MOISTURE AND BUILT-UP ROOFING

CARL G. CASH

Simpson Gumpertz & Heger, Inc.
Arlington, Mass.

ABSTRACT

Data in this paper show that the total thermal resistance of a substrate and the moisture content of roofing felts influence the blistering tendency of built-up roofing systems. This study shows that the tendency to blister increases as the total thermal resistance of the substrate and the moisture content of the felts increase.

A tabulation of the equilibrium moisture content (EMC) for many roofing system components defines when these materials are wet, i.e. when they can supply water to surrounding gases or solid materials. The calculated EMC for membranes is compared with the water recovered from laboratory prepared and conditioned roofing membranes.

An empirical equation is presented to estimate the thermal resistance of wet insulations. Comparison of the calculated results with published test data validates the equation within limits that make it suitable for estimating purposes.

An alternative to ASTM test method D95 is proposed to measure moisture in bituminous systems. The preliminary tests show that the alternate method is faster than the current method. It also reduces the laboratory hazards of solvent exposure and fire, has a trap that is self-cleaning when boil-overs take place and uses a lower cost solvent.

Recommendations are made for future work.

Previous work has established that moisture decreases the tensile strength of roofing felt (1, 2, 3)*, and that loss of moisture causes shrinkage of roofing membranes (4). This paper presents previously unpublished data on:

- a possible explanation of the phenomena of blistering of built-up membranes over urethane insulation,
- the equilibrium moisture content of roofing materials,
- a formula for estimating the thermal resistance of wet roofing materials, and
- a new method for measuring moisture in bituminous membranes.

BUILT-UP MEMBRANE BLISTERING

Much discussion and supposition in the literature has been devoted to the higher incidence of blistering in roofing systems that include urethane as compared to systems that are insulated with glass fiber, fiberboard, or perlite board. it has been established that the blistering is due, in part, to moisture in or on the system during application. We tested the relative effects of moisture in the felts in relation to the thermal resistance of the substrate on the tendency of the system to blister.

The test program measured the influence of the total thermal resistance of a substrate and the varying moisture content of organic felts on the boiling of a film of hot steep asphalt:

- The three substrates selected were ⅛-inch-thick plate steel (R = 0), 1-inch-thick perlite board (R = 2.78) and 2-inch-thick urethane foam (R = 11.11). All were dried to constant weight prior to testing. Thus, moisture in the substrate was not a factor in the tests. Thermal resistance, R, is expressed in $h \times ft^2 \times {}^\circ F \times Btu^{-1}$.
- Thirty-six 12″ × 12″, #15 asphalt-organic felts were conditioned to constant weight: 12 each in a desiccator (0.3 mass percent water), at 45 percent RH @ 20C (2.9 mass percent water), and at 90 percent RH @ 20C (6.1 mass percent water).
- A fresh sample of steep asphalt was heated to and maintained at its equiviscous temperature.
- Each conditioned felt square was placed on a level substrate and a uniform quantity of hot asphalt was poured on the felt.
- The mean diameter and the area of the residual craters, or pinholes, in the cooled steep asphalt were measured by two independent observers.

The hot asphalt bubbled as it was poured over the felt. These bubbles broke and left a crater or pinhole. The bubbles in the asphalt over the urethane substrate appeared at once and were up to 5/16 inch (7.9mm) in diameter. The bubbles over the perlite insulation appeared after a short delay and were up to ⅛ inch (3.2mm) in diameter. The craters in the asphalt over the steel substrate were not visible until the asphalt cooled. They were up to 1/16 inch (1.6mm) diameter.

Figure 1 shows a plot of the mean pinhole diameter in the steep asphalt as a function of the thermal resistance of the substrate.

Figure 2 is a table that summarizes the test data and lists the linear regression coefficient (r), the "Y" intercept (α), and the slope (β) of the least squares regression equation.

The data show that the pinholed area, and hence the blistering potential, increases as the total R value of the substrate increases and as the moisture content of the felt increases.

There is no visible effect of changing the nature of the substrate, aside from its thermal resistance. With respect to the area of pinholes produced a 1 percent increase in organic felt moisture content is roughly equivalent to an increase of one unit of substrate thermal resistance.

The increase in pinholing with increasing felt moisture content is an obvious cause-and-effect relationship. The increase in pinholing with increased substrate thermal resistance is less clear. It is probably due to increased time needed to cool the asphalt, thereby concentrating heat in the felt and the quantity of moisture driven off.

A total pinholed area of over three percent may be dangerous to the performance of a built-up membrane. Careful brooming of the felts may avoid blisters when a modest quantity of pinholing or craters are predicted by the moisture in the system and the R value of the substrate. However, no amount of brooming will be effective when the R value and moisture content of the felt are both high.

EQUILIBRIUM MOISTURE CONTENT

All materials absorb and give up water as the ambient relative humidity changes. The quantity of water held after long-term exposure at constant relative humidity is the equilibrium moisture content (EMC) at that specific temperature. When the material contains more water than its EMC, it is wet and may donate water to surrounding air or materials.

