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Corrosiveness Testing of Thermal Insulating Materials — A Simulated Field Exposure Study Using a Test Wall

K. Sheppard
R. Weil
A. Desjarlais

Part of
The National Program for
Building Thermal Envelope Systems
and Materials

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CORROSIVENESS TESTING OF THERMAL INSULATING MATERIALS – A SIMULATED FIELD EXPOSURE STUDY USING A TEST WALL

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FOREWORD

This is one of a series of reports to be published describing research, development, and demonstration activities in support of the National Program for Building Thermal Envelope Systems and Materials. The National Program involves several federal agencies and many other organizations in the public and private sectors who are addressing the national objective of decreasing energy wastes in the heating and cooling of buildings. Results described in this report are part of the National Program through delegation of management responsibilities for the DOE lead role to the Oak Ridge National Laboratory.

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BTESM REPORTS

B. MATERIALS

1. ORNL/SUB-7556/I: *Assessment of the Corrosiveness of Cellulosic Insulating Materials* (June 1979).

2. ORNL/SUB-7504/3: *Recessed Light Fixture Test Facility* (July 1979).

3. ORNL/SUB-7559/I: *Problems Associated with the Use of Urea-Formaldehyde Foam for Residential Insulation* (September 1979).

4. ORNL/Sub-7551/I: *Interim Progress Report on an Investigation of Energy Transport in Porous Insulator Systems* (October 1979).

5. ORNL/TM-6494: *A Technique for Measuring the Apparent Conductivity of Flat Insulations* (October 1979).

6. ORNL/Sub-79/13660/I: *Minnesota Retrofit Insulation In-Situ Test Program Extension and Review* (February 1980).

7. ORNL/TM-7266: *An Experimental Study of Thermal Resistance Values (R-Values) of Low-Density Mineral-Fiber Building Insulation Batts Commercially Available in 1977* (April 1980).

8. ORNL/Sub-7686/I: *Smoldering Combustion Hazards of Thermal Insulation Materials* (July 1980).

9. NBSIR 80-2085: *Fire Performance of Loose-Fill Cellulosic Insulation in Residential Occupancies* (August 1980).

10. ORNL/Sub-7556/2: *Corrosion Testing of Urea-Formaldehyde Foam Insulating Materials* (September 1980).

11. NBSIR 80-2129: *Modeling for Determination of Temperatures of Electrical Cables Within Thermally Insulated Walls* (October 1980).

12. DOE/CS-0192: *Insulation Fact Sheet*

13. NBSIR 80-2091: *Precision Measurements on Fibrous Glass Insulation* (November 1980).

14. ORNL/Sub-7715/1: *Operating Temperatures for a Convectively Cooled Recessed Incandescent Light Fixture* (December 1980).

15. ORNL/TM-7481: *Analysis of Heat Transfer in Building Thermal Insulations* (December 1980).

16. ORNL/Sub-7559/2: *Problems Associated with the Use of Urea-Formaldehyde Foam for Residential Insulation. Part II: The Effects of Temperature and Humidity on Free Formaldehyde, Extractable Formaldehyde, Formaldehyde Emission and Physical Characteristics of the Foam* (February 1981).

17. ORNL/Sub-7559/3: *Problems Associated with the Use of Urea-Formaldehyde Foam for Residential Insulation: Part III: Residential Studies in Colorado and Wisconsin* (February 1981).

18. ORNL/Sub-7559/4: *Problems Associated with the Use of Urea-Formaldehyde Foam for Residential Insulation. Part IV: The Relevance of Materials Standards to Problems Associated with the Use of Urea-Formaldehyde Foam Insulation* (February 1981).

19. NBSIR 81-1639: *Effective Thermal Conductivity of a Glass Fiberboard Standard Reference Material* (February 1981).

20. NBSIR 81-1640: *Effective Thermal Conductivity of a Glass Fiberblanket Standard Reference Material* (February 1981).

21. ORNL/Sub-7715/2: *Reduction in The Thermal Resistance (R-Value) of Loose-Fill Insulation and Fiberglass Batts Due to Compression* (April 1981).

22. ORNL/Sub-7715/3: *The Effect of Vibrations on the Density of Loose-Fill Insulations* (May 1981).

23. ORNL/Sub-7715/4: *Operating Temperatures of Recessed Fluorescent Fixtures with Thermal Insulation* (May 1981).

24. ORNL/Sub-78/86993/1: *Performance Characteristics of Foamed-In-Place Urea Formaldehyde Insulation* (June 1981).

25. NBSIR 81-2350: *Smoldering Combustion Hazards of Thermal Insulation Materials* (August 1981).

26. NBSIR 81-1657: *A Guarded-Hot-Plate Apparatus for Measuring Effective Thermal Conductivity of Insulations Between 80 K and 360 K* (January 1982).

27. ORNL/TM-6433: *Properties and Testing of Loose-Fill Cellulosic Insulation* (February 1982).

28. ORNL-CON-93: *On the Occurrence of Fungi in Loose-Fill Attic Insulation in Typical Single-Family Dwellings* (May 1982).

29. ORNL/Sub-7551/2: *Energy Transport in Porous Insulator Systems II. Performance of Vertical Enclosures* (August 1982).

30. ORNL-5825: *Investigation of Attic Insulation Effectiveness Using Actual Energy Consumption Data* (September 1982).

31. NBSIR 83-2674: *Error Analysis for the National Bureau of Standards 1016 mm Guarded Hot Plate* (April 1983).

32. ORNL/tr-4932: *Thermal Conductivity Measurements with the Plate Apparatus: Influence of the Guard Ring Width on the Accuracy of Measurement* (May 1983).

33. ORNL/TM-8891: *Assessment of Reflective Insulations for Residential and Commercial Applications* (October 1983).

34. ORNL/Sub-7559/5: *Problems Associated with the Use of Urea-Formaldehyde Foam for Residential Insulation - Part V: Effects of UFFI Additives on Formaldehyde Emission and Physical Characteristics of the Foam* (December 1983).

35. ORNL/Sub-7863/1: *Investigation of the Fire Performance of Building Insulation in Full-Scale and Laboratory Fire Test* (April 1984).

36. ORNL/Sub-7556/3: *Corrosiveness Testing of Thermal Insulating Materials* (May 1984).

37. ORNL/CON-159: *Development of Advanced Insulation for Appliances* (July 1984).

38. NBSIR 84-2917: *Environmental Cycling of Cellulosic Thermal Insulation and Its Influence on Fire Performance* (August 1984).

39. NBSIR 84-2906: *Thickness Effect in Low-Density Insulation* (August 1984).

40. NBS Technical Note 1210: *Urea-Formaldehyde Foam Insulations: A Review of Their Properties and Performance* (March 1985).

41. NBSIR 85-3026: *Round Robins on the Apparent Thermal Conductivity of Low-Density Glass Fiber Insulations Using Guarded Hot Plate and Heat Flow Meter Apparatus* (May 1985).

42. NBSIR 85-3146: *An Assessment of Needs for New Thermal Reference Materials and Recommended Research* (July 1985).

43. ORNL/IA-21428/1: *Specific Heat and Composition of SRM 1450 and CTS Insulations.*

44. ORNL/Sub-43366/1: *Analysis of Transient Behavior and Radiation Measurements of Commercial Thermal Insulation* (August 1985).

45. NBS Special Publication 260-98: *Standard Reference Materials: Glass Fiberboard SRM for Thermal Resistance* (August 1985).

46. NBSIR 85-3221: *An Assessment of the NBS 1-m Guarded Hot Plate Limits* (August 1985).

47. NBS Special Publication 260-103: *Standard Reference Materials: Glass Fiberblanket SRM for Thermal Resistance* (September 1985).

48. NBSIR 85-3212: *Forced Smolder Propagation and the Transition to Flaming in Cellulosic Insulation* (October 1985).

49. ORNL/Sub-89634/1: *Radiative Heat Transfer Under Transient Conditions* (October 1985).

50. ORNL/TM-9927: *Thicknesses, Densities, and Calculated Thermal Resistances for Loose-Fill Rock Wool Installed in Two Attic Sections of a Manufactured House* (February 1986).

51. ORNL/Sub-9009/1: *Effective Conductivity of Aging Polyurethane Foam* (March 1986).

52. ORNL/Sub-97333/1: *Building Materials Research Agenda* (April 1986)

53. ORNL/Sub-19712/1: *High Temperature Calorimeter Performance Variable Study* (April 1986).

54. CON-199: *Development of Advanced Thermal Insulation for Appliances, Progress Report for the Period* (May 1986).

55. ORNL/Sub-43366/2: *Transient Heat Transfer Analysis and Radiative Properties Measurements of Porous Thermal Insulation* (May 1986).

56. NBSIR 86-3326: *Magnesium Oxychloride Cement-Based Foam Insulation: A Review of Available Information and Identification of Research Need* (June 1986).

57. ORNL/Sub-9009/2: *Aging of Polyurethane Foams, The Influence of Gas Diffusion on Thermal Conductivity* (August 1986)

58. ORNL/Sub-22016/1: *Investigation of Dynamic Latent Heat Storage Effects of Building Construction and Furnishing Materials* (August 1986).

59. ORNL/CON-215: *The Thermal Resistance of Perlite Based Evacuated Insulations for Refrigerators* (September 1986).

60. DOE/CE-0180: *Insulation Fact Sheet* (May 1987).

61. ORNL/TM-10414: *Thickness and Density Measurements for Attic Loose-Fill Thermal Insulation in Eight Cities* (August 1987).

62. ORNL/Sub-86/56525/1: *Assessment of Foam-In-Place Urethane Foam Insulations Used in Buildings* (October 1987).

63. NBSIR 87-3642: *An Initial Investigation of the Properties and Performance of Magnesium Oxychloride Based Foam Thermal Insulations* (December 1987).

64. ORNL/Sub-55930/1: *Determination of Radiative Properties of Fiberglass and Foam Insulations* (December 1987).

65. ORNL/Sub-27494/1: *Calculational Model Development for Fibrous Thermal Insulation Transient Test Procedure* (February 1988).

66. NBSIR 87-3670: *Review of Autoclaved Aerated Concrete Products* (June 1988).

67. ORNL/Sub-84/89634/1: *Steady State Radiative Heat Transfer Through Insulations* (August 1988).

68. ORNL/Sub-7715/6: *Thermal Resistance of Wall Cavities Containing Reflective Insulation* (August 1988).

ABSTRACT

The corrosiveness of various residential thermal insulation materials was tested under simulated field conditions in a test wall structure. The test was conducted under controlled conditions typical of winter in the absence of a vapor barrier to create relatively severe moisture transport and possible condensation. The house-wall simulation was achieved by constructing a test panel containing 50 compartments into which various insulation materials were installed. The panel was located in an environmental chamber. The test samples included various cellulosic, glass fiber and rockwool insulations as well as sterile cotton as a control. Steel and copper coupons together with water-cooled copper pipes were embedded in the insulation and exposed for 6 months. It was found that moisture absorption by the insulation was the primary factor in causing corrosion but required that chemical activity from insulation components also be present. No corrosion occurred in the absence of insulation or in rockwool and glassfiber insulation. All cellulose insulations caused some corrosion. Mostly this was minimal but in a few cases severe pitting resulted. Such behavior of the cellulose did not correspond to previous laboratory test results in saturated insulation or leachants made from the insulation. However, laboratory testing of leachants made from some of the cellulose after the simulated wall test showed a change in pitting tendency, suggesting that time and/or exposure to moisture can change the corrosiveness. This should be further explored.

