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Making Buildings Better™

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Osmosis Testing - CIM Membrane

DATE June 2, 2020

REGARDING **Osmosis Testing - CIM Waterproofing Membrane**

Dear Mr. Libby,

As requested, RDH Building Science Inc. (RDH) is pleased to provide you with this report for the material testing of the CIM membrane. This membrane is a liquid applied urethane waterproofing system.[1] The tests include vapour permeance, water absorption, and osmotic flow measurements as part of our standard osmotic testing program. Absorption and osmotic flow measurements were also compared to reference membranes, chosen for their range in chemical makeup and physical properties. The following results have been obtained over the course of our testing.

1 Background

RDH Building Science Inc. (RDH) has been investigating and researching the in-situ performance of waterproofing membranes in North America over the past decade. Because of this research, we have identified products which tend to exhibit systemic water-filled blistering after 5 to 15 years in service. Our research has determined that the primary cause of the water blistering is osmotic flow. RDH has published several technical papers and presented at numerous venues that cover the research and the test methods used to prove the process of osmotic flow through these membranes[2, 3].

The process of osmosis can be described as the flow of a solvent, usually water, across a semi-permeable membrane from a solution of low solute concentration to a solution of high solute concentration. This is possible when the membrane separating the two solutions is slightly permeable to water yet impermeable to the solutes. Thus, the water flows across the membrane to balance out the solute concentrations on either side of the membrane. Figure 1.1 depicts this process.

[1] CIM 1000 High Performance and Linings. Technical Data Sheet; Date: 07/2010.
[2] Hubbs, B., Finch, G., and Bombino, R. *Osmosis and the Blistering of Polyurethane Waterproofing Membranes.* Building Envelope Technology Symposium, RCI, Inc., October 2009.
[3] Henderson, E., Finch, G., and Hubbs, B. *Solutions to Address Osmosis and the Blistering of Liquid Applied Waterproofing Membranes.* 15th Canadian Conference on Building Science and Technology, 2017.

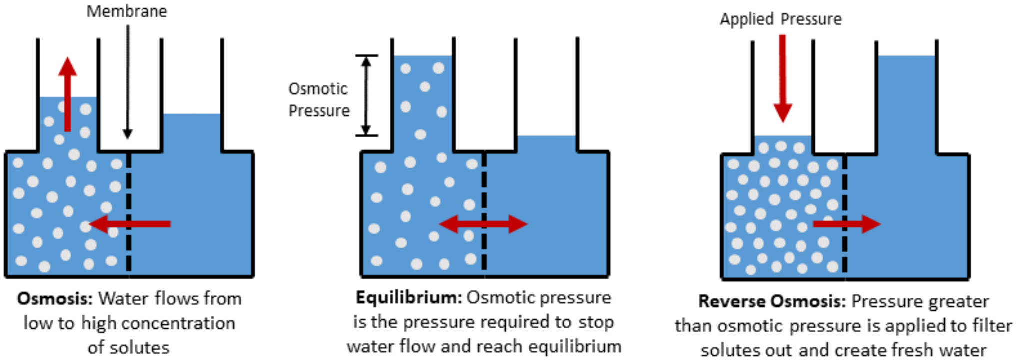

Figure 1.1 The process of osmosis, including its equilibrium state and reverse osmosis in a system with a semi-permeable membrane separating fresh water from a solute with high solute concentration.

If the vessel is open such as in the diagram above, the water level on one side rises until the hydrostatic pressure equals that of the osmotic pressure, defined by the following equation:

$$\pi = \varphi \cdot C \cdot R \cdot T$$

Equation 1

Where π = osmotic pressure (bar, SI unit of pressure)

φ = osmotic coefficient (unitless, value which characterizes the dissolution of the individual salts in solution.)

C = concentration of all dissociated solutes (mol/L where mol is the standard unit of measurement for an amount of substance)

R = universal gas constant (0.083145 L·bar/mol·K)

T = temperature (Kelvin, absolute measure of SI temperature equal to ˚C+273)

Osmotic pressure is a colligative property, meaning that the property depends on the concentration of the solutes and not on their identity. In other words, the osmotic flow across a system with 1.0 M sodium chloride (NaCl) as the solute is the same as an identical system with 1.0 M potassium iodide or a 1.0 M mixture of dissolved solids that come off a concrete slab when water is trapped within a blister below a waterproof membrane. Total dissolved solids (TDS) in water extracted from beneath in situ waterproofing membrane blisters was measured to be great enough to exhibit osmotic pressure up to 15 bar. The salts found within these blisters comprise mostly of organic compounds and various inorganic compounds including calcium, magnesium, potassium, sulfur, and silicon.

Typical Osmotic Blistering and Premature Failure of a Cold-Applied Waterproofing Membrane within an Inverted Roofing (PMR) Assembly over a Cast Concrete Slab

To date there is no industry standard test method to measure osmotic flow of waterproofing membranes. As part of our research, RDH has developed a validated osmosis laboratory test method and we have used this test to compile a relatively large database of new and existing waterproofing membranes for which blistering has, and has not been observed in service. Through this work, we are working with ASTM committee members to eventually update cold and hot-applied liquid waterproofing membrane requirements referenced by industry standards.