Figure 3 lists the EMC at 45 and 90 percent relative humidity (RH) and the moisture capacity for roofing materials currently covered by ASTM standards. Moisture capacity is a relatively new term, and is defined as the mass of water that a material can hold at its 90 percent RH EMC less the water it can hold at 45 percent RH EMC. The number may be useful for some future blistering studies, since substrates with a high moisture capacity are probably less likely to induce blistering than substrates with a low moisture capacity.

The EMC data on roofing membrane components were obtained from laboratory testing and from a round robin conducted by members of ASTM committee D.08. The moisture content found in laboratory prepared membranes (4) was compared with values calculated using the EMC of the felts involved.

Figure 4 compares the calculated data and the actual moisture content. A least squares regression coefficient of 0.98 was calculated. Actual moisture contents always were less than the calculated, showing that the calculated values are conservative. Perhaps I did not wait long enough for my membrane samples to come to moisture equilibrium before testing.

Figure 5 lists the EMC at 45 percent and 90 percent RH, and the moisture capacity of many types of insulation, decking, and other materials. These data were determined in our laboratory on a large number of samples over the last five years.

THERMAL RESISTANCE OF WET MATERIALS

The percent reduction in the thermal resistance (R) of an insulation layer with a high water content can be estimated by the following empirical equation that I hypothesized and tested against measured values from the literature:

$$P=\frac{100}{1+0.00064\,MD}$$

Where:

P = dry thermal resistance, %

M = mass moisture content, %

D = insulation density, pounds per cubic foot

The calculated thermal resistance of four insulating materials at various mass percent moisture contents are shown in Figure 6. In the formula, the wet thermal resistance depends on the density of the insulation as well as its moisture content. Therefore, for a given mass percent water content, heavy materials, such as vermiculite insulating concrete, show a greater change in thermal resistance than low density insulators such as urethane foam.

Two examples compare values calculated using this equation with data obtained from the literature:

Example 1

Given: Vermiculite insulating concrete, 6:1 mix (six volume parts of aggregate to one volume part of cement), 90 percent mass water (M), 25 pounds per cubic foot dry density (D), 0.11 dry thermal conductance (C).

$$P=\frac{100}{1+0.00064\,MD}=\frac{100}{1+.00064\times 90\times 25}=41\%$$

The estimated wet thermal resistance is:

$$R=\frac{1}{C}\times\frac{P}{100}=\frac{1}{0.11}\times\frac{41}{100}=3.73\ \mathrm{h}\times\mathrm{ft}^2\times{}^\circ\mathrm{F}\times\mathrm{Btu}^{-1}$$

In addition to reducing the strength of the roofing membrane, water also reduces the thermal resistance of the vermiculite concrete by 59 percent.

Example 2

Given: 0.27 dry thermal conductance of $^{15}/_{16}$ inch thick rigid glass fiber insulation with 5 percent of water added (M) and a density of 12.8 pounds per cubic foot (D).

$$P=\frac{100}{1+.00064\,MD}=\frac{100}{1+.00064\times 5\times 12.8}=96\%$$

This estimate is 5 percentage points lower than a measured value of 91 obtained from the literature (5). This difference is insignificant, since it represents less than one unit of thermal resistance ($0.05\times\frac{1}{0.27}=0.2\mathrm{h}\times\mathrm{ft}^2\times{}^\circ\mathrm{F}\times\mathrm{Btu}^{-1}$).

Figure 7 shows the dry insulation thermal resistance, the wet thermal resistance calculated with the proposed formula and the wet thermal resistance taken from data reported by Tobiasson & Ricard (6).

The least squares regression coefficient for the paired data is 0.99, which is good considering the variety of insulatipns and moisture exposure conditions used in the study.

The results obtained using this equation are very conservative. The actual thermal resistance of wet insulation can be expected to differ from the value calculated, but the equation seems a valid estimate for moisture contents in the 0 to 150 percent mass percent range checked.

MEASURING MOISTURE IN BITUMINOUS SYSTEMS

ASTM D95 is the most frequently used method for determining the moisture content in built-up roofing membranes and other bituminous materials and is the only method currently approved by ASTM Committee D08.

The method detailed in D95 involves mixing a weighed quantity of the specimen in a water-free solvent such as xylene and distilling the mixture. Water from the mixture separates by gravity in a special calibrated trap, and the quantity of water is read directly at the bottom of the trap.

This method has several drawbacks: the use of a flammable solvent, relatively long distillation time, and cleaning difficulties when very wet samples boil over into the trap.

Figure 8 lists some properties of industrial solvents that might be used in the ASTM D95 method. Only 1,1,1 trichloroethane has no flash point and does not burn. In addition, it has a lower boiling point than the solvents typically used and is less toxic than any of the solvents on the list.