INTRODUCTION

A task group of ASTM Subcommittee C16.31 has been developing a uniform corrosiveness test procedure that would be applicable to all types of residential insulation. To support their efforts, data have been obtained and provided to the task group by Stevens Institute of Technology under sponsorship of the Department of Energy through Oak Ridge National Laboratory. Some results of this work have been previously reported [1-5]. Appendix I gives the existing standards for corrosiveness testing.

It is clearly desirable that any new laboratory test procedure produce results that reflect the corrosiveness of thermal insulation under service conditions. It is also desirable to be able to discriminate between corrosiveness and corrosion. It is possible for the latter to occur even with an inert insulation material because of the insulation's ability to trap or draw moisture to a metallic surface without taking part in aggravating the corrosion that could subsequently occur. One major weakness of existing test procedures is that they were developed without the benefit of field performance data. The reason for this is the almost complete absence of published field performance data on the corrosiveness of residential insulation. The few published field studies [6,7] containing data on corrosion were not specifically designed to investigate corrosion. The investigators did not deliberately examine metal components in the buildings under study;

in fact, generally such locations were avoided. One of the reports [7], in fact, called for "a more rigorous examination of the potential for corrosion." The availability of reliable field data has been limited by the cost and difficulty associated with gaining access to metal components in the walls of houses and by problems with obtaining adequate environmental histories at each location. Some limited field testing in attics of residential buildings at various geographical locations was previously carried out [3], but no significant corrosion was found.

Corrosion requires the presence of moisture. House wall cavities are more probable sites for moisture accumulation, that could potentially lead to corrosion, than are attics. Aside from leakage, e.g., from bathrooms, condensation is possible under severe conditions when a vapor barrier is not present or is compromised. The presence of cold-water pipes can also cause condensation of moisture.

BACKGROUND

One of the field studies previously mentioned [6] found that 12.5% of a sample of 96 houses had suffered water leakage into the wall cavity. This figure does not include numerous other leaks that were found but not further investigated by opening the wall. Clearly, leakage is an important source of moisture and the potential for corrosion cannot be ignored; however, the present work concentrates on moisture originating from condensation. In the previously cited study the authors calculated that on average over the winter of their study the opportunity for condensation existed from 40% to 80% of the time in insulated walls.

Wang [8] has reported that in two test houses studied during a winter in Michigan that condensation occurred in the wall cavity. Outdoor conditions were 0-7°C, indoor conditions 21-24°C. The condensation occurred with both medium (30-35% RH) and high (50-55% RH) interior humidity settings. At the medium humidity value a Kraft paper vapor barrier prevented condensation but did not at the high humidity value. However, it should be noted that Wang also reports that field inspections of over 70 houses in the US and Canada having a variety of constructions, insulations, vapor barriers, sidings, etc. did not reveal evidence of condensation.

It is against this background that a simulation was constructed to determine the potential corrosiveness of various residential thermal insulation materials under relatively severe conditions, conducive to moisture transport and possibly condensation, that might be experienced by an insulated house wall cavity without a vapor barrier during a winter condition.

EXPERIMENTAL

The house-wall simulation was achieved by constructing a test

panel containing 50 compartments into which various insulation materials were installed. The panel was located in an environmental chamber. The chamber was constructed such that the environmental conditions (temperature and relative humidity) on both sides of the test panel could be independently controlled. The panel was conditioned for 190 days (this being a nominal 6-month period) with the environmental conditions maintained at approximately 22°C and 45% relative humidity on the interior (hot) side and 3°C and 95% relative humidity on the exterior (cold) side. This would be expected to produce a vapor pressure differential of 6.19 mm of Hg (0.12 psi). These conditions, although relatively severe in terms of vapor pressure drop, are within those to be expected during a winter in the USA (see, for example, the study by Wang [8] cited above).

Test Panel Configuration

The test panel used in this program was dimensioned 210 cm long by 150 cm high by 11.5 cm thick and was constructed with standard 2 by 4 studs around the perimeter of the test panel and 1.25 cm thick gypsum board sheathing to represent the interior side of the wall. The exterior side was sheathed with two different products; 1.25 cm thick plywood and 1.25 cm thick aluminum foil-faced polyisocyanurate foam board. The left half (Cells 1-4, 11-15, 21-25, 31-35, and 41-45) of the test panel was sheathed with plywood while the right half (all remaining cells) of the test panel was sheathed with the foam board. The purpose of using two different sheathings was to demonstrate the effect of the water vapor permeability of the exterior sheathing on the potential for corrosion. The panel was designed such that there would as far as possible be pairs of cells with identical insulation materials with the only variable being the sheathing material. The panel was mounted vertically.

The interior of the test panel was divided into fifty (50) identically sized cells laid out in an array 10 cells wide by 5 cells high. The cells were numbered 1 through 50 with Cell 1 being the upper left corner, Cell 10 the upper right corner, and Cell 50 the lower right corner when viewed from the interior side. The walls of the cells were fabricated from 1.25 cm thick extruded polystyrene foam glued with silicone cement to seal the cells from each other. The resulting cell size was 29 cm high, 20 cm wide and 9 cm deep.

The insulation materials employed in the test were identified as Cellulose #1, Cellulose #2, Cellulose #3, Cellulose #4, Cellulose #6, Cellulose #527G, Rockwool, Glassfiber B, Glassfiber O, Glassfiber T, and sterile cotton wool as a control. For this test no degreasing was used on the cotton. The presence of natural oils in the cotton may have resulted in less moisture absorbtion and thus possibly reduced corrosion compared to degreased cotton. However, the choice of cotton, whether degreased or not, as an inert control is arbitrary. In previous tests at Stevens Institute [3] Celluloses 1, 2, 3, 4, and 6 all passed the federally mandated HH-I-515D corrosiveness test which is

equivalent to that in ASTM C739 Specification for Cellulosic Fiber (Wood-Base) Loose-Fill Thermal Insulation. Cellulose 527G failed this test. No ASTM C665 (Standard Specification for Mineral-Fiber Blanket Thermal Insulation For Light Frame Construction And Manufactured Housing) standard corrosiveness test data were available to us for the glassfiber and rockwool insulations, but in various other corrosiveness tests at Stevens, Rockwool and Glassfiber B produced low corrosion levels, less than a distilled water control [3]. Glassfiber O and T were not part of those tests and were purchased from retail outlets. The other insulations were supplied by the manufacturers. More information on these materials is given in Table 1. In addition, some cells were left without insulation. Figure 1 details which insulating materials were installed in each cell. The loose-fill materials were applied based on manufacturers' values for applied density as shown in Table 2. Applied densities rather than settled densities were used because the former had been specified by the ASTM C16.31 Corrosiveness Task Group for the laboratory testing at Stevens and we wished to maintain consistency. It might be anticipated that some small differences in moisture absorption within each cell might have resulted if settled rather than applied densities had been used. The batt materials were cut to size and placed into the cells. To the extent possible, it was desired to test all of the insulating materials used in previous laboratory tests at Stevens and to include steel and copper coupons which could not be located together in the same cell because of the possibility of galvanic corrosion. The same insulating materials were placed in the two corresponding cells with different exterior sheathings. Due to the limited number of cells it was not possible in all cases to test both copper and steel in each insulation with each of the outer sheathings.

Metal coupons (5.08x2.54x0.3 cm) were inserted into the insulation materials installed in Cells 1 through 40. The coupons were either AISI 1010 steel or Cabra 110 tough-pitch copper. Prior to installation, the coupons were abraded to a 600 grit finish on silicon carbide abrasive paper, washed in distilled water and ultrasonically degreased with 1.1.1 trichlorethane. After doing this they were then accurately weighed. The coupons were centered in the cell at mid-thickness of the insulation with the large faces of the coupons parallel to the sheathing. When there was no insulation in the cell, the coupon and pipe sections (copper) were suspended in the center of the cell with a nylon thread.

Corrosometer* probes, which were previously described [3], were installed in Cells 11 through 20 along with test coupons. These probes allow monitoring of corrosion during the test by changes in electrical resistance of one of the probe elements. The probe contains two identical steel sheet elements, one of which is protected from the environment. The two elements are connected in a bridge circuit. Changes in

*Rohrback Industries

TABLE 1

MATERIALS INCLUDED IN TEST

Cellulose No. 1	1 part borax (5 mole); 2 parts boric acid, 25% chemical content
Cellulose No. 2	2 parts borax; 1 part boric acid, 25% chemical content
Cellulose No. 3	1 part borax; 1 part boric acid; 1 part aluminum trihydrate, 25% chemical content
Cellulose No. 4	1 part borax; 4 parts ammonium sulfate, 30% chemical content
Cellulose No. 6	2 parts borax, 2 parts boric acid; 1 part aluminum sulfate, 25% chemical content
Cellulose No 527G	Ammonium sulfate, 19% chemical content
Rockwool	Loose fill
Glass Fiber B	1/2" appliance type
Glass Fiber O*	$3^1/_2$" batts
Glass Fiber T*	$3^1/_2$" batts
Sterile Cotton*	Wool

*Purchased retail, all other insulation were those previously employed in the test program at Stevens and were supplied by manufacturers.

FIG. 1 LOCATION OF CELLS AND THEIR CONTENTS IN TEST WALL

←PLYWOOD SHEATHING→					←POLYISOCYANURATE BOARD SHEATHING→				
1 Copper in air (no insulation)	2 Steel in Cellulose 1	3 Steel in Glassfiber T	4 Steel in Cellulose 3	5 Steel in Cellulose 6	6 Copper in air (no insulation)	7 Steel in Cellulose 1	8 Steel in Glassfiber T	9 Steel in Cellulose 3	10 Steel in Cellulose 6
11 Steel in Cellulose 4	12 Steel in Cellulose 527G	13 Steel in Cellulose 2	14 Steel in Glassfiber B	15 Steel in Rockwool	16 Steel in Cellulose 4	17 Steel in Cellulose 527G	18 Steel in Cellulose 2	19 Steel in Glassfiber B	20 Steel in Rockwool
21 Steel in Cellulose 527G	22 Steel in Fiberglass O	23 Steel in Fiberglass T	24 Steel in Cellulose 4	25 Steel in Cellulose 2	26 Steel in Cellulose 527G	27 Steel in Glassfiber O	28 Steel in Glassfiber T	29 Steel in Cellulose 4	30 Steel in Cellulose 2
31 Copper in Glassfiber B	32 Copper in Cellulose 2	33 Copper in Rockwool	34 Copper in Cellulose 527G	35 Steel in Sterile Cotton	36 Copper in Glassfiber B	37 Copper in Cellulose 2	38 Copper in Glassfiber O	39 Copper in Cellulose 527G	40 Steel in Sterile Cotton
41 Copper in air (no insulation)	42 Copper in Cellulose 2	43 Copper in Cellulose 527G	44 Copper in Sterile Cotton	45 Copper in Glassfiber T	46 Copper in air (no insulation)	47 Copper in Cellulose 2	48 Copper in Cellulose 527G	49 Copper in Glassfiber O	50 Copper in Glassfiber T