Through our investigative work and research, it has become apparent that the building industry is in need of a proven membrane to replace the current asphalt modified polyurethane and other cold-applied membrane products on the market which are susceptible to osmotic flow and therefore unsuitable for many waterproofing applications. Field experience and investigations have shown us that hot rubberized waterproofing, built-up asphalt, torch applied mod-bit, and other impermeable membranes are not likely susceptible to osmotic blistering, however there may also be other liquid applied products which exhibit acceptable properties.

The testing presented here helps demonstrate the relative performance of your waterproofing system as compared to other systems and helps establish a baseline of material properties for inclusion into industry test standards.

2 Scope of Work

We have carried out the following scope of services to investigate the material properties for the CIM membrane, including its osmotic potential:

→ Measure the wet cup and inverted wet cup vapour permeance of the membrane in general conformance with ASTM E-96.

→ Measure the long-term water absorption of the membrane. The long-term water absorption test follows ASTM test standards, though exceeds the standard 24-hour or 7-day test period.

→ Determine the osmotic potential of the test sample in general conformance with the standard osmosis test procedure developed by RDH.

→ Compare the osmotic flow rate against our database of reference membranes that we have tested in the past. The reference membranes range from very low (non-blistered samples) to very high (samples from large blisters) osmotic flow rates.

→ Evaluate the CIM system based on the osmosis test, the vapour permeance tests, and the water absorption test.

This laboratory report presents the results of our findings and comparison to other generic systems in terms of risk of osmotic blistering.

3 Vapour Permeance

In our past research experience, we have identified a correlation between vapour permeance and osmotic flow. Thus, we carried out vapour permeance testing to elucidate if the CIM system is in a range that could lead to osmosis.

3.1 Procedure

The ASTM E-96 test procedure was used for both wet cup and inverted wet cup vapour permeance measurements. In general, distilled water is placed within a glass jar and the material being tested is sealed on top such that it separates the interior of the cup to the controlled relative humidity (RH) conditions of a climate chamber. The vapour pressure gradient created between the water in the cup (100% RH) and climate chamber conditions (50% RH) results in the moisture leaving the cup through the test material. The average RH of the sample during the wet cup measurement is 75%, which is generally representative of exterior conditions. Wet cup measurements are typically recommended over dry cup for describing the in-service properties of water resisting barrier sheathing membranes as they are exposed to high RH levels for most the year.

The inverted wet cup test is different from the regular wet cup method in that is simply inverts the standard wet cup apparatus in the climate chamber and exposes the top side of the membrane to liquid water. The average RH the material sees in this case is the same as the wet cup however liquid water, and potentially capillary flow, is present. Inverted wet cup measurements are recommended for the in-service properties of waterproofing membranes that are in contact with liquid water for significant periods of time, especially those used in protected membrane roofs.

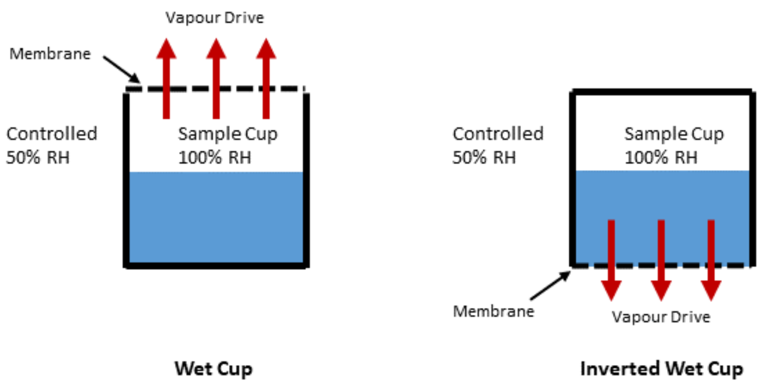

Figure 3.1 Schematic showing wet cup and inverted wet cup vapour permeance test procedures per ASTM E-96. Note, RH is Relative Humidity – the relative amount of water vapour within the air compared to the maximum at saturation vapour pressure.

The amount of moisture leaving or entering the apparatus is measured using a laboratory scale and the resulting vapour permeance is calculated.

The preparation of the samples for the wet cup and inverted wet cup tests follows the same steps as sample preparation for the osmosis measurements (Section 5.1), although the water inside the jars is distilled (fresh) water instead of salt water in the case of the osmosis test samples.

Figure 3.2 An example of a sample container. The same sample container set up is used for wet cup and inverted wet cup vapour permeance testing.

3.2 Results

The above procedure was used to obtain vapour permeance values for the CIM samples. The wet cup and inverted wet cup results are listed in the table below for the triplicate samples of the membrane. In some cases, the required 1.0 gram of water loss per ASTM E-96 was not yet reached, but due to time limitations and the clear low permeance of the samples, the experiments were stopped and the results are reported below. Permeance of the samples are reported along with the measured thicknesses. Permeability is also reported as a thickness-normalized metric.