However, 1,1,1 trichloroethane's density is 1.35 Mg/m^3. Consequently water separated from the solvent-water mixture will float to the top of trap currently being used and run back into the refluxing flask. To solve this problem, we designed a new trap *(Figure 9)* with a return to the refluxing flask from the bottom of the trap rather than from the top of the trap, as currently used.

This new trap meets all the requirements for moisture recovery tests outlined in ASTM D95. Tests take less than half the time usually required—the hazards of solvent exposure and flammability are reduced. In addition, the new trap is self-cleaning in case of boil-overs, and 1,1,1 trichloroethane reclaimed from the dry cleaning industry costs less than the solvents usually used.

SUMMARY

The studies show:

- The blistering observed in insulating roofing systems is partly influenced by the thermal resistance of the substrate and partly by the moisture content of the felts.
- The equilibrium moisture content data on many roofing system components are listed as an aid in determining when materials are "dry" (contain less water than the 45 percent RH EMC); "moist" (contain more water than the 45 percent RH EMC, but less water than the 90 percent RH EMC); and "wet" (contain more water than the 90 percent RH EMC).
- An empirical method of reasonably accurately estimating the thermal resistance of wet insulation materials is presented.
- A new trap for ASTM D95 and the use of 1,1,1 trichloroethane reduces the time needed for moisture determinations; reduces the solvent and fire hazards in the laboratory; results in a self-cleaning trap; and is more economical than current methods.

FUTURE STUDIES

These data suggest the following future studies:

- Determine the blistering potential of various common roof insulations with varying substrate water content, but with constant thermal resistance.
- Determine the equilibrium moisture content of roofing system materials not yet tested, such as elastomeric and modified bitumen sheets and insulations.
- Refine the accuracy of the empirical equation to improve the accuracy of calculating the thermal resistance of water containing materials.
- Publish a proposed revision of ASTM D95 so that all concerned may review and test this new alternative method as soon as the new trap design becomes commercially available.

ACKNOWLEDGEMENT

These studies were supported by the Principals and Associates of Simpson Gumpertz & Heger Inc. as in-house research.

REFERENCES

[1] Laaly, H. O., "Effect of Moisture on the Strength Characteristics of Built-up Roofing Felts", *Roofing Systems,* ASTM STP 603, 1976 pp 104-113.

[2] Schwartz, T. A. and C. G. Cash, "Equilibrium Moisture Content of Roofing and Roof Insulation Materials and the Effect of Moisture on the Tensile Strength of Roofing Felts," *Proceedings of the Symposium of Roofing Technology,* NBS/NRCA 1977, pp 238-243.

[3] Laaly, H. O., "Effects of Moisture and Freeze-Thaw Cycles on the Strength of Bituminous Built-up Roofing Membrane," *Proceedings of the Symposium of Roofing Technology,* NBS/NRCA 1977, pp 244-251.

[4] Cash, C. G., "Low Temperature Shrinkage of Built-up Roofing Membranes Due to Moisture Loss," *Second International Symposium on Roofs and Roofing* Soc. of Chem. Ind., London, 1981, Vol. 1, pp 573-584.

[5] Dechow, F. J. and K. A. Epstein, "Laboratory and Field Investigations of Moisture Absorption and its Effect on the Thermal Performance of Various Insulations," *Thermal Transmission Measurements of Insulation,* STP 660, R.P. Tye, Ed., ASTM 1978, pp 234-260.

[6] Tobiasson, W. and J. Ricard, "Moisture Gain and Its Thermal Consequences for Common Roof Insulations," *Proceedings of the 5th Conference on Roofing Technology* NBS/NRCA 1979, pp 4-16.