TABLE 2
DATA SUMMARY

			INSULATION WEIGHT, GRAMS				COUPON WEIGHT, GRAMS			
CELL NO.	MATERIAL	DENSITY, PCF	INSTALLED	FINAL	% CHANGE	COUPON	INSTALLED	FINAL	CHANGE	% CHANGE
1	NONE	---	---	---	---	Cu 1	38.756	38.756	0.000	0.00
		---	---	---	---	Cu PIPE 1	26.000	25.993	0.007	0.03
2	CELLULOSE 1	3.14	220.07	270.42	22.88	Fe 21	27.935	27.905	0.030	0.11
3	GLASSFIBER T	0.568	39.79	40.52	1.83	Fe 22	29.192	29.142	0.050	0.17
4	CELLULOSE 3	3.12	218.50	304.43	39.33	Fe 1	29.345	29.274	0.071	0.24
5	CELLULOSE 6	2.91	203.39	228.69	12.44	Fe 2	28.495	28.493	0.002	0.01
6	NONE	---	---	---	---	Cu 2	38.292	38.241	0.051	0.13
		---	---	---	---	Cu PIPE 6	25.760	25.764	-0.004	-0.02
7	CELLULOSE 1	3.14	220.07	231.09	5.01	Fe 3	28.770	28.767	0.003	0.01
8	GLASSFIBER T	0.534	37.39	37.78	1.04	Fe 4	29.047	29.047	0.000	0.00
9	CELLULOSE 3	3.12	218.50	265.98	21.73	Fe 5	28.722	28.722	0.000	0.00
10	CELLULOSE 6	2.91	203.39	276.99	36.19	Fe 6	28.808	28.791	0.017	0.06
11	CELLULOSE 4	3.17	221.99	269.10	21.22	Fe 7	28.969	28.967	0.002	0.01
						PROBE 11	---	---	---	---
12	CELLULOSE 527G	3.12	218.33	278.39	27.51	Fe 8	28.583	28.576	0.007	0.02
						PROBE 12	---	---	---	---
13	CELLULOSE 2	3.24	226.84	342.49	50.98	Fe 9	29.218	29.197	0.021	0.07
						PROBE 13	---	---	---	---
14	GLASSFIBER B	0.491	34.36	36.26	5.53	Fe 19	29.067	29.068	-0.001	0.00
						PROBE 14	---	---	---	---
15	ROCKWOOL	2.78	194.80	191.03	-1.94	Fe 10	28.957	28.958	-0.001	0.00
						PROBE 15	---	---	---	---
16	CELLULOSE 4	3.17	221.99	235.90	6.27	Fe 11	28.790	28.785	0.005	0.02
						PROBE 16	---	---	---	---
17	CELLULOSE 527G	3.12	218.33	250.23	14.61	Fe 12	28.708	28.698	0.010	0.03
						PROBE 17	---	---	---	---
18	CELLULOSE 2	3.24	226.84	236.02	4.05	Fe 13	28.631	28.623	0.008	0.03
						PROBE 18	---	---	---	---
19	GLASSFIBER B	0.498	34.86	35.16	0.86	Fe 20	28.683	28.685	-0.002	-0.01
						PROBE 19	---	---	---	---
20	ROCKWOOL	2.78	194.80	190.69	-2.11	Fe 14	28.911	28.750	0.161	0.56
						PROBE 20	---	---	---	---
21	CELLULOSE 527G	3.12	218.33	358.32	64.12	Fe 15	28.255	28.263	-0.008	-0.03
22	GLASSFIBER O	0.615	43.02	43.09	0.16	Fe 28	25.927	25.926	0.001	0.00
23	GLASSFIBER T	0.443	31.01	32.10	3.51	Fe 16	28.811	28.814	-0.003	-0.01
24	CELLULOSE 4	3.17	221.99	274.35	23.59	Fe 17	28.878	28.880	-0.002	-0.01
25	CELLULOSE 2	3.24	226.84	454.16	100.21	Fe 30	25.764	25.660	0.104	0.40
26	CELLULOSE 527G	3.12	218.33	257.16	17.79	Fe 18	28.045	28.040	0.005	0.02
27	GLASSFIBER O	0.633	44.26	44.73	1.06	Fe 29	25.812	25.812	0.000	0.00

TABLE 2
(Continued)

			INSULATION WEIGHT, GRAMS				COUPON WEIGHT, GRAMS			
CELL NO.	MATERIAL	DENSITY, PCF	INSTALLED	FINAL	% CHANGE	COUPON	INSTALLED	FINAL	CHANGE	% CHANGE
28	GLASSFIBER T	0.483	33.77	33.86	0.27	Fe 24	25.575	25.575	0.000	0.00
29	CELLULOSE 4	3.17	221.99	248.32	11.86	Fe 25	25.793	25.760	0.033	0.13
30	CELLULOSE 2	3.24	226.84	250.93	10.62	Fe 26	25.756	25.750	0.006	0.02
31	GLASSFIBER B	0.524	36.67	38.72	5.59	Cu 3	39.861	39.812	0.049	0.12
32	CELLULOSE 2	3.24	226.84	526.32	132.02	Cu 4	38.297	38.283	0.014	0.04
33	ROCKWOOL	2.78	194.80	191.95	-1.46	Cu 5	38.995	38.998	-0.003	-0.01
34	CELLULOSE 527G	3.12	218.33	308.73	41.41	Cu 6	38.267	38.265	0.002	0.01
35	STERILE COTTON	1.3	90.77	94.71	4.34	Fe 23	25.083	25.082	0.001	0.00
36	GLASSFIBER	0.512	35.86	36.18	0.89	Cu 7	39.145	39.148	-0.003	-0.01
37	CELLULOSE 2	3.24	226.84	255.05	12.44	Cu 8	38.542	38.526	0.016	0.04
38	GLASSFIBER O	0.505	35.35	35.37	0.06	Cu 10	38.506	38.508	-0.002	-0.01
39	CELLULOSE 527G	3.12	218.33	267.12	22.35	Cu 9	38.564	38.562	0.002	0.01
40	STERILE COTTON	1.35	94.54	95.89	1.43	Fe 27	25.983	25.984	-0.001	0.00
41	NONE	---	---	---		Cu PIPE 41	55.970	55.950	0.020	0.04
42	CELLULOSE 2	3.24	226.84	558.65	146.27	Cu PIPE 42	57.950	57.885	0.065	0.11
43	CELLULOSE 527G	3.12	218.33	636.00	191.30	Cu PIPE 43	59.490	59.315	0.175	0.29
44	STERILE COTTON	1.31	91.62	164.08	79.09	Cu PIPE 44	58.440	58.431	0.009	0.02
45	GLASSFIBER T	0.558	39.08	40.06	2.51	Cu PIPE 45	58.350	58.325	0.025	0.04
46	NONE	---	---	---		Cu PIPE 46	59.430	59.399	0.031	0.05
47	CELLULOSE 2	3.24	226.84	335.57	47.93	Cu PIPE 47	58.010	57.997	0.013	0.02
48	CELLULOSE 527G	3.12	218.33	479.23	119.50	Cu PIPE 48	60.580	60.529	0.051	0.08
49	GLASSFIBER O	0.577	40.38	44.48	10.15	Cu PIPE 49	57.740	57.697	0.043	0.07
50	GLASSFIBER T	0.434	30.34	30.49	0.49	Cu PIPE 50	57.280	57.246	0.034	0.06

resistance of the exposed element can therefore be determined and converted to a corrosion rate by assuming uniform loss in thickness due to general corrosion. The probe material was AISI 1010 steel. Care was taken to insure that there was a reasonable separation between these probes and the steel coupons mounted into the same cell. Small holes were cut into the gypsum board sheathing to allow the probe cables to exit the test panel. These openings were sealed with duct tape as were the edges of the inner and outer sheathings.

Sections of copper pipe cleaned on the outside in the manner described above and weighed were installed in Cells 1, 6, and 41-50. The individual sections of pipe in Cells 41-50 were connected together with Tygon tubing and the ends of the tubing exiting Cells 41 and 50 were attached to a refrigerated circulation bath in order to simulate the presence of cold water pipes in the insulation. The Tygon tubing allowed electrical isolation of the pipe sections in each cell, preventing possible galvanic corrosion effects between sections in different cells. The cells 41-50 were those at the bottom of the test wall when mounted in the conditioning chamber.

Test Chamber Description

A test chamber was constructed to accommodate the test panel and create the required environmental conditions. The inside dimensions of the chamber were 210 cm long by 172 cm high by 50 cm deep. It was constructed from plywood on a framework of 5.08x15.24 cm (2"x6") studs spaced 60 cm on center. All the walls were insulated with R-19 glass-fiber batts. One of the 210x150 cm walls was removable to gain access to the chamber interior. All of the joints inside the chamber were reinforced with glass-fiber cloth and the interior surfaces of the chamber were waterproofed with epoxy.

Heat exchangers of similar surface dimensions as the test panel were mounted to the chamber such that, with the test panel in place, the heat exchangers would be 7.5 cm from each surface of the test panel. The heat exchangers were constructed from 9 mm thick anodized aluminum plates with 1.25 cm rigid copper tubing attached to the back side. The copper tubes were spaced 7.5 cm apart and connected in a parallel configuration to minimize the pressure drop across the heat exchanger. The heat exchangers were connected to temperature-controlled recirculating baths; the exterior and interior baths had cooling capacities of 2400 and 366 watts at 0°C, respectively. A series of fans were also mounted on each side of the test panel to circulate air across the surfaces of the test panel and maintain uniform environmental conditions.

Each side of the test panel was outfitted with a saturated salt bath to maintain the required levels of humidity. The salt baths were connected to distilled water level controllers which would maintain a continuous supply of water to the baths without opening the chamber. The salts used in the exterior and interior baths were zinc sulfate and

magnesium nitrate, respectively.

Ten thermocouple temperature sensors and a lithium-chloride type humidity detector were installed on each side of the test panel to monitor the environmental conditions during the course of the experiment.

The environmental chamber is shown in Figure 2 with one of the heat exchanger plates lifted to reveal the space where the test wall was installed. A schematic of the test chamber is shown in Figure 3.

Conditioning Procedure

Periodically, the output from the temperature sensors and the humidity detectors were scanned to verify the performance of the temperature and humidity control equipment. The outputs of the ten corrosometers were monitored at the same frequency. The environmental conditions for the duration of the exposure are shown graphically in Figures 4 and 5. The hot side averaged 70.8°F (21.6°C) and 44.3% RH, while the cold side averaged 38.0°F (3.3°) and 95.4% RH.

The conditioning equipment was maintained for 190 days. During this period of time, there was one six-hour period when one of the refrigerated circulators required maintenance and was off-line.

The refrigerated circulator attached to the copper pipes in Cells 41 through 50 was operated daily for eight hours. The temperature of the coolant in this loop was 10°C (50°F).

The likelihood of condensation under the conditions of the test was evaluated using the estimated temperature and vapor pressure profiles obtained by the method described in the ASHRAE Handbook [10]. This approximate calculation placed the condensation plane inside the wall cavity for both types of outer sheathing, being 1.4 cm and 0.8 cm from the inside surface of the plywood and foam board respectively. Assuming condensation actually occurred at the inside surface of the outer sheathing, the vapor pressure profile was recalculated and a moisture accumulation rate estimated. Moisture accumulation was found to be approximately twice as high with the plywood as with the foam sheathing. These results are shown in more detail in Appendix II.