TABLE 3.1 VAPOUR PERMEANCE TEST RESULTS			
SAMPLE	THICKNESS mm (mil)	WET CUP VAPOUR PERMEANCE ng/Pa·s·m² (US Perms)	INVERTED WET CUP VAPOUR PERMEANCE ng/Pa·s·m² (US Perms)
CIM 60 mil			
VP – 1.1	1.47 (58)	5.63 (0.10)	4.80 (0.08)
VP – 1.2	1.55 (61)	5.58 (0.10)	4.80 (0.08)
VP – 1.3	1.78 (70)	3.60 (0.06)	4.82 (0.08)
Average	**1.60 (63)**	**4.88 (0.08)**	**4.80 (0.08)**
Average Permeability,* ng/Pa·s·m (US Perm-inch)		**0.01 (0.00)**	**0.01 (0.00)**
CIM 120 mil			
VP – 2.1	3.15 (124)	2.61 (0.05)	3.65 (0.06)
VP – 2.2	3.33 (131)	2.45 (0.04)	4.52 (0.08)
VP – 2.3	3.58 (141)	2.29 (0.04)	4.53 (0.08)
Average	**3.35 (132)**	**2.44 (0.04)**	**4.25 (0.07)**
Average Permeability,* ng/Pa·s·m (US Perm-inch)		**0.01 (0.00)**	**0.01 (0.00)**

*Permeability was calculated using the sample dry thickness. Previous testing by CIM using the ASTM E96 Procedure E found permeance to be 0.03 US Perms at 100 mil.[4]

Previous testing by RDH has found a correlation between the inverted wet cup vapour permeance and the osmotic flow rate. This correlation is discussed in more detail in Section 6. Overall, we suggest a target of <0.1 US Perms for inverted wet cup permeance

[4] CIM 1000 High Performance Coatings and Linings. Technical Data Sheet; Date: 07/2010.

to limit the risk of osmotic blistering occurring in the field. The thinner CIM 60 membrane is below this threshold at 0.08 US Perms at 63 mil and the thicker CIM 120 membrane is also below this at 0.07 US Perms at 132 mil. Vapour permeance of reference membranes (asphalt-modified polyurethane and SBS) is shown for comparison in the complete results summary table in Section 6.

4 Water Absorption

Water absorption measurements of the membrane is part of the standard osmosis testing procedure developed by RDH for two main reasons:

- **To understand the long-term effects of contact with liquid water**. The absorption of water by waterproofing membranes can change their properties over time. Water absorption can dissolve some components of the material over time, as well as loosen the adhesion of layers including fibre reinforcement. These changes to the chemical and physical properties of membranes can lead to decreased performance and failures in the field. Very high moisture absorption rates have been shown to fail waterproofing membranes on their own without osmosis occurring due to swelling, softening, or material degradation.
- **To calibrate the osmosis results**. Most membranes in the osmosis experiments go through a wetting process during which they absorb water, although this does not necessarily contribute to water permeating *through* the material. The standard osmosis test procedure developed by RDH decouples these two processes. For this reason, the effect of absorption is subtracted from the osmosis experiment measurements and the corrected results are shown in Section 5.2.

4.1 Procedure

Water absorption testing was performed for the CIM membrane. Our testing procedure generally follows industry standard water absorption tests (immersion of sample in room temperature water), but for a longer period of time than what is specified by most test procedures. We have found that the 24-hour moisture absorption specified in various ASTM standards (including ASTM D-570 for plastics) to be insufficient to accurately assess the long-term moisture uptake of a waterproofing membrane in an inverted roofing application. This is important as long-term water absorption into a waterproofing membrane will affect its durability and material properties (i.e. susceptibility to osmosis and material strength etc.). As part of our test, we measure the water uptake and moisture content of a membrane until saturation of the membrane is reached. For some membranes, this may take several months to occur.

4.2 Results

Water absorption by the membrane has the largest impact on the gravimetric analysis in the osmosis testing procedure during the first few months of the experiment. To monitor and isolate this effect, we carried out absorption measurements throughout the length of the osmosis experiment. Over the course of six months:

- CIM 60 mil absorbed approximately 0.4% water by weight
- CIM 120 mil absorbed approximately 0.2% water by weight

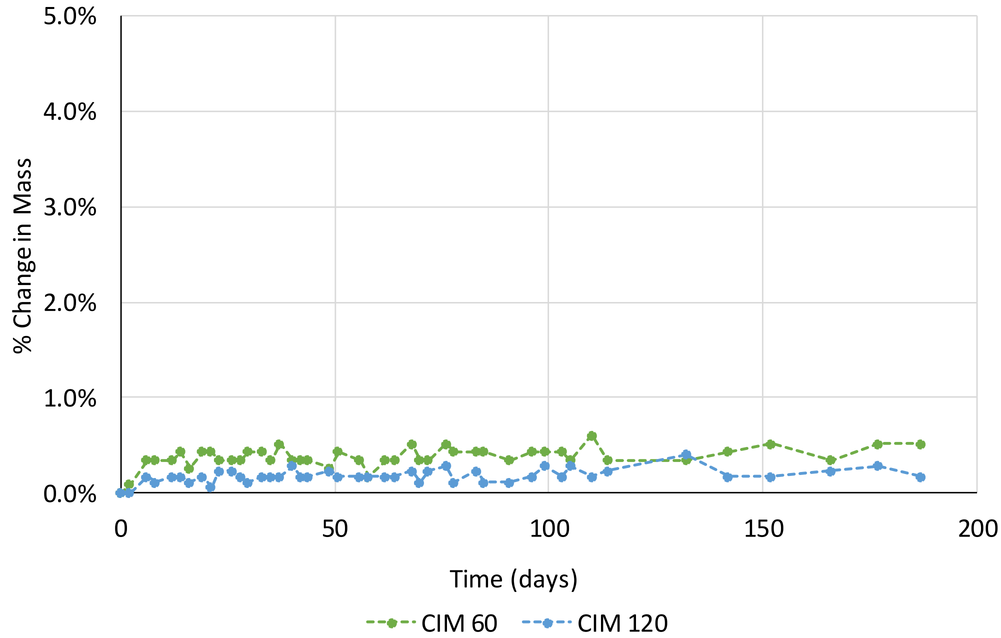

Figure 4.1 Water absorption testing results for the CIM membrane samples.

