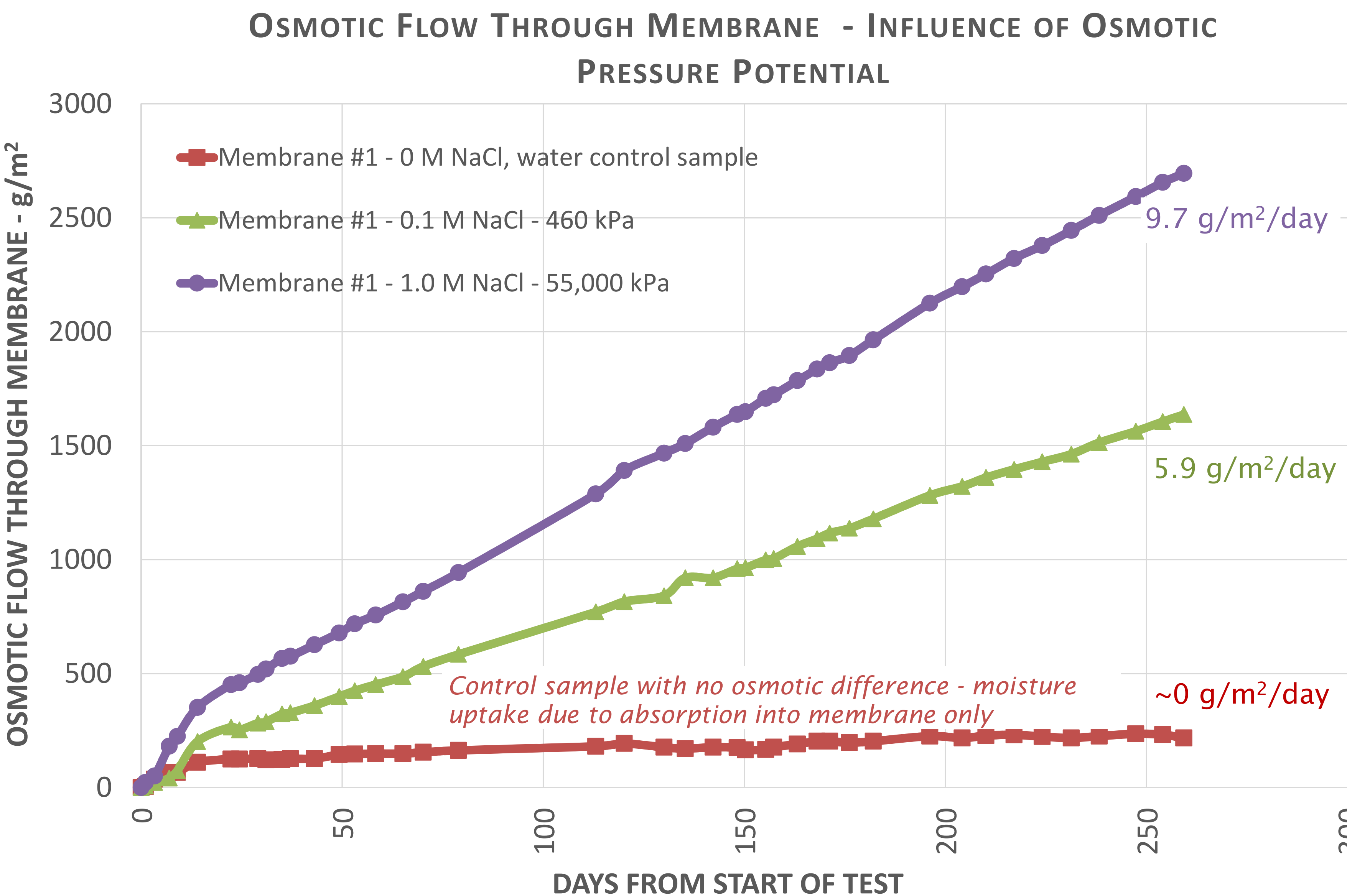


Osmosis occurs until Pressure within container reaches the Osmotic Pressure

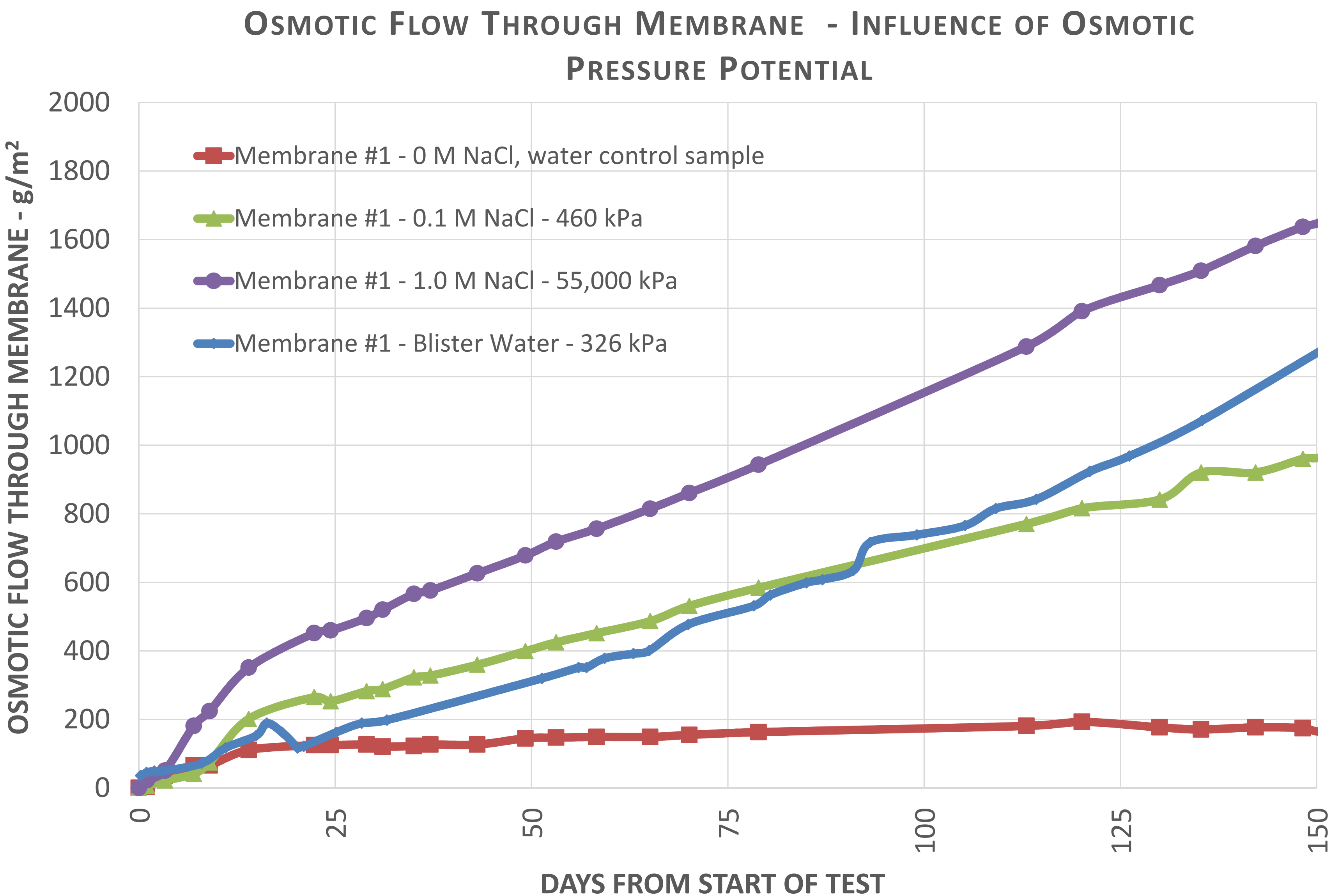


At Last... Some Results

Measured Osmotic Flow – Control Samples



Measured Osmotic Flow – Blister Water



New vs Aged Membrane Testing

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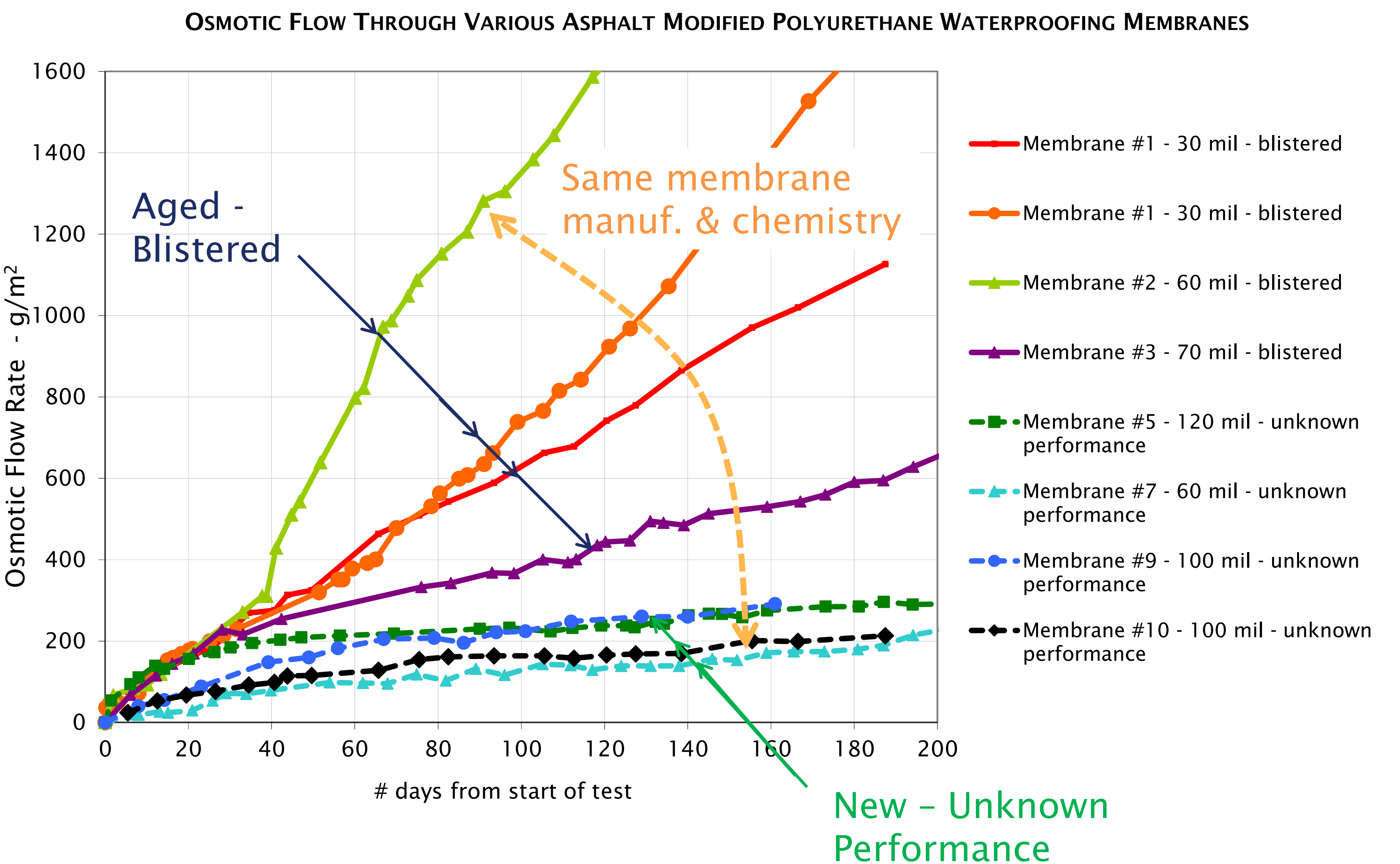
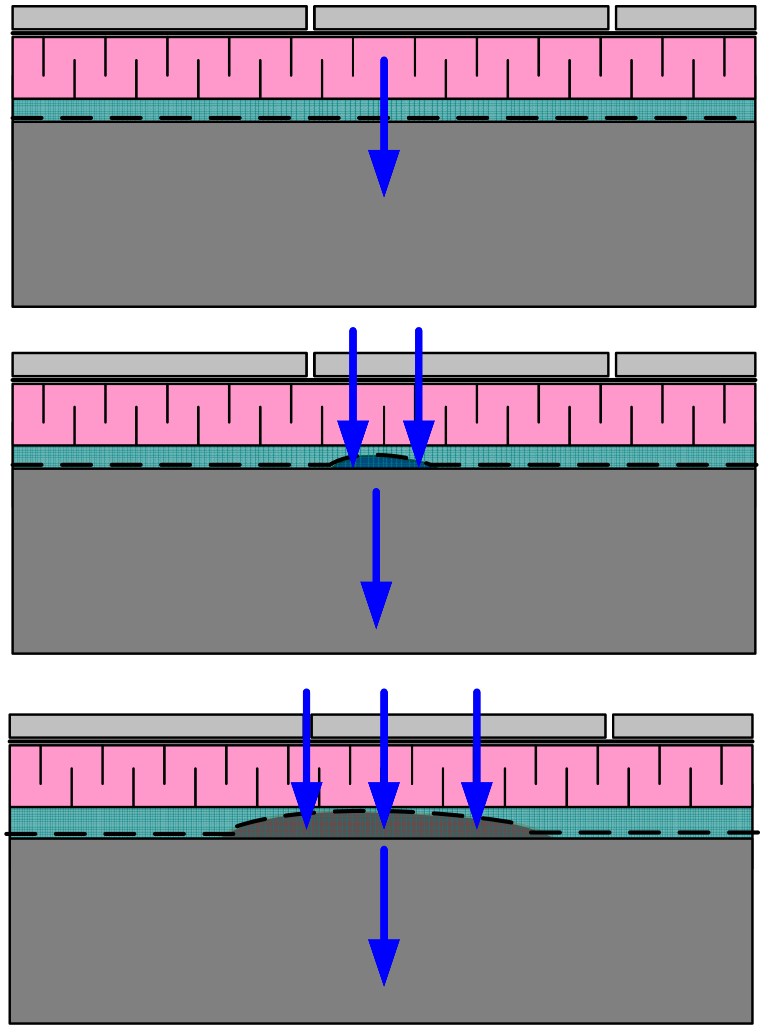


Summary: Osmotic Blistering Process



- → 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
- → **If membrane stays dry then not a problem…**

Findings – Asphalt Modified Polyurethane Membranes

- Tested asphalt modified polyurethane membranes found to have serious shortcomings as "waterproofing"
  - Vapor permeance of 30-120 mil membranes typically found to be >5 US Perms when removed from site
  - Osmotic Flow Rates of 5-12 $g/m^2/day$, (up to 20+ $g/m^2/day$ through some thin and old membranes)
  - Aged/weathered values much worse than initial specified
    - Impacts of alkaline environment and constant wetting?

- Solutions? – Reduce osmotic flow rate through membrane to less than the vapor diffusion drying rate downward through concrete slab then could we be okay?

Beyond a BC Problem

- Reports of similar water filled membrane blistering problems reported from all across the world over past decade
- Tend to hear about more issues in wet and humid climates where water sits on the membrane year-round
  - West coast Canada/US
  - Florida & Southern US, Hawaii
  - New Zealand
  - Europe & Asia
- Planters, ponds and other wet roofs particularly problematic

New and Ongoing Research

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- Between 2008 and 2016 we have worked with numerous waterproofing membrane manufacturers to address osmosis
  - Measure osmotic flow rate and assess the impacts of thickness, reinforcing, concrete primers, membrane fillers, cure method, different chemistries, etc.
  - Have tested many alternate non-asphalt based membrane chemistries & membrane types (cold-applied)
    - 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)