Test Panel Disassembly

Upon completion of the 190-day conditioning exposure period, the test panel was opened and the metal coupons, copper pipes, and corrosometers were removed from the cells. The insulation materials were carefully removed from each of the cells and weighed to determine their moisture gain during the test. These results are presented in Table 2. The weights of the coupons and pipes are shown before testing and after post exposure cleaning also in Table 2. The cleaning procedure to remove corrosion products followed ASTM G1 Standard Practice For Pre-

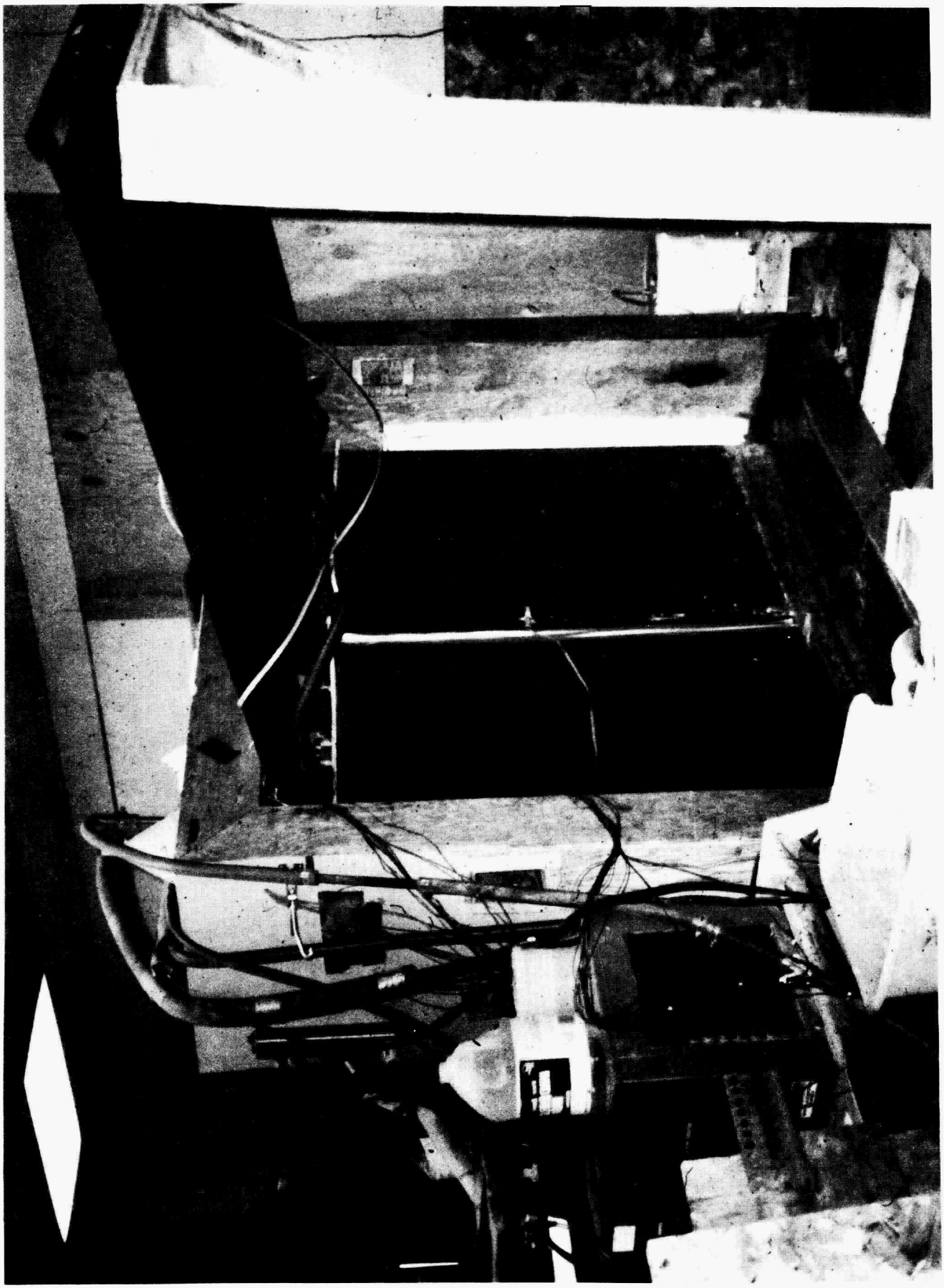


Fig. 2 Environmental chamber with one heat exchanger lifted.