Comparison to reference membranes that were tested previously is shown below, in Figure 4.2 and in Table 4.1. The absorption results show that the uptake of water by the asphalt-modified polyurethane reference membrane plateaus within 3-4 weeks, although the CIM sample takes longer to reach absorptive equilibrium. For this reason, we continued the absorption and osmosis experiments for over 150 days. This way the fraction of weight gain due to water absorption could be subtracted from the osmosis data.

Very high absorption rates have been shown to fail waterproofing membranes on their own without osmosis occurring, due to swelling, softening, or material degradation. The asphalt-modified polyurethane has high water absorption and is also at high-risk for osmosis. After its maximum absorption has been reached, the weight of this modified polyurethane sample can be seen to decrease over the course of the experiment (Figure 4.2). This weight decrease points to the loss of material by dissolution into the water bath. This was confirmed by measuring increased total dissolved solids (TDS) in the water bath over time. For this reason, the water bath was changed weekly and replenished with distilled water.

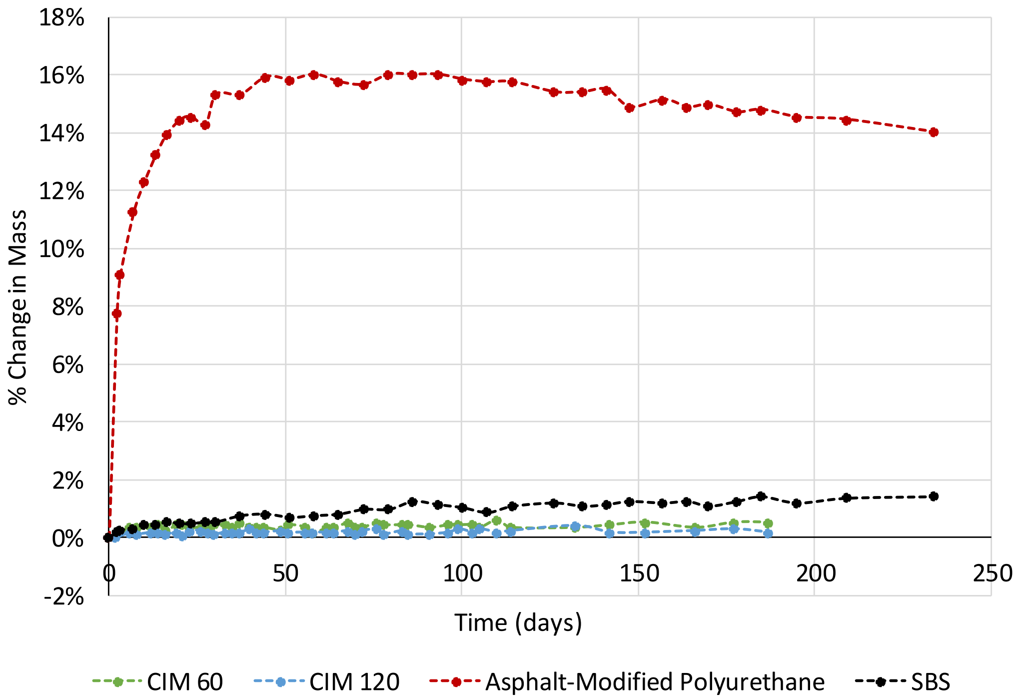

Figure 4.2 Absorption testing results for the CIM system – as well as reference membrane samples of asphalt-modified polyurethane and SBS.

TABLE 4.1 ABSORPTION RESULTS SUMMARY			
MEMBRANE	THICKNESS (mil)	MAXIMUM ABSORPTION (% by weight gain)	TIME TO EQUILIBRIUM (days)
CIM 60 mil	**85**	**0.6%**	**14**
CIM 120 mil	**130**	**0.4%**	**12**
Asphalt-modified Polyurethane	58	16.0%	44
SBS	100	1.4%	86

5 Osmosis Testing

5.1 Procedure

To measure osmotic flow through the membranes, each membrane was cut and sealed to the open side of a glass container to separate between fresh and saltwater (1.0 M NaCl). In general, the process of osmosis will result in a flow of water from the fresh to the salty side of the membrane. The apparatus was designed so the flow of water from the fresh side to the salty side could be easily measured by the mass increase within the containers for several concurrent test specimens. Gravimetric measurements were taken at regular intervals and the osmotic flow of water into the container (g/m²/day) was calculated after subtracting the water absorption of the membranes that was measured concurrently (see Section 3). Control containers with impermeable metal lids instead of a membrane were also measured, and the weight gain from wetting of the apparatus in these controls was also subtracted from all sample osmosis measurements.