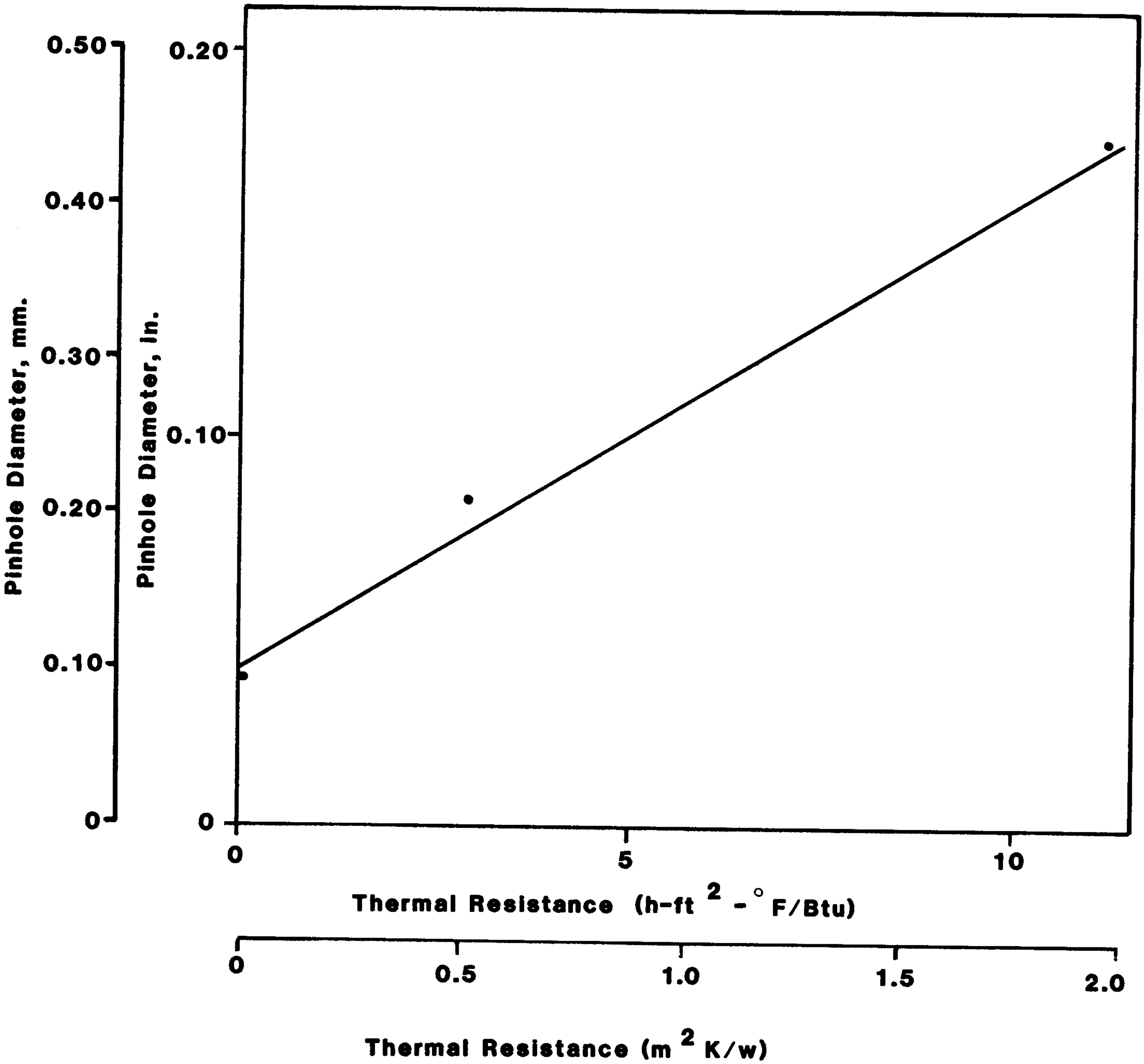

Figure 1 *Mean steep asphalt pinhole diameter vs. substrate thermal resistance*

SUBSTRATE			MASS % WATER IN FELT						
TYPE	$\frac{m^2 K}{W}$	$\frac{h \cdot ft^2 \cdot {}^{\circ}F}{Btu}$	0.3	2.9	6.1	n	r	α	β
			% AREA OF PINHOLES IN ASPHALT						
Steel	6.3×10^{-6}	3.6×10^{-5}	0.068	0.149	0.680	12	.94	-.04	0.108
Perlite	0.49	2.78	0.326	3.189	8.285	12	.995	-.35	1.381
Urethane	1.96	11.11	1.456	15.805	23.756	12	.98	1.913	3.793
		n	12	12	12	36			
		r	.998	.998	.996				.995
		α	.027	-.256	1.525				.270
		β	.127	1.434	2.026		.96	.197	.322