FIG. 3 SCHEMATIC OF ENVIRONMENTAL CHAMBER

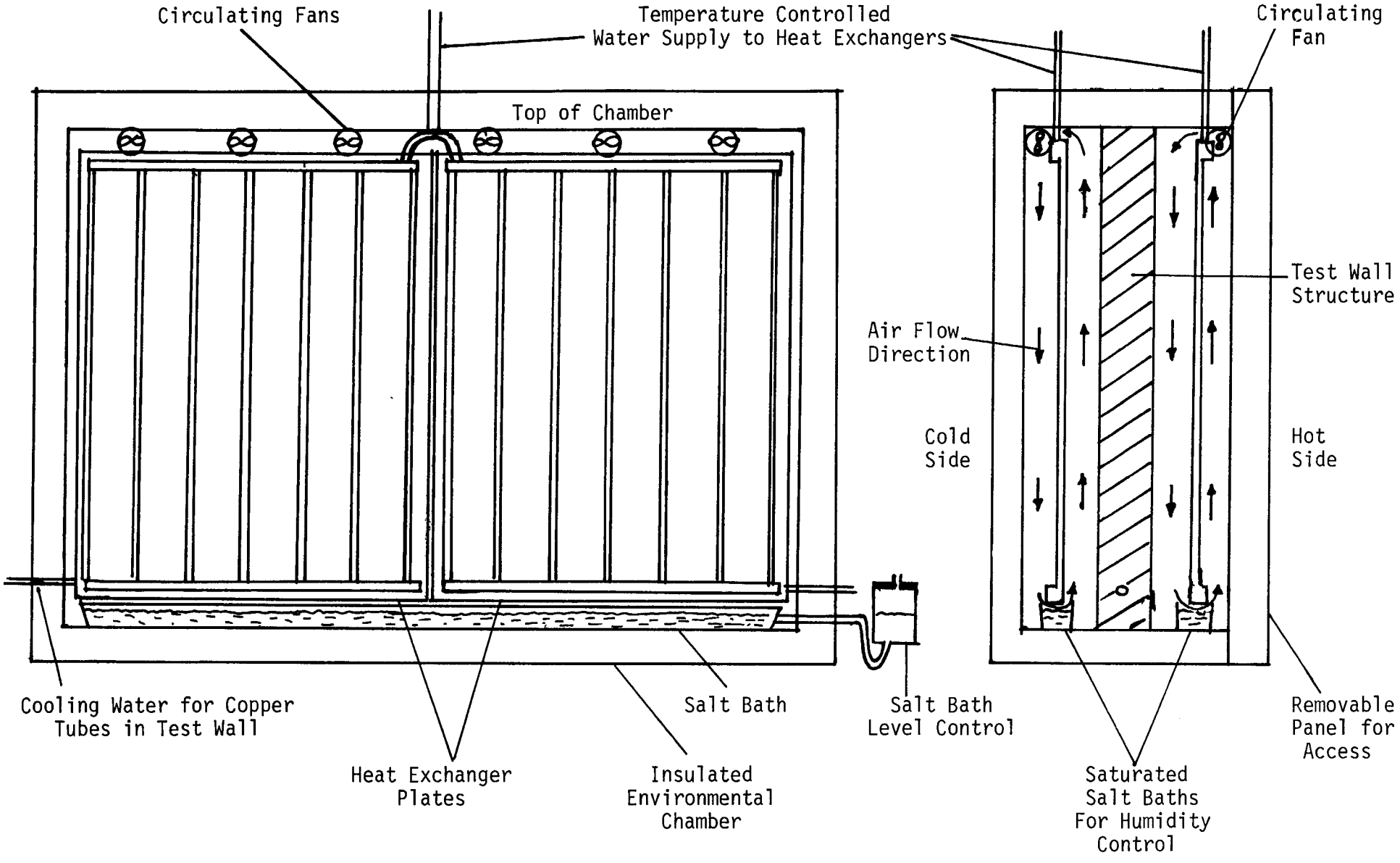


FIGURE 4

ENVIRONMENTAL CHAMBER TEMPERATURE LEVELS

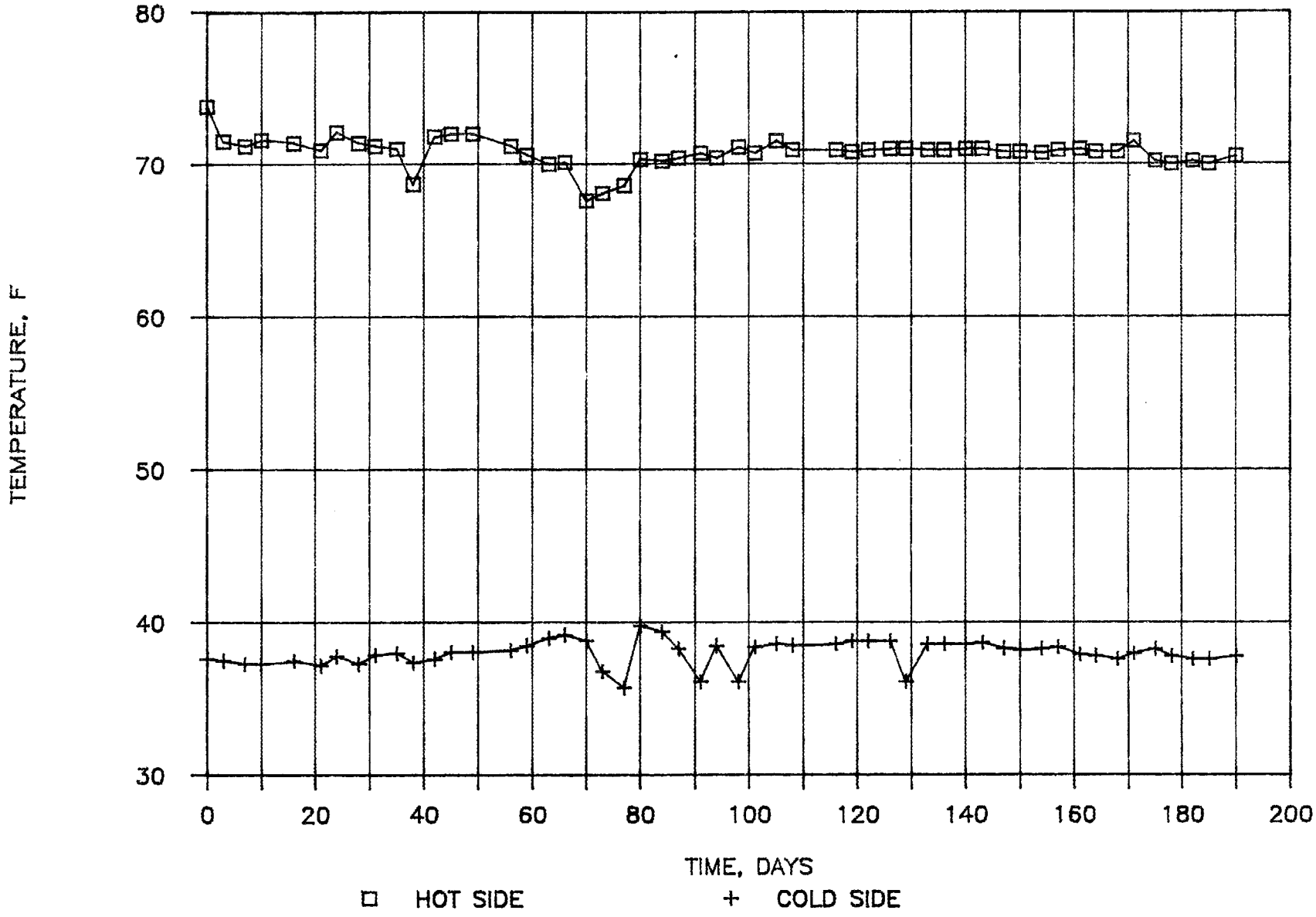
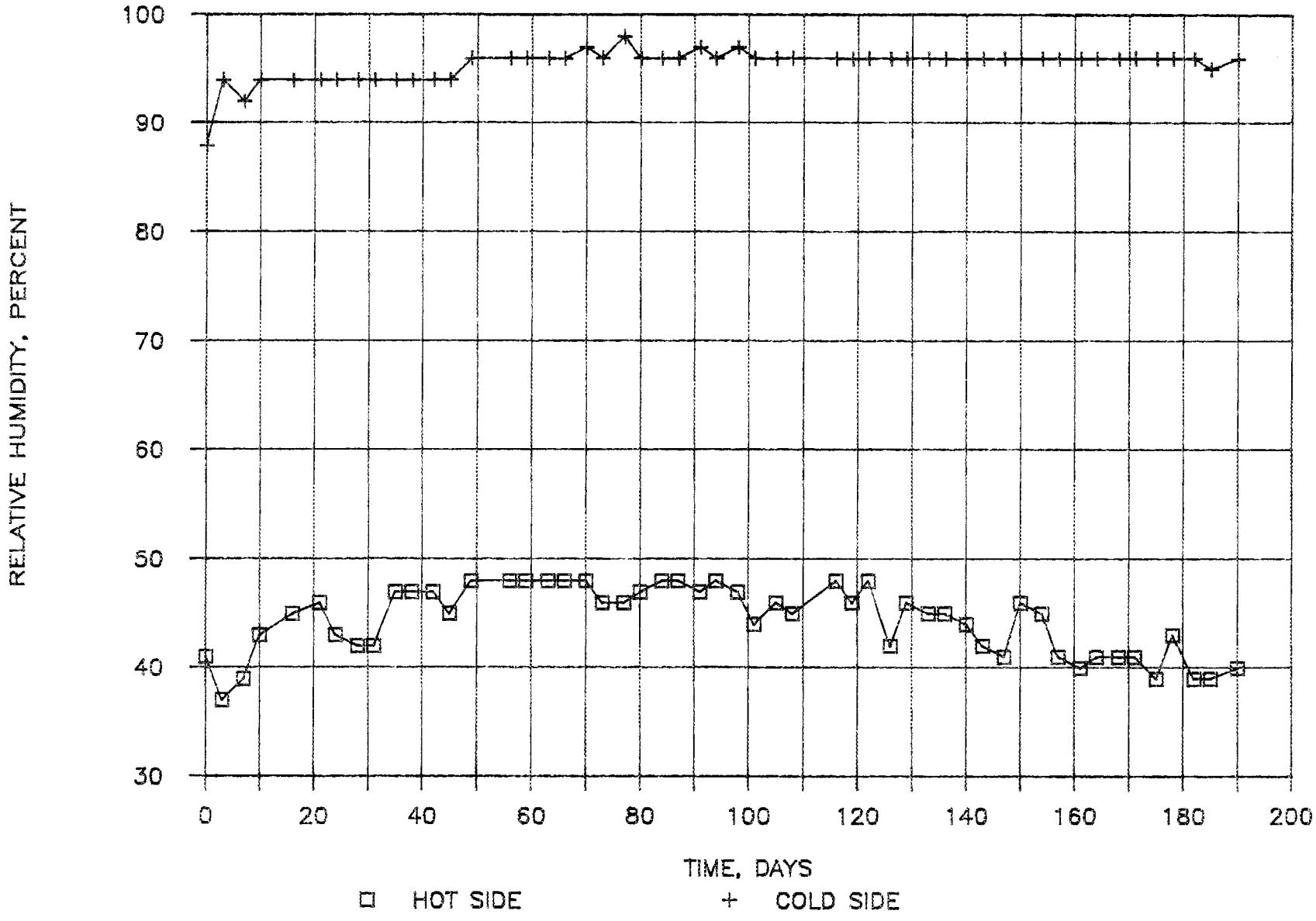


FIGURE 5

ENVIRONMENTAL CHAMBER RLATIVE HUMIDITY LEVELS



paring, Cleaning and Evaluating Corrosion Test Specimens, using Clarke's solution for the steel and hydrochloric/sulfuric acid mixture for the copper.

Weight losses were not converted to corrosion rates as that would have assumed uniform corrosion over the entire specimens surface. Visual observation showed this was not the case for the corroded specimens. The weight loss data were able to give a relative measure of the severity of attack if one treats them with caution and considers them along with visual observations. In addition, for those coupons and pipes that showed observable pitting, the maximum pit depth was measured by differential focussing at high magnification with an optical metallograph. Accuracy of this technique was estimated at ± 2 μm.

RESULTS AND DISCUSSION

Results for the moisture gains of the insulation materials and the weight changes due to corrosion of the metal coupons and pipes are recorded in Table 2. Figures 6-9 are photographs of the metal coupons and pipes after completion of the test but prior to cleaning and weighing. The photographs are arranged to show both faces of each coupon, i.e., that toward the high-temperature side and that toward the cold side, for each of the two types of outer sheathing. The copper pipes are only included in one photograph from each outer sheathing pair, as orientation was not important. The maximum pit depth data for those samples showing pitting are given in Table 3.

Due to the limited number of cells available, it was not possible to have a complete set of matching metal/insulation pairs located behind the two sheathing types and this, unfortunately, reduced the number of direct comparisons based on sheathing permeability. However, the following observations can be made from the photograph and data.

Coupon Corrosion

In no case was corrosion observed to be uniform over the entire coupon surface. Even those coupons with the most corrosion showed attack in patches of localized pitting. On coupons where corrosion was observed, it was found, in general, that more attack occurred on the faces toward the high-temperature side of the wall. This was true for both types of sheathing. This result is probably due to the direction of water vapor transport being from the hot to the cold side.

No Insulation

Copper coupons that were exposed in cells with no insulation were not corroded, indicating that condensation did not occur in the absence of insulation. This is to be expected as the absence of insulation would result in a less severe drop in saturation pressure within the wall cavity than if insulation were present and less probability that

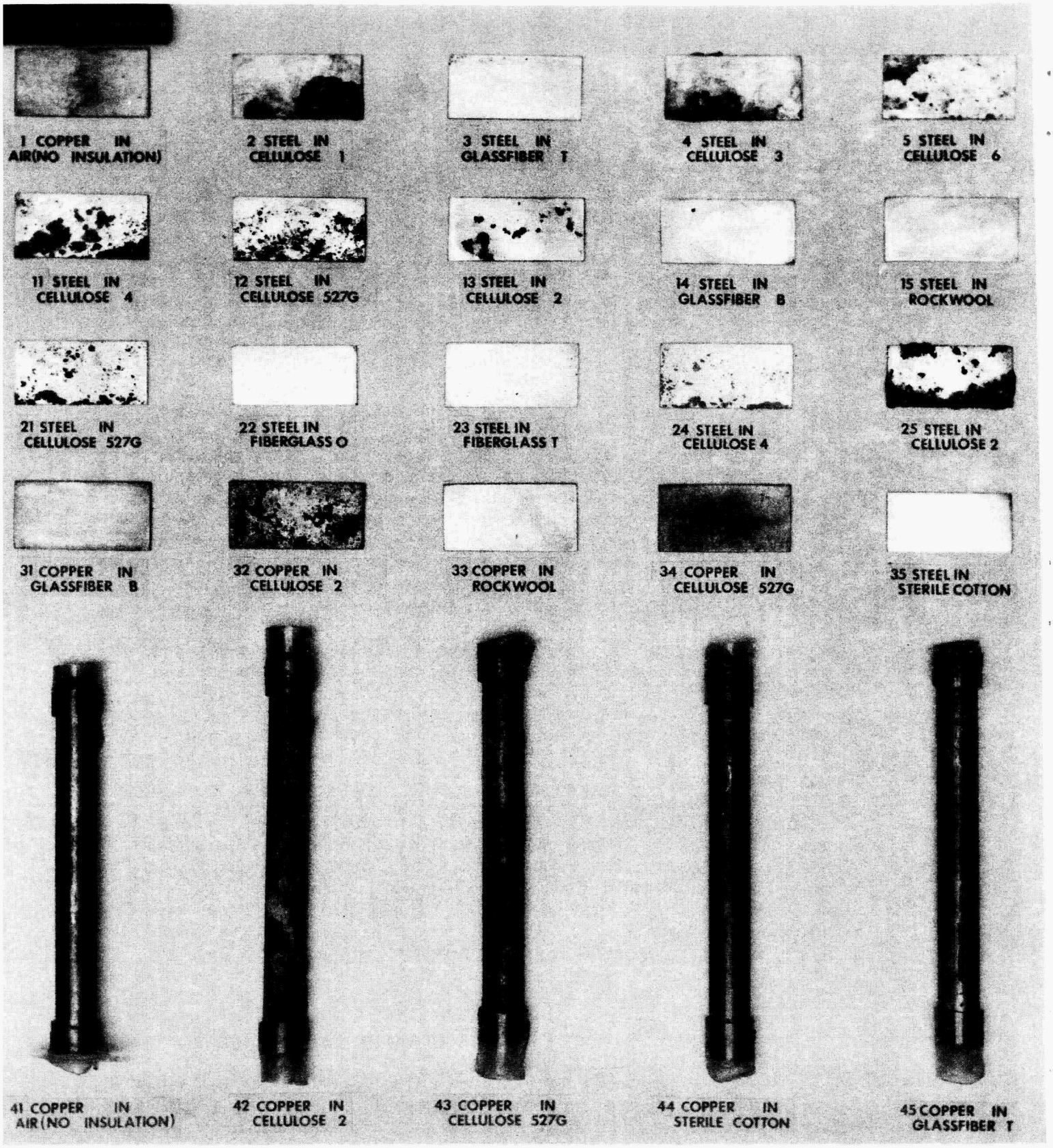


Fig. 6 Metal specimens after 6 months exposure in cells sheathed with plywood, showing faces of coupons toward warm side of wall.