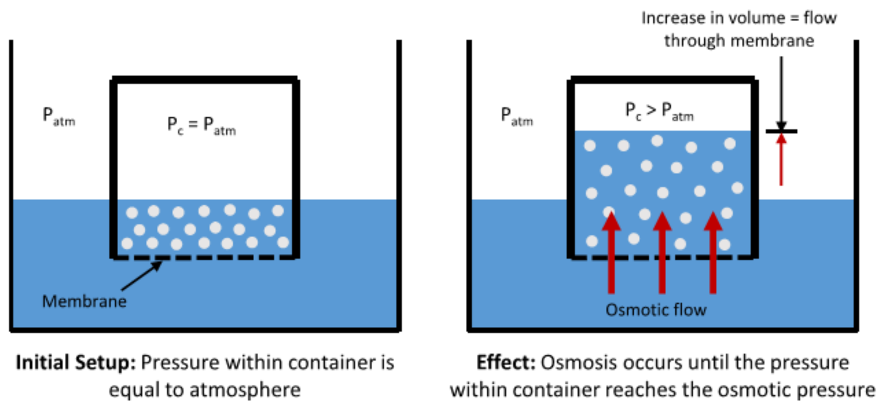

Figure 5.1 Schematic of the osmotic flow testing apparatus at the beginning of the experiment (left) and after osmosis has occurred (right).

5.2 Results

The osmotic flow rate was measured for both the thinner CIM 60 mil membrane and thicker CIM 120 mil membranes. The osmosis experiments were carried out for several months to obtain the rate of water uptake into the containers as described in the procedure. The CIM samples were compared to reference membranes analyzed under identical conditions. Reference membranes were selected to include a wide range of membrane types, including a sample that is known to exhibit osmosis (asphalt-modified polyurethane) and a hot rubber that has not exhibited osmosis in the field (SBS).

A mass-weighted fraction of water absorption by the membrane (as measured in Section 3) was subtracted from the gravimetric analysis of the osmosis samples. The Control samples with impermeable metal lids also showed mass increase over time, which indicates that the experiment apparatus has some baseline weight gain throughout this experiment (e.g. from water absorption to the container sealing epoxy). The average Control sample mass uptake was subtracted from the CIM samples. This resulted in a rate of water influx (osmotic flow) into each experimental container. Figure 5.2 shows the control-corrected, estimated osmotic flow through the CIM samples, measured in three CIM 60 mil and two CIM 120 mil samples and then averaged for each.

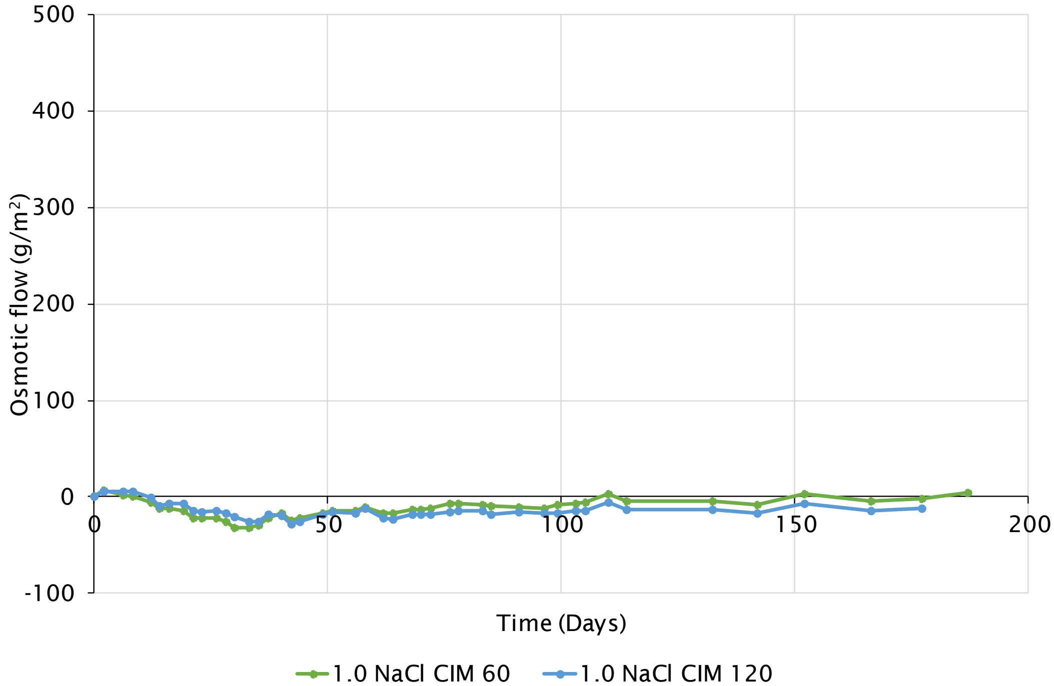

Figure 5.2 Osmotic flow over the course of the osmosis experiment for the CIM system.