Figure 2 % pinholed area in asphalt on organic felts on three substrates

ASTM Designation		Common Name	Dry Mass		EMC, Mass % @ 20°C		Moisture Capacity *	
			g/m²	lb/100 ft²	45% RH	90% RH	g/m²	lb/100 ft²
D173		Saturated Cotton	340	7	3.7	5.5	6.1	0.13
D224	(1)	Smooth Roll Roofing	1943	40	1.4	2.7	25.3	0.52
	(2)		2666	55	2.0	3.8	48.0	0.99
D225		Asphalt-Organic Shingles	4638	95	1.2	2.4	55.7	1.14
D226	(1)	#15 Asphalt-Organic Felt	635	13	4.3	8.2	24.8	0.51
	(2)	#30 " " "	1270	26	4.1	7.9	48.3	0.99
	(3)	#20 " " "	830	17	4.3	8.2	32.4	0.66
D227		Coal-Tar Organic Felt	635	13	4.3	8.2	24.8	0.51
D249		90# Roll Roofing	3610	74	1.5	2.8	46.9	0.96
D250	(1)	#15 Asphalt Asbestos Felt	630	13	1.7	2.7	6.3	0.13
	(2)	#30 " " "	1370	28	1.6	2.6	13.7	0.28
	(3)	#20 " " "	830	17	1.7	2.7	8.3	0.17
	(4)	#25 " " "	1030	21	1.8	2.8	10.3	0.21
D371	(1)	#45 Wide Selvage	1806	37	1.7	3.2	27.1	0.56
	(2)	#55 " "	2260	46	2.1	4.0	42.9	0.87
D1327		Saturated Burlap	330	7.7	14.8	23.4	0.50	
D1668	(1)	Asphalt-Glass Fabric	65	1.3	1.4	1.6	0.13	<.01
	(2)	Coal-Tar Glass Fabric	69	1.4	1.3	1.5	0.14	<.01
	(3)	Resin-Glass Fabric	50	1.0	1.8	2.1	0.15	<.01
D2178	(1)	Utility Glass Felt	356	7	0.5	0.6	0.36	0.01
	(3)	Standard Glass Felt	474	10	0.6	0.7	0.47	0.01
	(4)	Heavy Duty Glass Felt	342	7	0.9	1.1	0.68	0.01
	(5)	Comb. Base Sheet	713	15	0.6	1.1	3.6	0.08
D2626		Asphalt Coated Organic Base Sheet	1806	37	1.5	2.9	25.3	0.52
D3158		Asphalt Coated Organic Ply Sheet	1420	29	1.9	3.7	25.6	0.52
D3378	(1)	Asphalt Coated Asbestos Base Sheet	1810	37	0.6	0.9	5.4	0.11
	(2)		1900	39	0.7	1.2	9.5	0.20
D3462		Glass Felt Shingles	3564	73	0.1	0.1	0.42	0.01
D3672	(1)	Asbestos Venting Felt	2930	60	0.4	0.6	5.9	0.12
	(2)	Glass Venting Felt	2440	50	0.1	0.1	0.24	<.01
D3909		90# (Glass Felt)	3085	63	0.1	0.1	0.59	0.01