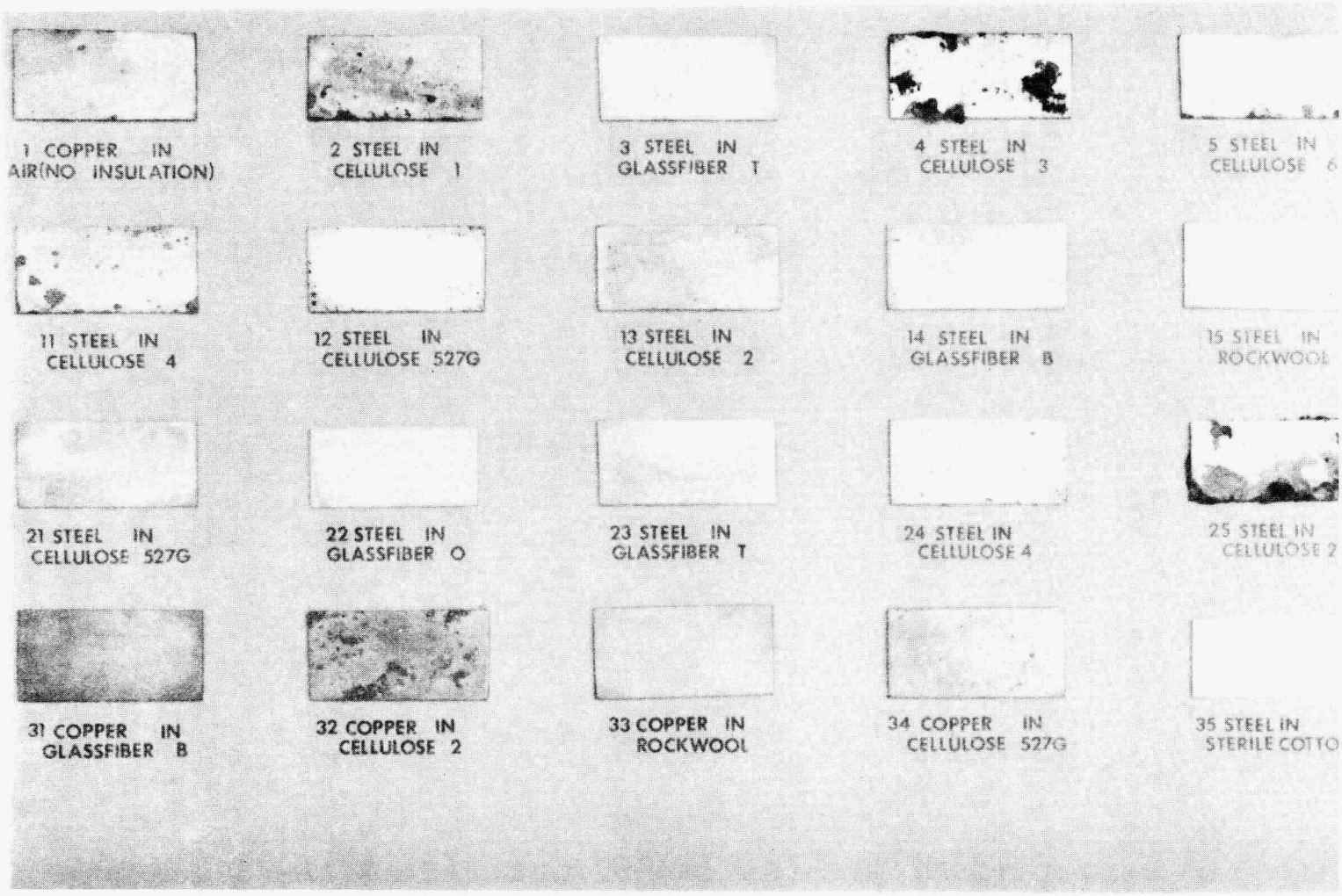


Fig. 7 As Fig. 6 except showing coupon faces toward the cold side of wall.

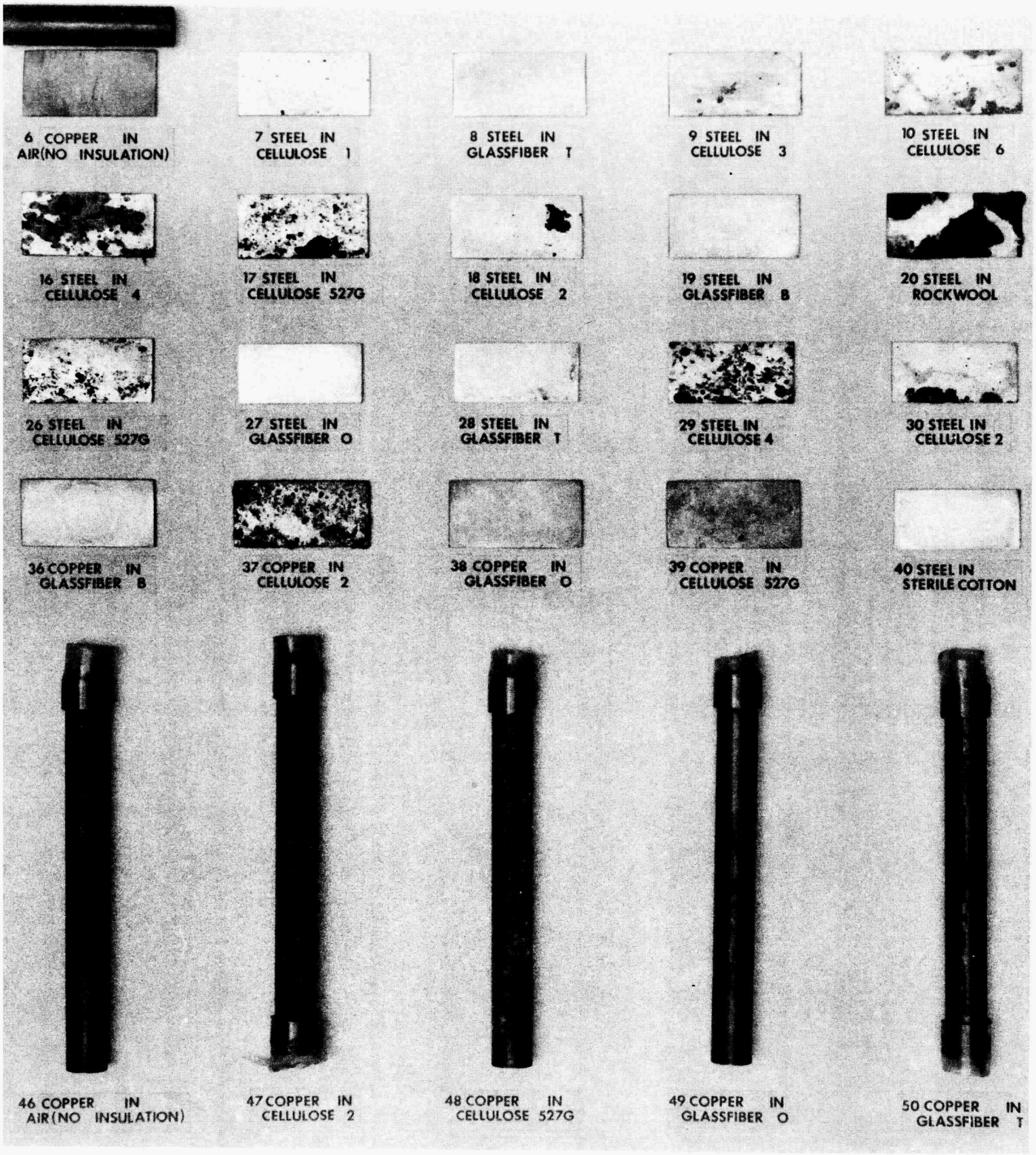


Fig. 8 Metal specimen after 6 months exposure in cells sheathed with polyisocyanurate foam. Faces of coupons toward the warm side of wall.

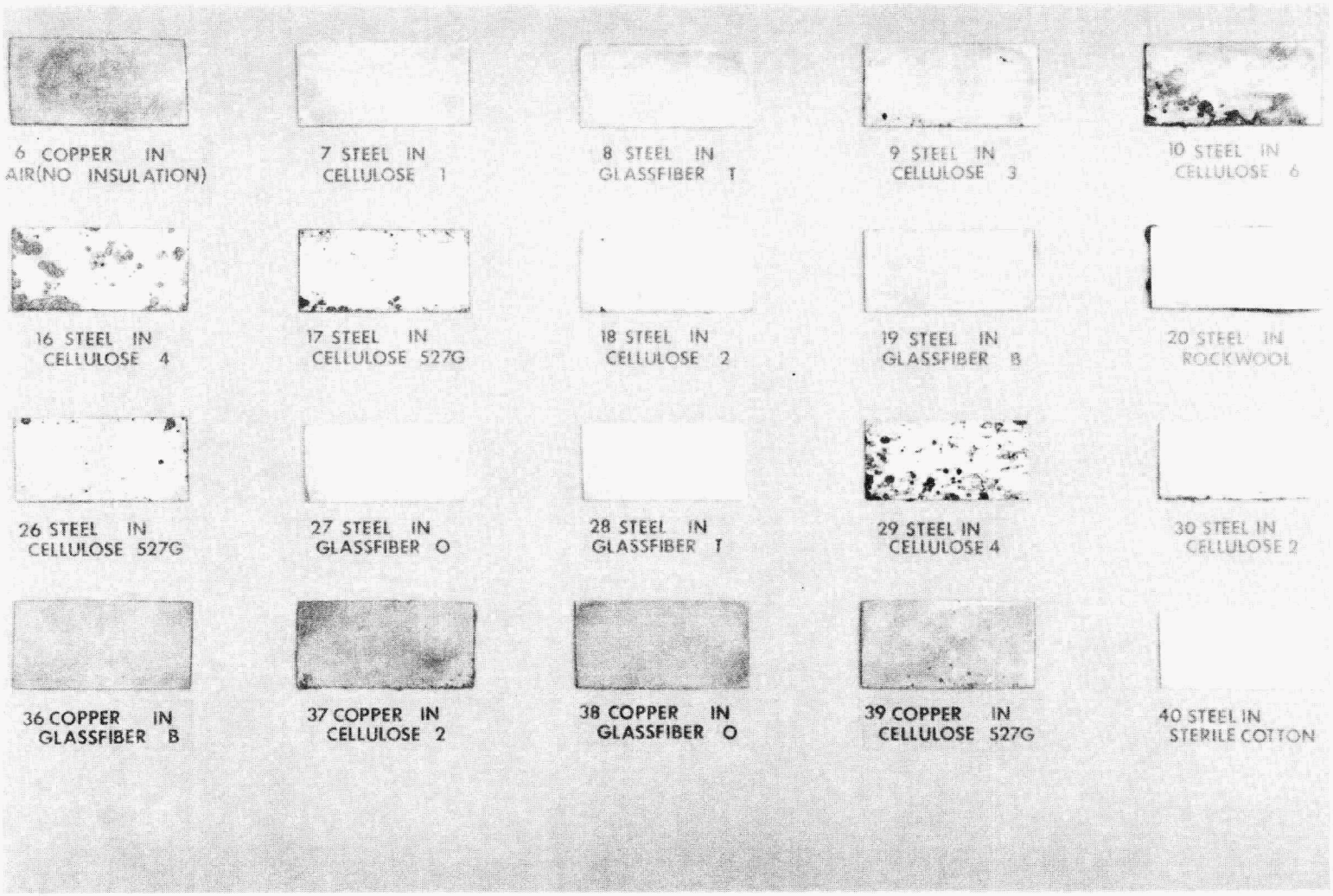


Fig. 9 As Fig. 8, except showing coupon faces toward the cold side of wall.

TABLE 3

MAXIMUM PIT DEPTH FOR METAL SPECIMEN THAT EXHIBITED PITTING CORROSION

Cell	Metal	Insulation	Max Pit Depth (μm)
2 HP	Fe coupon	Cellulose 1	104
4 HP	Fe coupon	Cellulose 3	580
5 HP	Fe coupon	Cellulose 6	96
13 HP	Fe coupon	Cellulose 2	648
16 LP	Fe coupon	Cellulose 4	54
18 LP	Fe coupon	Cellulose 2	196
25 HP	Fe coupon	Cellulose 2	616
32 HP	Cu coupon	Cellulose 2	86
37 LP	Cu pipe	Cellulose 2	36
42 HP	Cu pipe (cooled)	Cellulose 2	94
43 HP	Cu pipe (cooled)	Cellulose 527G	40

HP = high permeability plywood sheathing
LP = low permeability foam sheathing

For comparison a pit penetration of 150 μm in 6 months (the test period) would extrapolate to penetration of 1/16" (0.159 cm) in approximately 5 years assuming a constant rate.

the dew point would be reached within the wall.