A comparison of the CIM membranes to the reference membranes are shown below in Figure 5.3. All samples shown in this figure had 1.0 M NaCl solution in the sample container and the exterior distilled water bath was changed regularly to prevent build up of TDS in the water outside the jars. The asphalt-modified polyurethane shows significantly higher osmotic flow than the SBS reference membrane and the CIM samples.

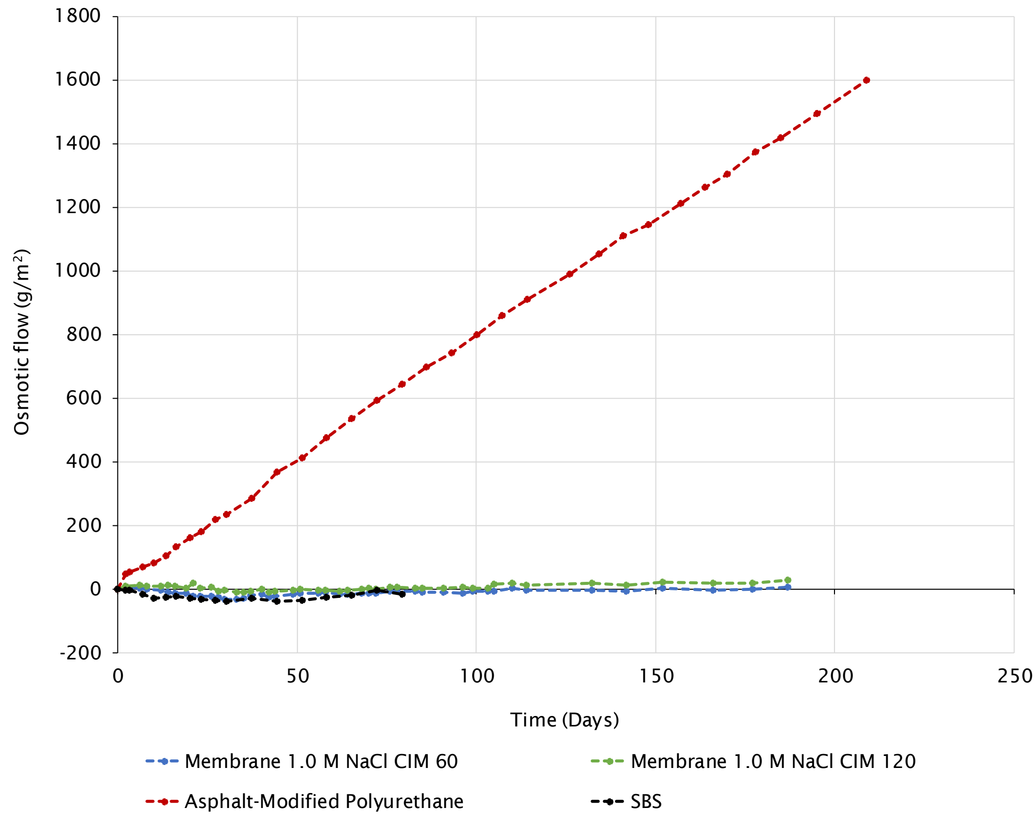

Figure 5.3 Osmotic flow over the course of the osmosis experiments for reference membranes in addition to the CIM samples.

TABLE 5.1 OSMOSIS EXPERIMENT RESULTS		
MEMBRANE TYPE (name of material)	MEMBRANE THICKNESS (mil)	OSMOTIC FLOW RATE (g/m²/day)
CIM 60 mil	**70**	**0.2 ± 0.03**
CIM 120 mil	**144**	**0.2 ± 0.02**
Asphalt-modified polyurethane	50	7.6 ± 0.6
SBS (1-ply)	100	0.4 ± 0.6

On average, the osmotic flow through the un-aged samples was measured to be less than 1.0 g/m^2/day for both the 70 and 144 mil CIM samples (0.2 g/m^2/day). The reference membrane with the largest osmotic flow rate is the asphalt-modified polyurethane (ranging from 1.4 – 26.2 g/m^2/day[5]), which is a membrane that has exhibited extensive osmotic blistering on buildings over the past two decades. Previously tested SBS and hot rubberized asphalt (2-ply) membranes exhibited flow rates below 1.0 g/m^2/day.

In past research, RDH has discovered that aged membranes tend to perform worse than their newer counterparts depending on the membrane chemistry. The long-term performance of waterproofing membranes with this rate of initial un-aged osmotic flow is

[5] There is a large range of observed membrane thicknesses and osmotic flow rates for asphalt-modified polyurethane samples due to the macroscopic variations in the samples retrieved from sites. Henderson, E., Finch, G., and Hubbs, B. *Solutions to Address Osmosis and the Blistering of Liquid Applied Waterproofing Membranes.* 15th Canadian Conference on Building Science and Technology, 2017.

unknown in the field. However, we have observed that membranes with a measured 'new membrane' osmotic flow rate of as low as approximately 2.0 g/m²/day (and higher) have blistered after aging in the field for 5 to 10 years. In contrast, conventional roofing products including SBS and hot-rubberized asphalt have an osmotic flow rate near 0.0 g/m²/day (± 1.0 g/m²/day with experimental variation)—as tested in our current experimental procedure—and we have not observed osmotic blistering phenomenon with these membranes. Thus, we currently recommend a limit near 0.0 g/m²/day (± 1.0 g/m²/day with experimental variation) under the conditions of the RDH osmotic test method[6] (with 1.0 M NaCl) with additional considerations for absorption and vapour permeance as discussed further in Section 6.