*Mass of moisture at 90% RH less mass of moisture at 45% RH

Figure 3 Equilibrium moisture content—roofing material

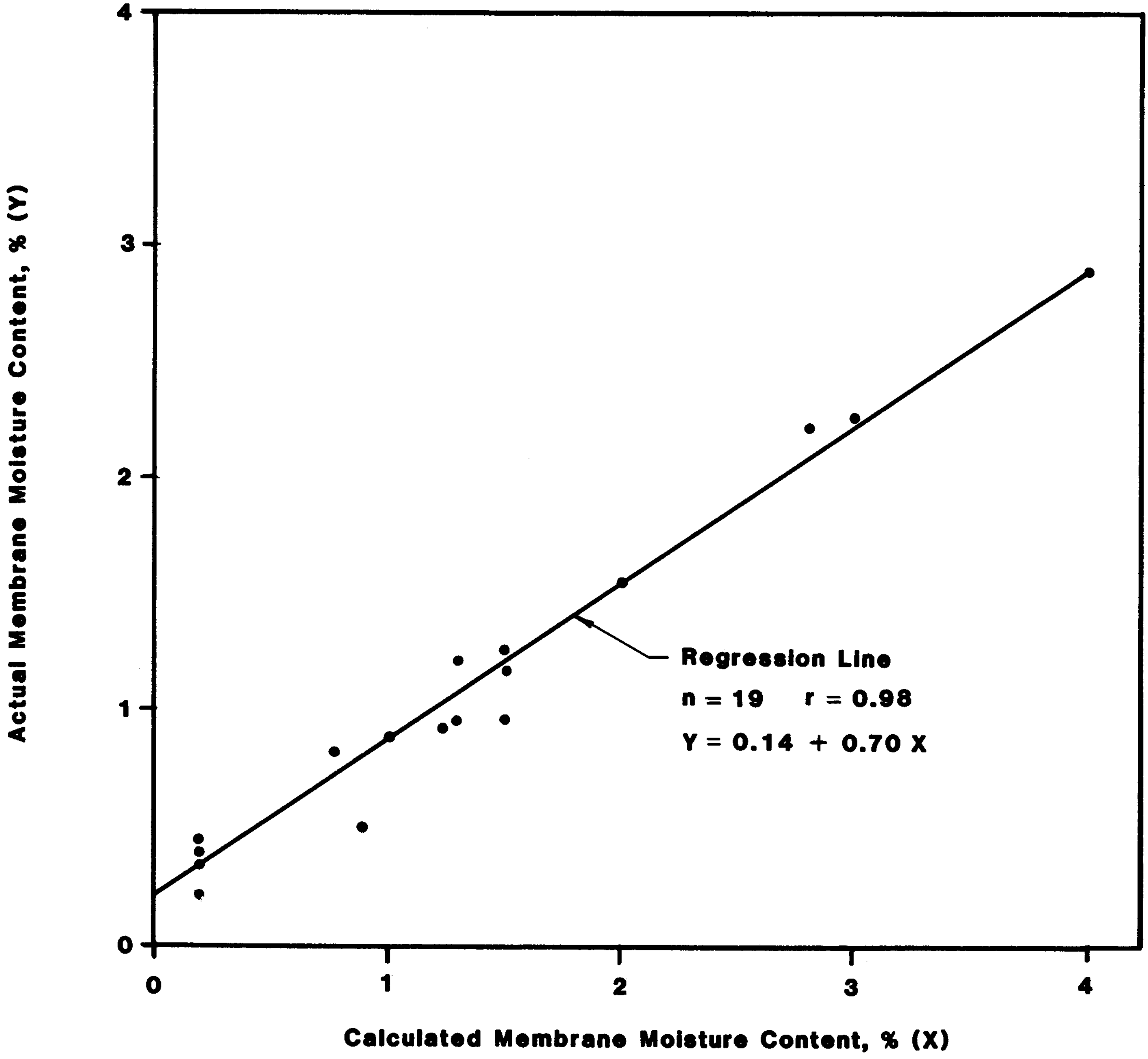

Figure 4 *Built-up roofing membrane moisture content vs. calculated moisture content*

Common Name	Thickness mm	Thickness in.	Density kg/m³	Density pcf	EMC, Mass % @ 20°C 45%RH	EMC, Mass % @ 20°C 90%RH	Moisture Capacity kg/m³	Moisture Capacity pcf
HOMOGENIOUS INSULATIONS (without facer sheets):								
Fiberboard	-	-	256	16	5.4	15.	24.7	1.54
Glass Fiber Board	-	-	107	6.7	0.6	1.1	0.5	0.03
Glass Foam Board	-	-	133	8.3	0.15	0.2	.2	0.01
Isocyanurate Foam	-	-	48	3	1.4	3.0	0.8	<.01
Perlite Board	-	-	176	11	1.7	5.0	5.8	0.36
Phenolic Foam	-	-	*32	*2	6.4	23.4	0.5	0.34
Polystyrene - Beadboard	-	-	16	1	1.9	2.0	<0.1	< 0.01
Extruded	-	-	34	2.1	0.5	0.8	0.1	0.01
Urethane Foam			27	1.7	2.0	6.0	1.1	0.07

FACED INSULATIONS:

Common Name	Thickness mm	Thickness in.	Mass/unit area kg/m²	Mass/unit area pps	EMC, Mass % @ 20°C 45%RH	EMC, Mass % @ 20°C 90%RH	Moisture Capacity g/m²	Moisture Capacity pps
Glass Fiberboard	24	15/16	4.9	100	0.4	0.5	4.9	0.10
	35	1-3/8	5.5	113	0.4	0.8	22.0	0.45
	43	1-11/16	7.7	158	0.4	0.60	15.6	0.32
Isocyanurate Foam	30	1-3/16	2.4	50	1.1	2.9	43.9	0.90
Perlite - Urethane Composit:								
(Per. - Ureth.)	41	1-5/8	5.2	107	1.6	4.2	134.	2.74
(Per. - Ureth.)	44	1-3/4	5.5	112	1.6	4.1	137.	2.80
(Per. - Ureth.)	70	2-3/4	5.5	112	1.8	9.8	437.	8.96
(Per. - Ureth. - Per.)	73	2-7/8	8.8	180	1.5	4.1	228.	4.68
(Per. - Ureth.)	76	3	5.9	120	1.3	3.9	152.	3.12
Urethane Foam	25	1	1.9	38	2.4	5.8	63.	1.29
	27	1-1/16	2.9	60	1.8	5.3	103.	2.10
	30	1-3/16	2.5	52	1.9	4.8	74.	1.51
	60	2-3/8	3.8	78	1.4	2.6	46.	0.94

DECK & MISCELLANEOUS MATERIALS

Common Name	Thickness mm	Thickness in.	Density kg/m³	Density pcf	EMC, Mass % @ 20°C 45%RH	EMC, Mass % @ 20°C 90%RH	Moisture Capacity kg/m³	Moisture Capacity pcf
Asphalt - Perlite	-	-	400	25	0.3	0.4	0.3	0.02
Gypsum (with wood)	-	-	-	-	0.6	1.7	-	-
" (without wood)	-	-	-	-	0.4	0.6	-	-
Kraft Paper	-	-	-	-	3	6	-	-
Sheathing Paper	-	-	-	-	7	8	-	-
Vermiculite Concrete	-	-	416	26	2.6	6.6	16.7	1.04
Wood (HEM - FIR)	-	-	-	-	7.5	17	-	-