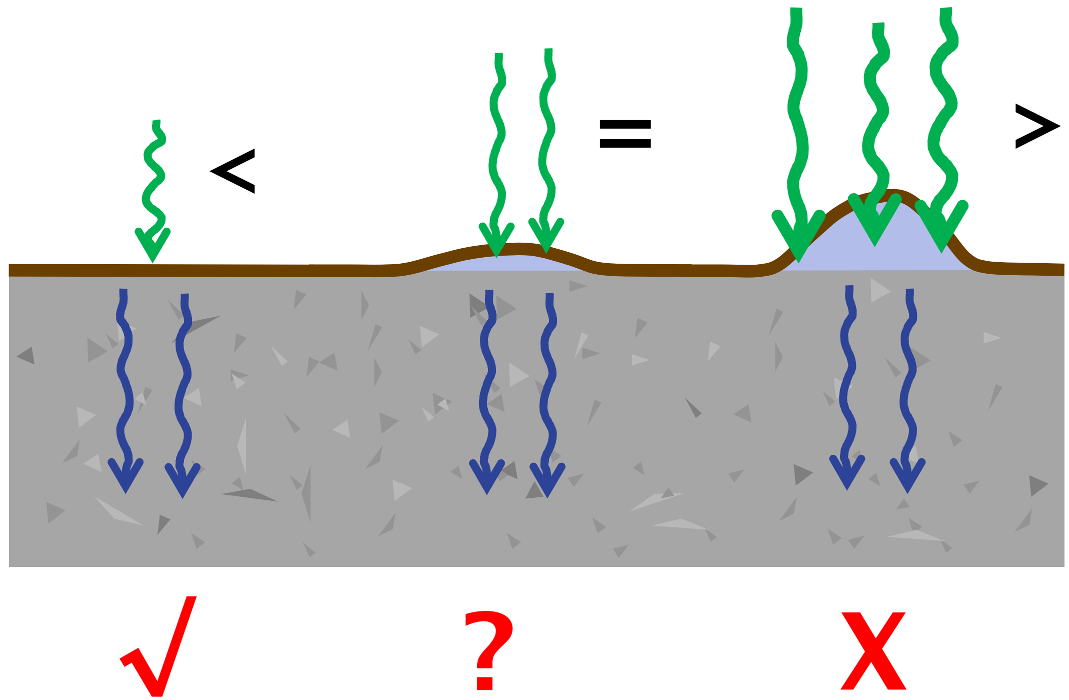
Updated Osmosis Test Procedure & Targets

- **Key Membrane Performance Attributes**
  - **Vapor Permeance** – Inverted wet cup result (<0.1 perms, *want this as low as possible*)
  - **Osmotic Flow Rate** – measure by apparatus with control blister water solution for several months (<0.1 g/m^2/day, *want this to be less than can dry through concrete slab*)
  - **Water Absorption** – soak it until it stops & not degraded (<1% ?)

Osmotic Flow Rate

VS.

Concrete Vapour Diffusion Rate



What About Polyurea Membranes?

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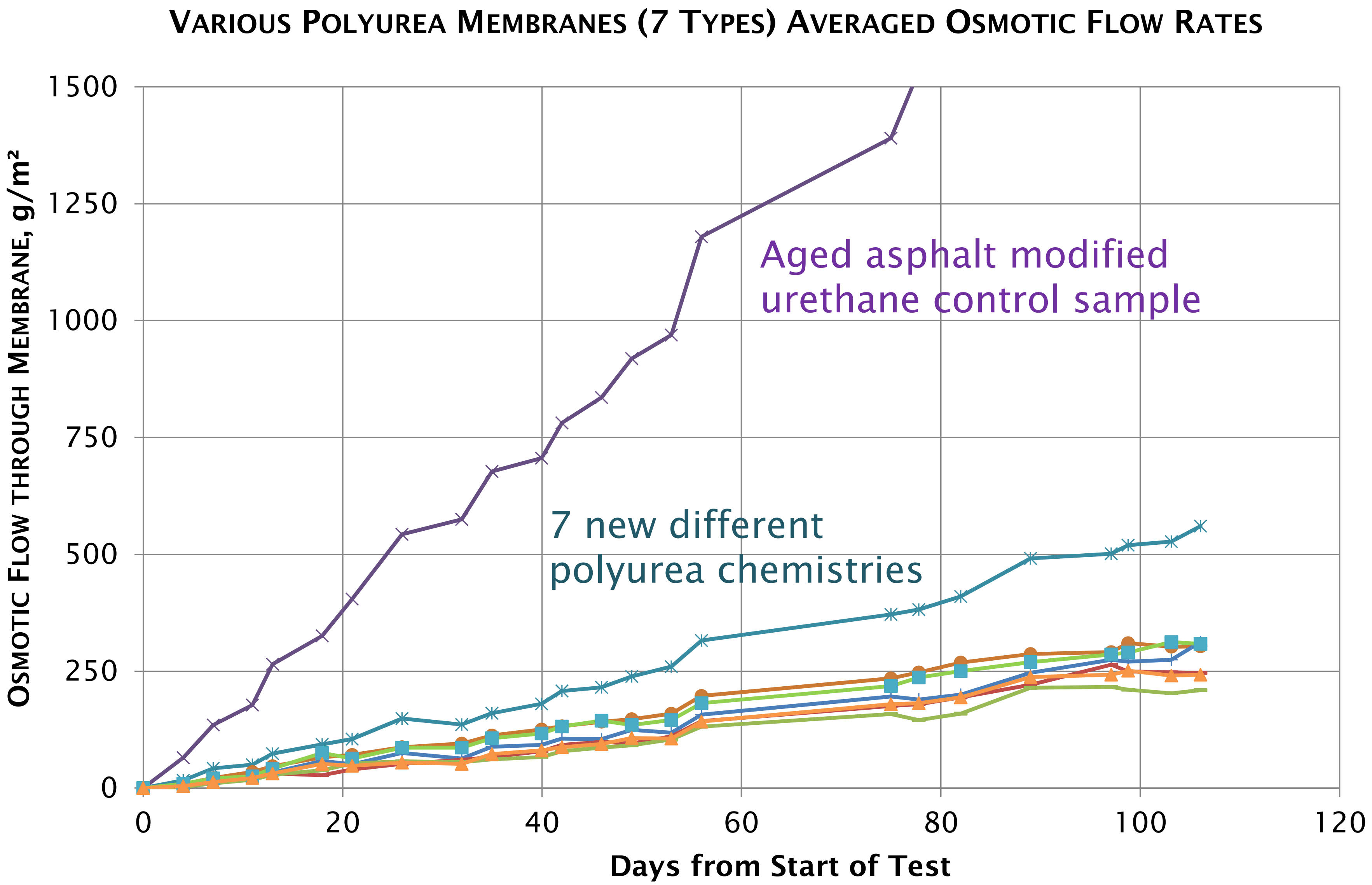