6 Discussion and Recommendations

A summary of the test results for vapour permeance, water absorption, and osmotic flow rate are shown below. Results are provided for the CIM system, as well as reference membranes: a single sheet of hot rubber (SBS) and asphalt-modified polyurethane.

TABLE 6.1 SUMMARY OF VAPOUR PERMEANCE, ABSORPTION, AND OSMOSIS TESTING RESULTS

MEMBRANE SAMPLE	AVERAGE THICKNESS, mil	VAPOUR PERMEANCE, ng/Pasm² (US Perms)		WATER ABSORPTION, % mass	OSMOTIC FLOW RATE, g/m²/day
		Wet Cup	Inverted WC		
CIM 60 mil	**70**	**4.88 (0.08)**	**4.80 (0.08)**	**0.4%**	**0.2 ± 0.03**
CIM 120 mil	**144**	**2.44 (0.04)**	**4.25 (0.07)**	**0.2%**	**0.2 ± 0.02**
Asphalt-modified polyurethane	50	117 (2.00)	110 (1.90)	16.0%	7.6 ±0.6
SBS (1-ply)	100	~0.0 (0.00)	~0.0 (0.00)	1.4%	0.4 ±0.6
Other hot rubberized asphalt	244	0.2 (0.00)	2.1 (0.04)	1.8%	0.5 ±0.5

Osmotic flow rates near 0.0 g/m²/day (± 1.0 g/m²/day with experimental variation) represent membranes that do not exhibit significant osmotic flow.[6] CIM is within this threshold, although its vapour permeance should also be considered, as described in more detail below.

It is our recommendation that inverted waterproofing membranes have an installed vapour permeance of less than the concrete substrate. This is partially to prevent the accumulation of moisture and the resulting saturated concrete surface that is required to start the osmosis cell. The osmosis mechanism is different from water vapour flow within an inverted (exterior insulated) roof, in which vapour predominantly flows from the warm interior (high vapour pressure) outwards to the colder exterior (lower vapour pressure). In contrast, the osmosis mechanism draws moisture inwards through the saturated

[6] The testing apparatus itself exhibits a very minor weight increase throughout the osmosis experiment, which is consistent in all tests. Controls with no membranes (impermeable metal lids) have been measured and that background weight increase has been subtracted from all results.

membrane surface (due to water pooling or extended rain) into concrete below. Water then accumulates between the membrane and the concrete substrate because the concrete is not permeable enough to dissipate the moisture towards the interior.

The wet cup vapour permeance of a 6” concrete slab is generally reported to be in the range of 0.1 to 0.5 US Perms. The thinner CIM 60 mil membrane is below this range at 0.08 US Perms at 63 mil and the thicker CIM 120 mil membrane is also below this at 0.07 US Perms at 132 mil. If this low permeance is maintained over the lifespan of the installed membrane, installation risk for blistering or significant water accumulation below this membrane is low.

To better understand how vapour permeance is related to osmotic flow, a graph showing this relationship is shown below. The CIM 120 mil membrane and the CIM 60 mil membrane have been added to the data collected from past research. In general, there is a correlation between vapour permeance and osmotic flow. The larger scatter with the asphalt-modified polyurethane samples is due to macroscopic variation in surface properties between the samples, such as air bubbles, inconsistent thickness, and embedded particles. Also, these samples may have aged differently in the field.

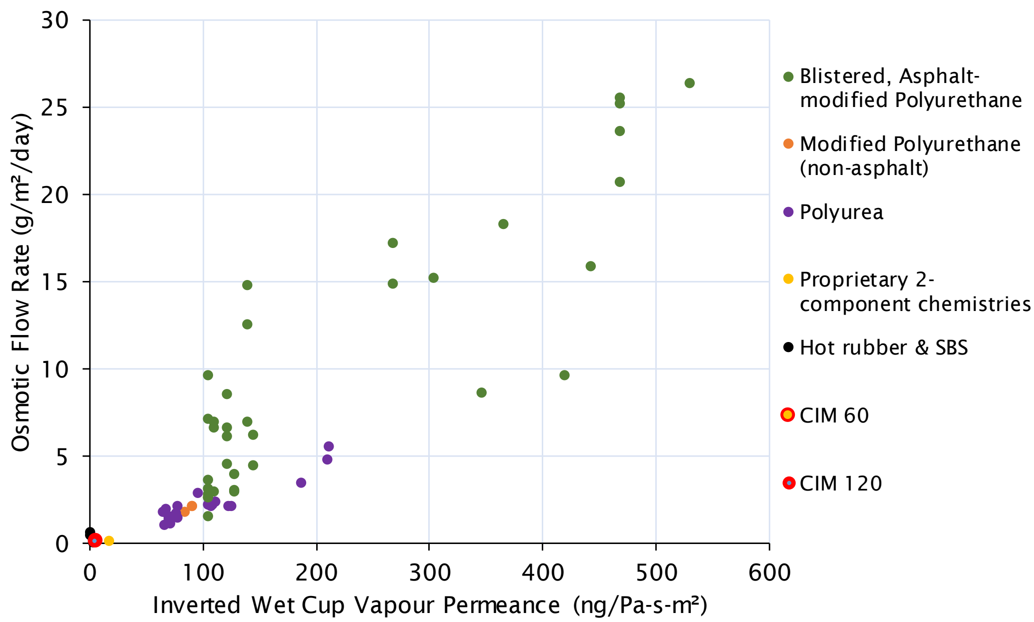

Figure 6.1 Osmotic flow rate of waterproofing membranes versus inverted wet cup vapour permeance. Data includes results from past RDH research with new CIM 60 data (yellow and outlined in red) and CIM 120 (light blue and outlined in red) added for comparison. The samples that have exhibited osmotic blistering in the field are noted in the legend as “Blistered.”