Sterile Cotton

Steel coupons exposed in the cells containing the sterile cotton control material were not corroded. This is probably due to the low moisture gains in these cells, 4% when there was plywood sheathing and 1% when the sheathing was foam.

Glass-Fiber and Rockwool

No corrosion occurred on any of the steel and copper coupons embedded in the glass fiber and rockwool insulation samples for both types of outer sheathing. One exception, a steel coupon (Cell 20) in rockwool had corrosion on its high-temperature facing side, but no corrosion on its other face. The weight loss for this coupon of 0.56% was the largest observed of any in this experiment. This cell was in the foam sheathed half of the wall. The equivalent coupon in the plywood half of the wall was not corroded. The copper coupon in rockwool also showed no corrosion. There does not appear to be an obvious explanation as there was no weight gain of the insulation due to moisture pickup for any of the three cells containing rockwool. In fact, each experienced a slight weight loss during the test. It may be that the rockwool in Cell 20 had some local contamination. We, therefore, consider the result anomalous; however, it does illustrate that product contamination could easily influence corrosiveness. The lack of corrosion for coupons in the glass fiber and rockwool insulations appears to be due to the very low moisture gains of these materials during the test, the maximum being 6% for Glass Fiber B in the plywood sheathed part of the wall. These results are also consistent with our previous laboratory corrosiveness testing [3-5] in which the glassfiber and rockwool insulation samples tested consistently proved of low corrosiveness relative to a distilled water control.

Cellulose

All of the coupons embedded in cellulosic insulation displayed some corrosion; however, in most cases it was minor surface staining with no significant loss of metal. The weight gains due to moisture for the cellulosic insulation samples was generally very much greater than for the glassfiber and rockwool, with gains from 4% to 100%. With one exception (Cell 10), moisture gains were substantially greater in the cells with the plywood sheathing which had a higher permeability than the foam sheathing. This correlates with the previously discussed estimates of moisture accumulation. Many of the coupons were corroded more where the moisture content was higher, but there were exceptions, notably the coupons in Celluloses 4 and 527G. In the former case, the coupons from the foam-sheathed part of the wall (Cells 16 and 29) were corroded more than from the plywood side (Cells 11 and 24) in spite of lower moisture contents in the insulation. The coupons in 527G were corroded about the same in both halves of the wall (Cells 12, 16, 31,

26) although again moisture contents were much higher in the cells on the plywood size.

While in many cases the weight loss data correlate with visual observations of corrosion, there are exceptions. Coupons from Cells 36, 29 and 31 had large weight losses compared to those typically found for the other coupons. These results did not correlate to the visual evidence. It is possible that an error may have been introduced as a result of the cleaning procedure or from the weighing process itself. The before-and-after weighings were done many months apart and the weight losses involved were typically very small. The probability of error is therefore high and the weight loss data should be treated with appropriate caution. We are also concerned about the reliability of the ASTM G1 cleaning procedure which we plan to investigate further.

For Celluloses 2, 4, and 527G it was possible to examine the reproducibility of corrosion for cells that had nominally the same conditions. Samples of Cellulose 2 which were located in Cells 18 and 30 in the foam-sheathed part of the wall gave similar visual and weight loss results. The samples in Cells 13 and 25 on the plywood-sheathed side had different results. The coupons from Cell 25 appeared to be much more corroded and had a larger weight loss. There was also a large difference in moisture gains. The insulation in Cell 13 gained 51% while that in Cell 25 gained 100%. No obvious reason for these results is apparent. Possibly the chemical loading was greater for the sample of the cellulose insulation in Cell 25. Moisture gain has previously been shown to be a function of the type of additive and its concentration in the insulation [9].

The samples in Cellulose 4 located in Cells 11, 16, 25 and 29 exhibited reasonably good reproducibility when comparing visual evidence of corrosion, weight loss (except for an anomalously high result for Cell 29) and moisture gain. Similarly for Cellulose 527G (Cells 12, 17, 31, 26), the corrosion was about the same in each cell as was weight loss even though the moisture gain in Cell 21 was twice that in Cell 17. Apart from the exception (Cell 29) mentioned, reproducibility was reasonable between similar cells in the wall.

Although most of the corrosion in the cellulose insulation was limited to surface staining, samples were pitted. The maximum pit depths shown in Table 3 show that the pitting was quite deep in some cases. It should be noted, however, that pit distribution on the sample surfaces was limited. Most of the pitting was in the plywood-sheathed half of the wall. It can be seen that Celluloses 1, 2, 3, 4 and 6 all caused pitting of the steel, the most being in Cellulose 3 and in particular in Cellulose 2. Cellulose 527G did not cause pitting. These results are surprising in view of our previous laboratory test results with these materials [3]. In those tests Cellulose 2 which contained borax and boric acid consistently showed the least corrosiveness of the Cellulose samples, with minor pitting tendency, and Cellulose 527G containing ammonium sulfate the most producing

general corrosion rather than pitting. On completion of the test, samples of Cellulose 2 that had caused severe pitting were re-examined for pitting tendency using a voltammetric test (see Reference 5) in the insulation leachant. This showed a pitting tendency that had not been observed in the earlier experiments suggesting that the corrosiveness of the insulation may have changed with time and/or exposure to high moisture levels. Alternatively a sample containing less borax may have been used in the test suggesting poor additive distribution in the material supplied. One may speculate that chemical additives in the laboratory tests dissolve and the solution uniformly distributes across the metal surface allowing inhibiting chemicals to work effectively. In the test wall, hygroscopic particles of additives may have absorbed moisture and the resulting droplets in contact with the metal could form isolated localized cells. In these cells the outer part of the droplet, with more oxygen access, would become cathodic to the inner part (as in atmospheric corrosion by water droplets) resulting in a localized corrosion. If the borax, for example, which normally provides a corrosion-inhibiting effect for cellulose was not sufficiently well distributed to dissolve in all moisture droplets, it could not provide its effective inhibiting role typically obtained in the more uniform coverage of the laboratory test done with leachants. Settling or lack of sufficient milling during manufacture could produce this non-uniform distribution. However, this explanation does not explain why the ammonium sulfate in Cellulose 527G did not cause pitting. Corrosion of copper in Cellulose 527G was barely visible and was reflected in the low weight losses. The moisture gain in the 527G insulation was 41% with the plywood and 22% with the foam sheathings. This was approximately in the middle of the range for the various cellulose-containing cells and does not appear to have been a critical variable in the amount of corrosion given that a minimum moisture level was present.

Copper coupons in Cellulose 2 showed significant localized corrosion. The only pitting of copper coupons being in Cells 32 and 37. On the high-temperature sides of the coupons the corrosion was about the same. On the low-temperature side there was no corrosion in Cell 37, but a reasonable amount in Cell 32 which had the plywood sheathing. The moisture pickup in Cell 32 was 132%, which was the highest recorded, but it was only 12% in Cell 37. Therefore, variation in moisture content does not appear to have had a significant influence on the corrosion rate of copper coupons assuming that a minimum threshold was attained to initiate corrosion. That threshold appears to be equal to or less than the minimum 12% pickup found in these cells. For the steel coupons the threshold appears to have been as low as 4% (Cellulose 2, Cell 18) and 6% (Cellulose 4, Cell 16) to cause corrosion in certain of the cellulose insulation. There was apparently not enough moisture absorbed by the glass fiber and rockwool insulation to reach the threshold. The cellulosic insulation apparently absorbed enough moisture to cause corrosion. The differences in behavior is then explained by the differing efficacies of chemicals in the cellulose in inhibiting or aggravating the corrosion that would have occurred solely

due to the significant moisture pickup of this type of material. From the consideration of vapor pressure and saturation pressure profiles previously discussed, condensation within the wall cavity was a strong possibility, if not in the insulation, then on the inside sheathing surface.

Copper Pipe Corrosion

Corrosion did not occur on the water-cooled copper pipes in cells without insulation, or on cells containing glass fiber types O and T or cells with sterile cotton control. Insufficient material and limited cell locations precluded embedding the pipes in rockwool and Glass Fiber B samples. The moisture gains were quite low for the glass fibers (2.5% and 1% for Glass Fiber T, 10% for Glass Fiber O). The sterile cotton increased in weight by 79% without causing corrosion.

Copper pipes embedded in Cellulose 2 and 527G showed significant visual evidence of corrosion. Corrosion was more pronounced in the cells that had the plywood sheathing. Moisture gain in the four cellulose-containing cells was high, the larger increases being in cells that had the plywood sheathing. The gain for Cellulose 527G was higher, being 192% in Cell 43 and 120% in Cell 48, than for Cellulose 2, which was 146% in Cell 42 and 48% in Cell 47. The two figures for each insulation being for the two types of sheathing. The weight loss data for the pipes does not match well with the visual evidence. The pipes from Cells 42 and 43 which appeared the most corroded had the highest weight losses. However, based on weight loss it would not have been possible to differentiate between the other pipes which had losses between 0.02 and 0.08%. Yet the pipes from Cells 47 and 48 had evidence of corrosion while the others did not. It would again appear that the weight loss data are questionable for the reasons previously cited and it is also unknown how much corrosion occurred inside the pipe. The corrosion on the pipe in Cellulose 2 (Cell 42) appeared more extensive than on the copper coupon in the same insulation (Cell 32); however, they had similar maximum pit depths. These cells had similar moisture gains (146% and 132%, respectively). Pit depth for Cellulose 527G (Cell 43) was less than half that for the Cellulose 2 (Cell 42). Again surprising given the laboratory test results discussed above.

Electrical-Resistance Probes

The outputs of the electrical-resistance probes although showing some fluctuations were relatively unchanged during the test period. The outputs versus time for the probes is shown in Appendix III. These results indicated little corrosion occurred (the slope of the output versus time is proportional to corrosion rate). This was confirmed on examination of the probes following the test. One reason for the results, given that some of the cellulose samples had produced corrosion of coupons is that the sensing surfaces of the probes had faced the cold side of the wall. It had not been predicted before the test that facing the hot side would have been a more severe corrosion site.

CONCLUSIONS

1. Moisture absorption appears to be the primary, but not only factor in causing corrosion by insulating materials. Sterile cotton which exhibited a high moisture absorption in contact with a cooled copper pipe did not produce corrosion. It therefore appears that other factors, most probably the activity of chemicals from the insulation are required for corrosion, even if their role is just to increase the conductivity of the solution. They may also contribute aggressive species.

2. No corrosion occurred in the absence of insulation even on the cooled copper pipes.

3. No corrosion occurred on steel coupons, copper coupons or cooled copper pipes embedded in glassfiber or rockwool (except for one anomalous specimen) insulations in this simulation. This appears to be due to the low moisture absorption by these materials.

4. All of the cellulosic insulation materials tested produced corrosion of steel and copper. For many cases this corrosion was very minor, being in patches and resulting only in surface staining. Penetration depth can be considered negligible in terms of projected lifetime. However, in some materials a few deep pits were produced. In the worst cases, if they propagated at the same rate as in this test, they would result in penetration of a 1/16" (0.159 cm) thickness in as little as 18 months (steel coupons in Cellulose 2). It is, however, not known if this penetration rate would be maintained in a longer exposure.