What About Polyurea Membranes?

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Membrane Sample Name	Membrane Thickness: Average, mils Range, mils	Osmotic Flow Rate Average, $g/m^2/day$ Range, $g/m^2/day$	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?

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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	0.08 US Perms	0.08 US Perms	1.6%	>4.5% (has not stopped)	~0.7 (87 mils)
PE – Polyester Based	0.26 US Perms	0.27 US Perms	1.3%	0.2%	0.4 (55 mils)
PE2 Two component polyester	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?

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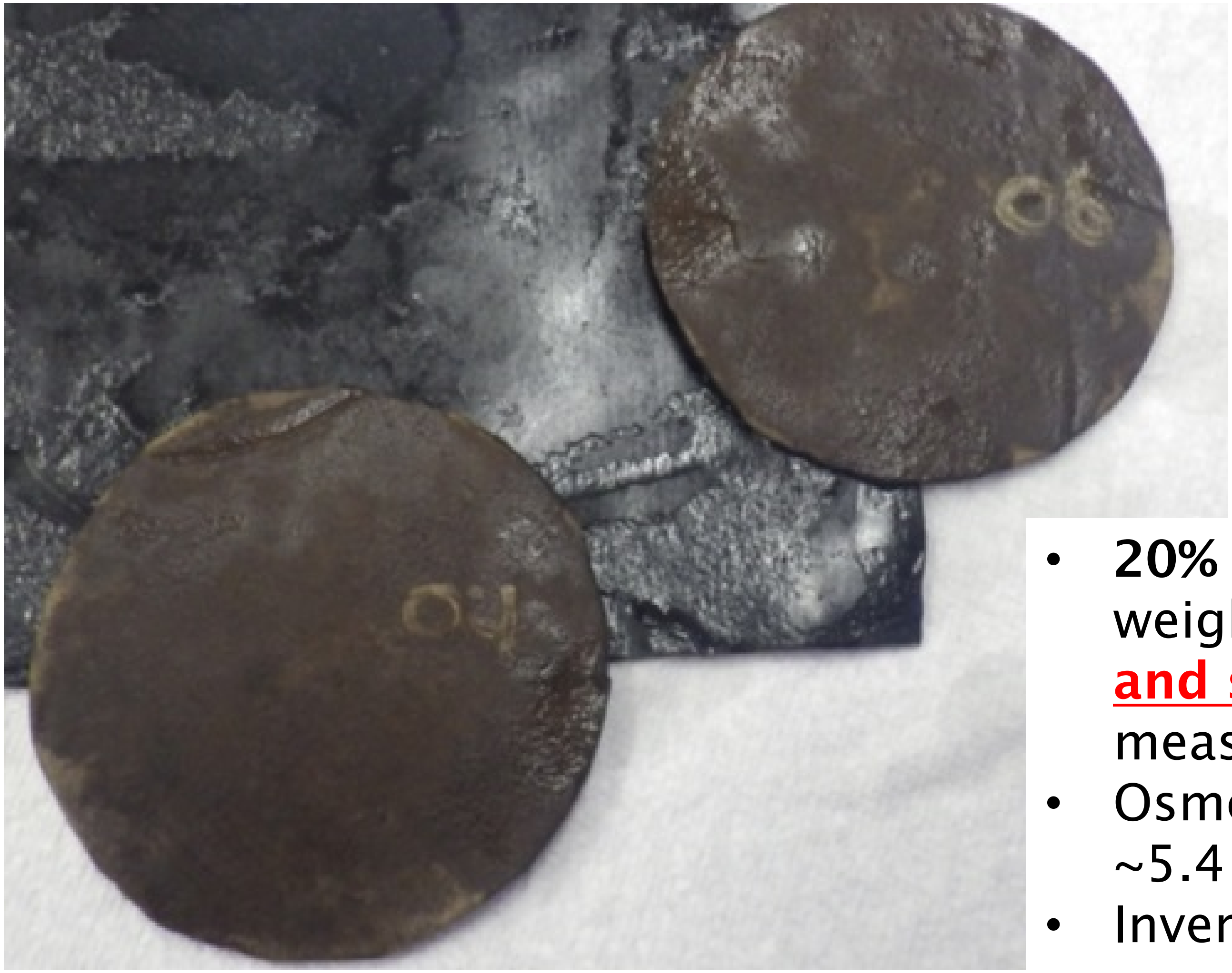
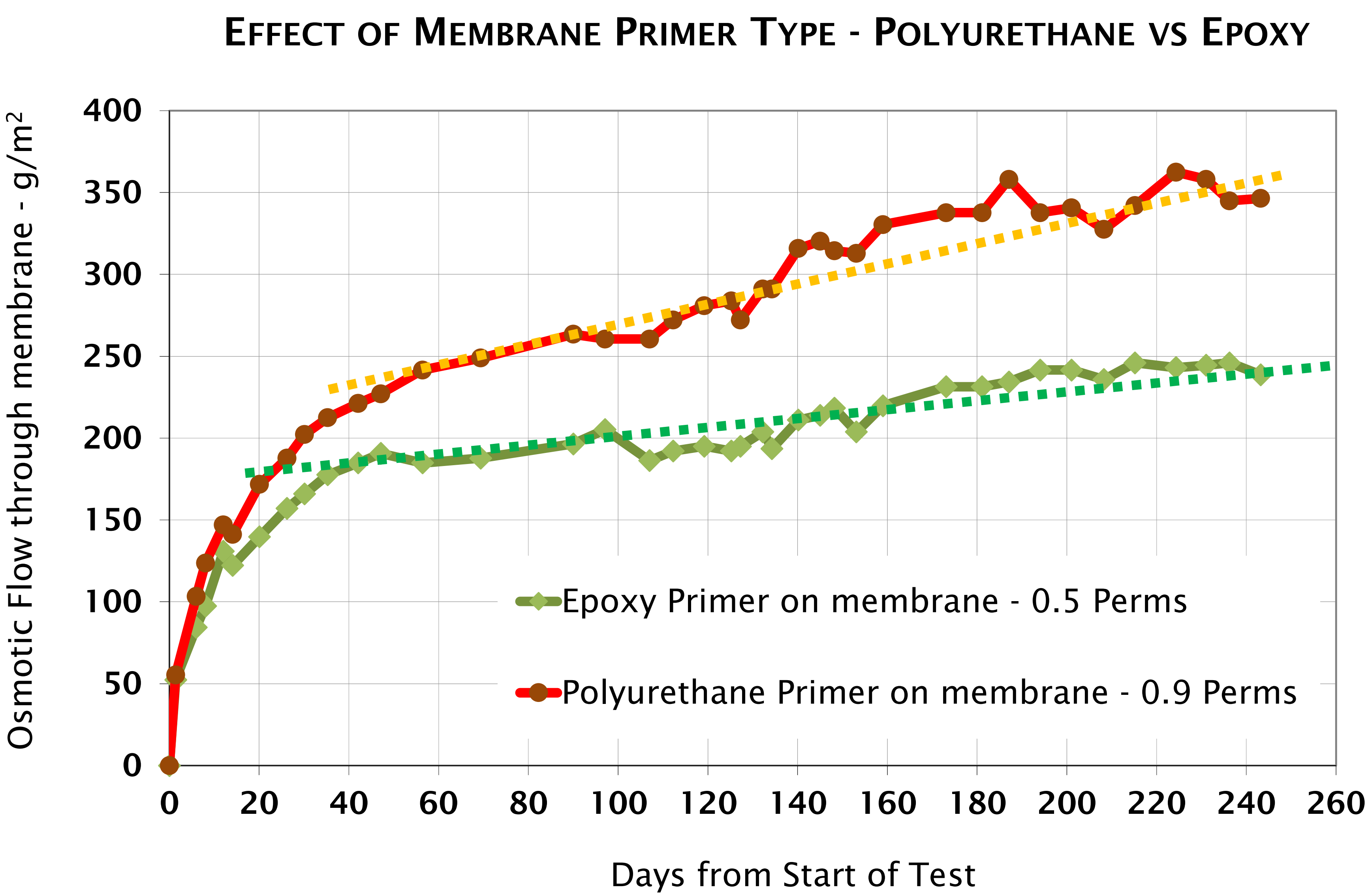
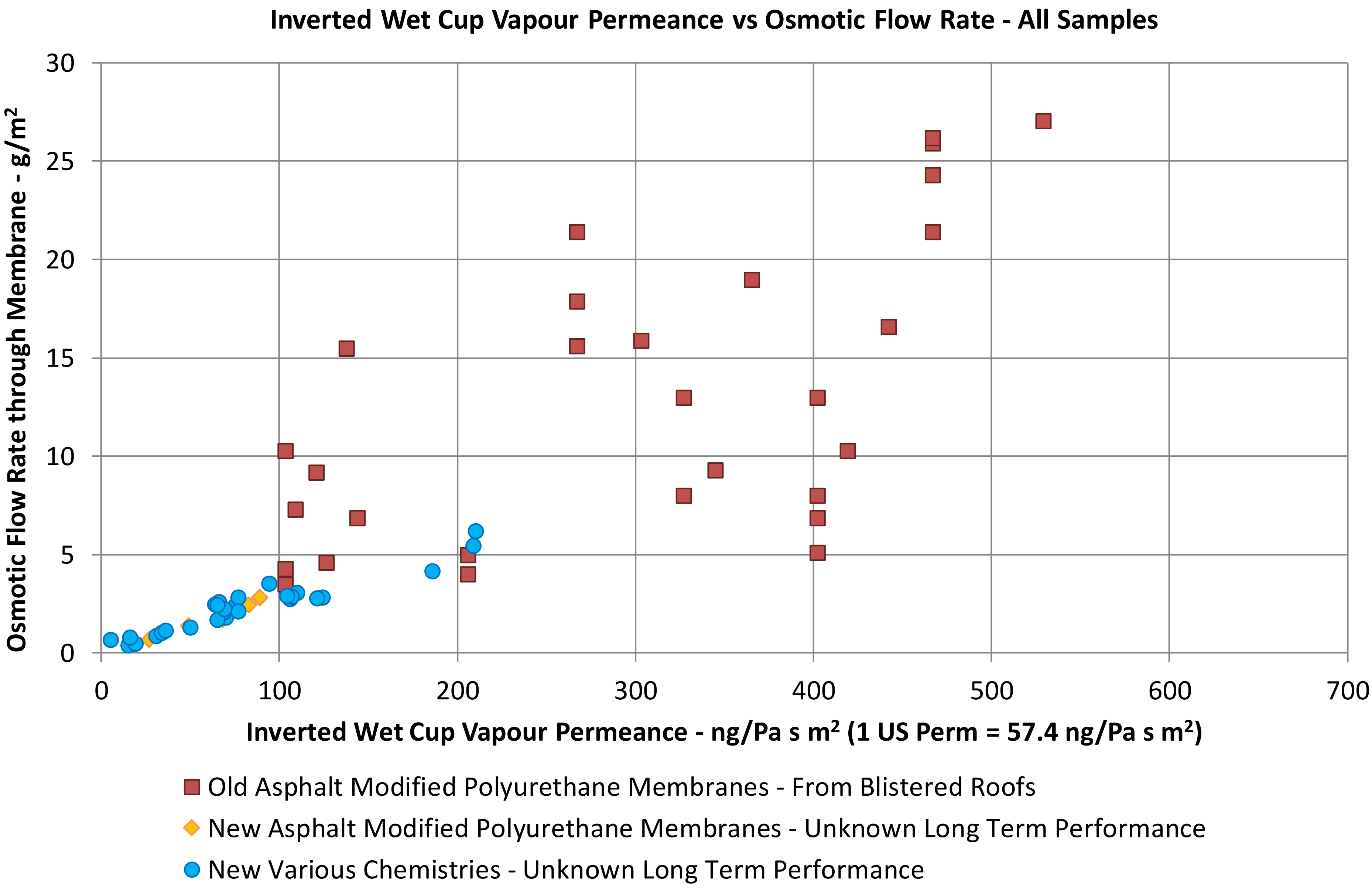