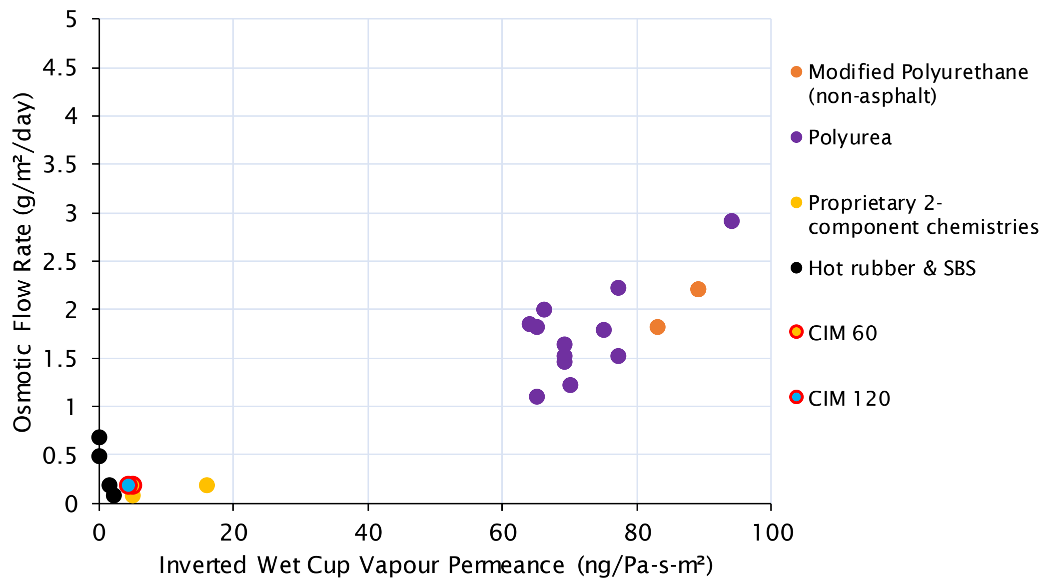

Figure 6.2 Data in Figure 6.1 zoomed in to show the CIM 60 (yellow and outlined in red), CIM 120 (light blue and outlined in red), and other 'low risk' membranes near 0.0 g/m²/day osmotic flow rate (± 1.0 g/m²/day) more clearly.

The goal of this testing is to relate the experimental results to the membrane performance in the field. It is important to remember that the reference asphalt-modified polyurethane has exhibited extensive osmotic blistering after 5 to 15 years on site, whereas many other widely used traditional waterproofing membranes have not been known to experience this problem in-service. We recommend that membranes in the osmotic flow rate range of these low-risk reference membranes can be deemed at low-risk for osmotic blistering: near 0.0 g/m²/day (± 1.0 g/m²/day with experimental variation) when tested with a 1.0 M salt solution,[7] and an inverted wet cup vapour permeance of <0.1 US Perms. In addition, we like to observe that long term absorption is minimal and stops after a few months with no apparent negative consequences on the integrity of the membrane.

→ The CIM 60 mil and 120 mil systems have a wet cup vapour permeance below the range of a typical 6" concrete slab (0.1–0.5 US Perms) and thus within our recommended threshold.

→ The CIM 60 mil and 120 mil systems have an osmotic flow rate within the recommended threshold of 0.0 g/m²/day (± 1.0 g/m²/day with experimental variation).

→ The CIM 60 mil system has an average water absorption of 0.4% by weight over 6 months of testing. The CIM 120 mil system has an average water absorption of 0.2% by weight over 6 months of testing.

This testing provides an indication of the initial performance for the CIM membrane relative to other membranes. This testing does not provide a substitute for the long-term field studies of the actual in-situ performance of the system, nor does it include any of the

[7] Tested with the currently osmosis test procedure: Controls in the osmosis experiment with no membranes (impermeable metal lids) have been measured and that background weight increase has been subtracted from all results.

other material properties which are desirable for a waterproofing membrane. As with other membranes, long-term aging and prolonged exposure to moisture and an alkaline concrete surface may degrade the performance of the membrane, and this may change the vapour permeance and osmosis risk of the membrane over time. We have observed this degradation in many previously tested membranes and it can be significant.

RDH takes no liability in the interpretation of the results, nor any responsibility for use of the tested products. In no way does this letter endorse or recommended use of this or any product or any specific product within a certain application.

We trust that this information is satisfactory, and should you have any questions, please do not hesitate to contact the undersigned.

Yours truly,

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