pps = pounds per 100 square feet.
* = without facer sheets

gure 5 *Equilibrium moisture content—insulation materials*

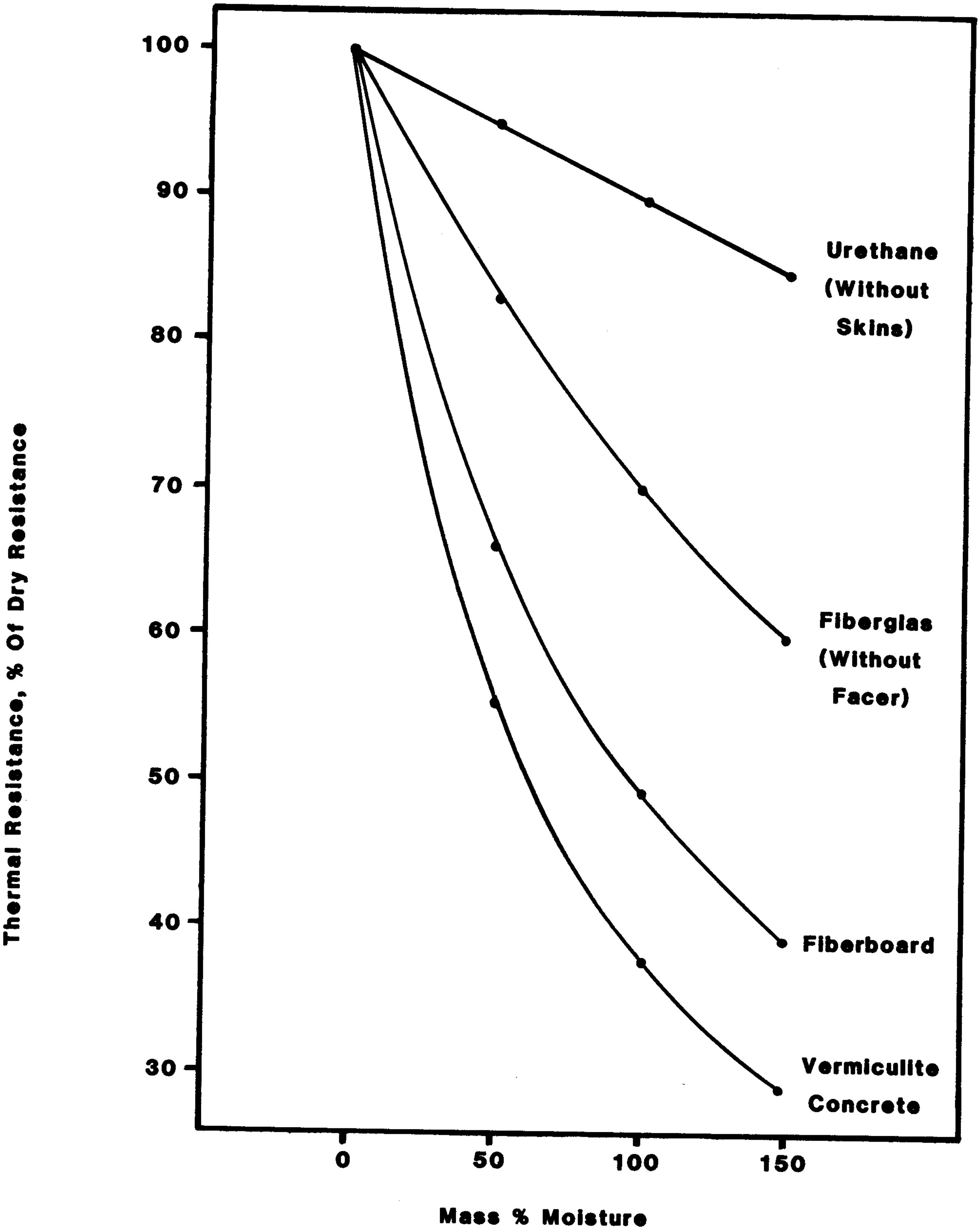

Figure 6 *Thermal resistance of wet insulations as a percent of the dry thermal resistance for 0 to 150 mass percent moisture content*

Mass % Water:	0 (dry)	50		100		150	
	Thermal Resistance $R = h \times ft^2 \times {}^{\circ}F \times Btu^{-1}$						
Insulation Type	Actual	Calc.	Actual	Calc.	Actual	Calc.	Actual
Cork	2.6	1.7	2.0	1.3	1.6	1.0	1.4
Fiber board	2.6	1.6	1.9	1.2	1.4	1.0	1.2
Perlite board	2.6	2.0	1.8	1.6	1.5	1.3	1.3
Glass Foam	4.4	4.3	4.2	4.2	4.0	4.1	3.9
Glass fiber	3.4	2.5	2.2	2.0	1.5	1.6	1.1
Polystyrene bead board	3.7	2.9	3.3	2.3	3.0	2.0	2.4
Extruded polystyrene	10.8	10.7	10.3	10.5	9.9	10.4	9.7
Urethane	5.5	4.7	4.6	4.1	3.8	3.7	3.1
Glass reinforced urethane	6.2	5.1	5.2	4.4	4.3	3.8	3.5
Perlite - urethane	8.2	6.4	6.7	5.6	6.2	4.8	5.8
Glass reinforced isocyanurate	6.5	4.9	4.0	3.9	2.7	3.2	2.0
Glass reinforced isocyanurate	14.1	11.4	10.8	9.6	9.3	8.2	8.3