- **20% absorption** by weight after 210 days **and still rising**, 20% measured swelling
- Osmostic flow rate: ~5.4 g/m²/day
- Inverted wet cup permeance 0.14 US perms for 121 mils

Impacts of Concrete Primers?



Comparison of Test Results to Date



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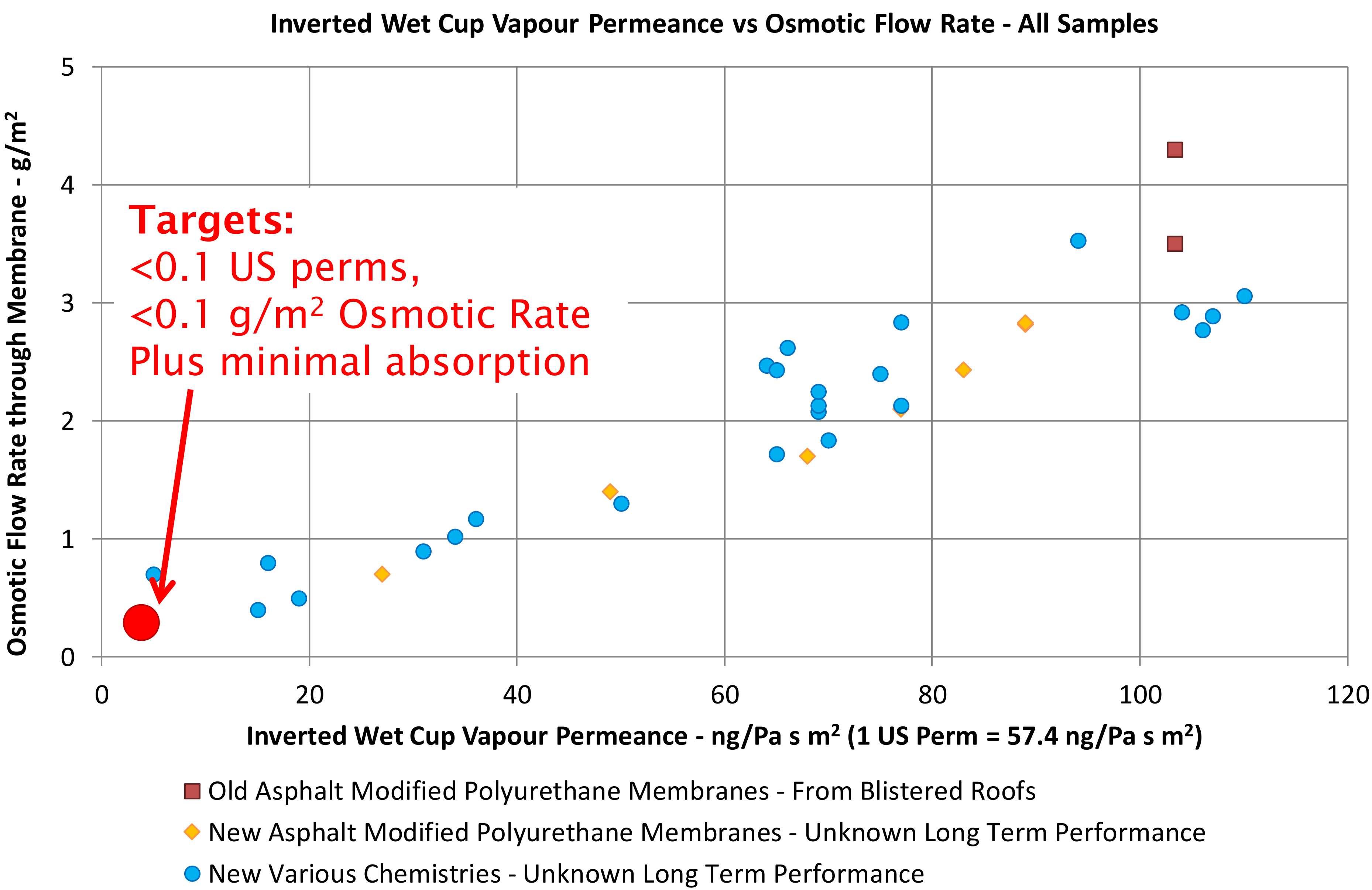