Figure 7 Thermal resistance of dry insulation, and the calculated and measured thermal resistance of insulations with 50, 100, and 150 mass percent water content

Solvent	Boiling Point		Density	TLV*	Flash Point	
	°C	°F	Mg/m³	ppm	°C	°F
Naphtha, petroleum	50	122	0.60	10	-48	-55
1,1,1 trichloroethane	74	165	1.35	350	none	
Benzene	81	178	0.88	10	-11	12
Toluene	111	231	0.87	200	4	40
p-Xylene	138	280	0.86	100	27	81
m-Xylene	139	283	0.87	100	29	85
o-Xylene	144	291	0.90	100	46	115
Naphtha, coal-tar	190	374	0.88	100	-38	-36

*TLV = Threshold limit value, constant exposure. This is the estimated exposure concentration that is believed to be harmless.

ppm = parts per million

Figure 8 Properties of industrial solvents

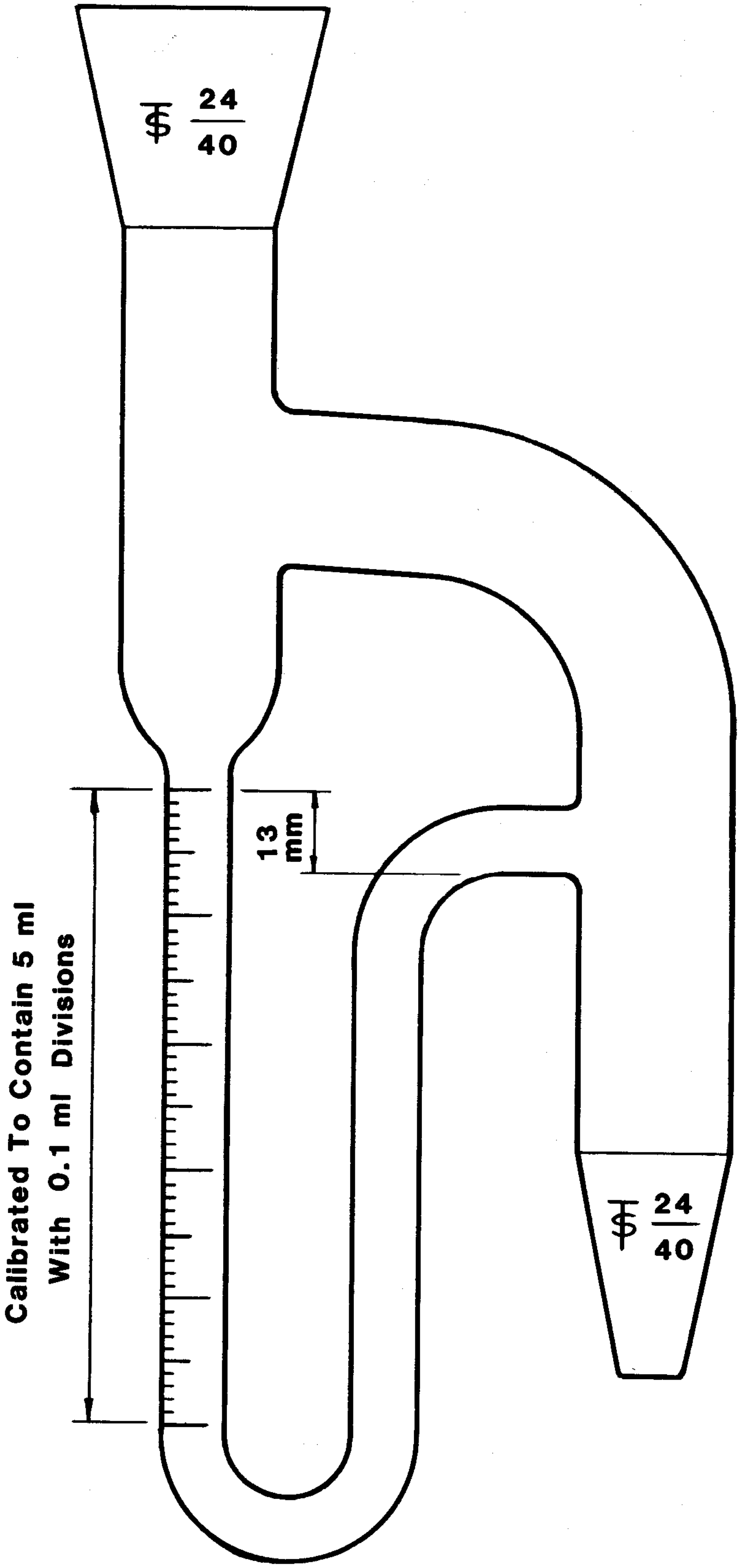

Figure 9 *Modified Dean-Stark trap material-pyrex*