Key Findings & Recommendations

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- Avoid use of cold applied membranes 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 new membranes marketed for “green concrete” as tend to be worse (higher vapor permeance)
  - Not just an asphalt modified membrane problem – affects all waterproofing types – be careful with polyureas, polyurethanes, polyesters, PMMAs etc.
  - Where “hands-tied” - keep water from getting down to the waterproofing (supplemental drainage above insulation)
- Stick to tried and true fully adhered impermeable membranes like: hot rubber, 2-ply SBS, built-up asphalt etc.

Recommendations

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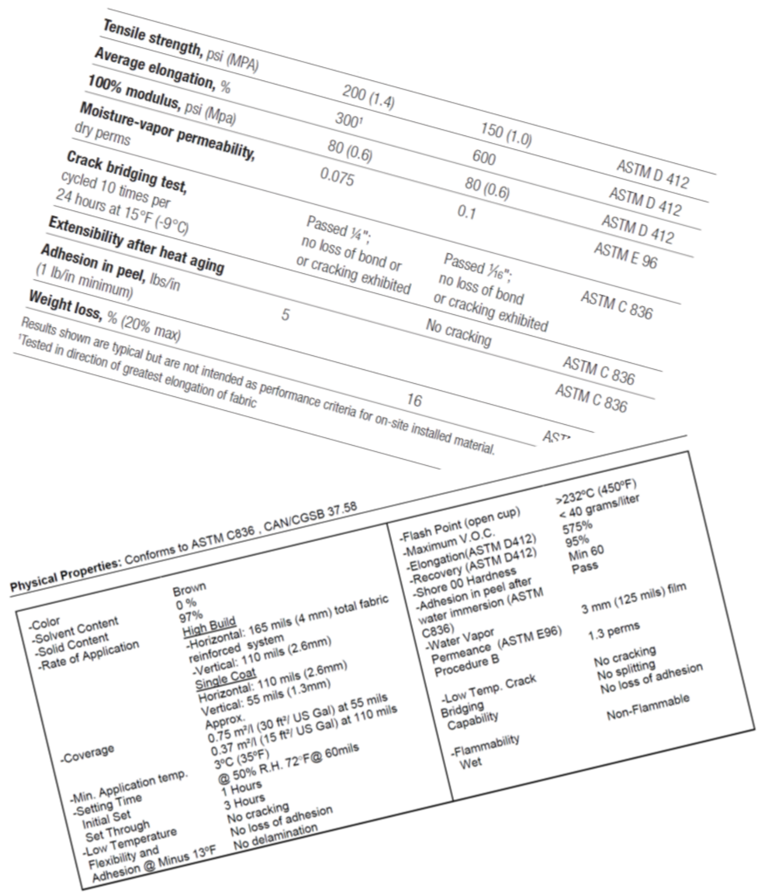
- Desired **inverted wet cup** vapor permeance to be less than 0.1 US Perms (<6 ng/Pa s m^2)
- Few manufacturers report **inverted wet cup**, usually just wet cup (Procedure B) (or worse still dry cup, Procedure A)
  - *Inverted wet cup* values typically 10 to 50% higher than *wet cup* and can be many times higher than *dry cup* values
- Review technical data sheets & ask manufacturers for data (some even have osmosis testing information)
- Watch for red flags & odd unit conversions



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 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	AST

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

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)	95%
		-Shore 00 Hardness	Min 60
		-Adhesion in peel after water immersion (ASTM C836)	Pass
		-Water Vapor Permeance (ASTM E96) Procedure B	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	-Low Temp. Crack Bridging Capability	No cracking No splitting No loss of adhesion
-Min. Application temp.	3°C (35°F) @ 50% R.H. 72°F@ 60mils	-Flammability Wet	Non-Flammable
-Setting Time Initial Set	1 Hours		
Set Through	3 Hours		
-Low Temperature Flexibility and Adhesion @ Minus 13°F	No cracking No loss of adhesion No delamination		

Next Steps

RDH

- → Need for a cold-applied solution & product that works!
- → Need for waterproofing industry champion to push revision to current industry standards (ASTM C836 and/or withdrawn CAN/CGSB–37.58-M86)
  - → Include a maximum inverted wet cup permeance and prolonged absorption rate) and bring forth requirements for resistance to osmotic flow
  - → Test new and accelerated aged samples with consideration for weathering and submersion within wet concrete alkaline environment
- → Hopefully no more problems?!

Discussion + Questions

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