5. Cellulosic insulations, in particular Cellulose 2, that had relatively low corrosiveness in previous laboratory testing, produced significant pitting in the test wall. It is postulated that this is due to formation of localized cells of concentrated additive solutions that promoted local corrosion. This occurred without the mediating effect of the borax inhibitor additive that was kept separated from the aggressive additive due to lack of saturation conditions. In the laboratory testing, the use of a saturated insulation or a leachant allowed the inhibitor to be effective. Additionally it is possible that changes in corrosiveness occur with time and/or moist air exposure due to changes in the chemical additives.

6. Corrosion was generally more severe on the sides of coupons which faced the warmer side of the test wall and were first in the path of moisture diffusing through the wall.

7. The Cellulose 527G containing ammonium sulphate, produced relatively little corrosion of the steel coupons considering the severe corrosion it produced in the ASTM C739 accelerated corro-

siveness test. An interesting explanation for this has been very recently suggested involving the activity of sulfate-reducing bacteria in accelerating corrosion [11]. Anaerobic bacteria can reduce sulfate to sulfide. The sulfide can accelerate corrosion of steel. Hydrogen to accomplish the reduction can be derived from cellulose by the bacteria [12]. Such bacteria may be less active or inactive under the more aerobic conditions of the test wall, leading to a reduced corrosion rate.

8. The plywood sheathing material generally resulted in a greater moisture gain in the insulation than the less permeable foam sheathing. This was anticipated from calculated accumulation rates. While the amount of moisture gain did not always correlate with the amount of corrosion in the cellulosic materials, there did appear to be a moisture-gain threshold below which corrosion was not significant and in this respect sheathing permeability could be an important factor.

RECOMMENDATIONS

1. Clearly it would be desirable to obtain information over a longer period. One must be very cautious in extrapolating the results of the six-months simulation reported here. Corrosion rates vary with time, e.g., as corrosion product films limit additional attack. It would also be desirable to test the effect of diurnal temperature and humidity fluctuations as well as other types of insulation.

2. The results suggest that further study is required on the effects of moisture saturation levels and aging on the corrosiveness of cellulosic insulations and the implications for development of a uniform accelerated laboratory testing procedure for all types of residential thermal insulation materials.

3. Pitting appears to be the primary form of corrosion and this should be reflected in accelerated laboratory test procedures, with an appropriate quantitative measure. Coupon weight loss is not appropriate. Pit depth measurements or the presence and size of a hysteresis loop in potentiodynamic electrochemical analysis are possible indices and are currently being pursued by us.

4. The effect on moisture gain by the insulation due to the absorptivity of the sheathing was not specifically addressed in this study. It may warrant further study.

5. The role of bacterial action in influencing corrosion, particularly of cellulosic insulation should be further investigated.

ACKNOWLEDGEMENTS

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REFERENCES

1. R. Weil and A. Graviano, "Assessment of the Corrosiveness of Cellulosic Insulating Materials," Technical Report ORNL/Sub-7556/1, Oak Ridge National Laboratory, Oak Ridge, TN, June 1979.
2. R. Weil, A. Graviano and K. Sheppard, "Corrosion Testing of Urea-Formaldehyde Foam Insulating Materials," Technical Report ORNL/Sub-7556/2, Oak Ridge National Laboratory, Oak Ridge, TN, September 1980.
3. K. Sheppard and R. Weil, "Corrosiveness Testing of Thermal Insulating Materials," Technical Report ORNL/Sub-78-7556/3, Oak Ridge National Laboratory, Oak Ridge, TN, August 1984.
4. K. Sheppard and R. Weil, "Aspects of Corrosion Testing of Thermal Insulating Materials," in Thermal Insulation, Materials and Systems for Energy Conservation in the 80's, ASTM STP 789, F. A. Govan, D. M. Greason and J. D. McAllister, Eds., American Society for Testing and Materials, Philadelphia, 1982, pp. 132-144.
5. K. Sheppard, S. Patel, M. Taneja and R. Weil, "Comparison of Several Accelerated Corrosiveness Test Methods for Thermal Insulating Materials," in Corrosion of Metals Under Thermal Insulation, ASTM STP 880, W. Pollock and J. Barnhart, Eds. American Society for Testing and Materials, Philadelphia, 1985, pp. 220-230.
6. Seton, Johnson and Odell, Inc., G. Tsongas and Applied Social Research, Inc., "A Field Study of Moisture Damage in Walls Insulating Without a Vapor Barrier," Technical Report ORNL/Sub-78/977261/1, Oak Ridge National Laboratory, Oak Ridge, TN, May 1980.
7. "Minnesota Retrofit Insulation In-Situ Program," Technical Report HCl/w 2843-91, U.S. Department of Energy, Washington, DC, 1978.
8. F. S. Wang, "Comparative Studies of Vapor Condensation Potentials in Wood-Framed Walls," ASHRAE/DOE Conference on Thermal Performance of the Exterior Envelopes of Buildings, December 1979, Orlando, Fl.
9. R. W. Anderson and P. Wilkes, Survey of Cellulosic Insulation Materials, Technical Report ERDA 77-23, Energy Research and Development Administration, Washington, D.C., 1977.
10. ASHRAE Handbook: Fundamentals, American Society of Heating, Refrigeration and Airconditioning Engineers, 1977, Chapter 21.
11. B.D. McGuire, Regal Industries, Crothersville IN 47229, private communication.
12. M.G. Fontana, "Corrosion Engineering", McGraw-Hill, 3rd Edition, 1986, pgs. 392-395.

APPENDIX I

INSULATION STANDARDS CONTAINING CORROSIVENESS TESTING PROCEDURES

Copies are included here of corrosiveness testing procedures specified in current U.S. Standards for residental thermal insulation materials. These include:

1. ASTM C739, Specification for Cellulosic Fiber (Wood-Base) Loose-Fill Thermal Insulation

2. GSA HH-I-515D, Federal Specification for Insulation Thermal (Loose Fill for Pneumatic or Poured Application): Cellulosic or Wood Fiber (This standard is federally mandated.) Procedure the same as ASTM C739 test method A.

3. ASTM C665, Standard Specification for Mineral-Fiber Blanket Thermal Insulation for Light Frame Construction and Manufactured Housing

4. ASTM C764 Mineral Fiber Loose-Fill Thermal Insulation. Procedure the same as ASTM 665.

ASTM - American Society for Testing and Materials.
GSA - General Services Administration.

Standard Specification for CELLULOSIC FIBER (WOOD-BASE) LOOSE-FILL THERMAL INSULATION[1]

This standard is issued under the fixed designation C 739; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification covers the composition and physical requirements of chemically treated, recycled cellulosic fiber (wood-base) loose-fill type thermal insulation for use in attics or enclosed spaces in housing, and other framed buildings within the ambient temperature range from −45.6 to 82.2°C (−50 to 180°F) by pneumatic or pouring application. While products that comply with this specification may be used in various constructions, they are adaptable primarily, but not exclusively, to wood joist, rafters, and stud construction.

1.2 The values stated in SI units are to be regarded as the standard.

5.2 *Corrosiveness*—The loose fill insulation material shall be tested for corrosiveness as specified in Section 9. The composition of the insulation material shall be such that after testing, no perforation of the 3-mil (76-μm) metal specimens shall be evident when the specimens are observed over a 40-W appliance light bulb. Notches extending into the coupon 3 mm or less from any edge shall be ignored.

9. Corrosiveness

9.1 *Scope*—This test method covers the determination of the corrosiveness of cellulosic insulation. The cellulosic insulation shall be tested for corrosiveness using the measured design density, as determined in Section 8. The pass/fail criteria is given in 5.2.

9.2 *Significance and Use*—This test method provides a basis for estimating the corrosiveness of cellulosic insulation in contact with steel, copper, and aluminum test materials. The test method represents one set of exposure conditions designed to accelerate possible corrosive effects, and may not simulate exposure conditions experienced in actual field applications.

9.3 *Apparatus and Materials:*

9.3.1 *Humidity Chamber (Test Method A)*, air-circulating, capable of maintaining a temperature of 48.9 ± 1.7°C (120 ± 3°F) and 97 ± 1.5 % relative humidity throughout the active portion of the chamber.

9.3.2 *Oven (Test Method B)*, air circulating, capable of maintaining a temperature of 48.9 ± 1.7°C (120 ± 3°F) throughout the active portion of the chamber.

9.3.3 *Crystallizing Dishes*, six, glass, 90 mm (3.54 in.) in diameter by 50 mm (1.9 in.) in height.

9.3.4 *Containers*, six, glass, polyethylene or polypropylene, with screw cap or friction top lid capable of sealing, 127 mm (5 in.) in nominal diameter and 76 mm (3 in.) in nominal height.

9.3.5 *Gloves*, clean and in good condition.

9.3.6 *Chemicals*—Reagent-grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available.[6]

[5] The precision and bias of the Cyclone-Shaker-Blower test method is under evaluation by Subcommittee C16.23 and may in the future include an adjustment figure or other modifications.

[6] "Reagent Chemicals, American Chemical Society Specifications," Am. Chemical Soc., Washington, DC. For suggestions on the testing of reagents not listed by the American Chemical Society, see "Reagent Chemicals and Standards," by Joseph Rosin, D. Van Nostrand Co., Inc., New York, NY, and the "United States Pharmacopeia."

9.3.7 *Water*, distilled or deionized.

9.3.8 *Forceps.*

9.3.9 *Test Coupons:*

9.3.9.1 Two, 3003 Bare Aluminum alloy, zero temper.

9.3.9.2 Two, ASTM B 152, Type ETP, Cabra No. 110 soft copper.

9.3.9.3 Two, low-carbon, commercial quality, cold-rolled, less than 0.30 % carbon, shim steel.

9.3.9.4 Each coupon shall be 50.8 by 50.8 by 0.076 mm (2 by 2 by 0.003 in.) thick, free of tears, punctures, or crimps. Six coupons shall be used for one test of the insulation.

9.4 *Sampling*—Samples of cellulose insulation used for testing shall be blown, combed, or otherwise mixed to reasonably assure homogeneity of the sample.

9.5 *Procedure:*

9.5.1 *Precleaning Metal Coupons:*

9.5.1.1 During fabrication, cleaning, or testing never touch the metal coupons by ungloved hands.

9.5.1.2 Handle cleaned coupons with only clean forceps.

9.5.1.3 In order to avoid exposing laboratory personnel to toxic fumes perform all cleaning in a fume hood.

9.5.1.4 Clean the coupons by vapor degreasing with 1-1-1 Trichloroethane for 10 min. Following vapor degreasing subject the coupons to caustic or detergent washing, or both, as appropriate. Following caustic or detergent washing, rinse the coupons in flowing water to remove residues. Inspect each coupon for a water-break free surface. (A water-break is a break, separation, beading, or retraction of the water film as the coupon is held vertically after wetting.) As the coupons are cleaned, the water film should become gradually thinner at the top and heavier at the bottom. Hot-air dry the coupons at 105°C (221°F).

9.5.2 *Preparation of Test Samples:*

9.5.2.1 Determine the design density of the sample in accordance with Section 8.

9.5.2.2 For each metal coupon, subdivide a 20-g (0.7-oz) sample of insulation into two 10-g (0.35-oz) portions. Determine the quantity of distilled or deionized water to be used for each 10-g (0.35-oz) portion using the following equation:

$$\frac{46}{d} \times 75 \text{ mL}$$

where:
d = design density, kg/m^3.
or

$$\frac{2.9}{d} \times 75 \text{ mL}$$

where:
d = design density, lb/ft^3.

9.5.2.3 Presaturate each 10-g (0.35-oz) portion with the determined amount of water. Place one presaturated 10-g portion into a crystallizing dish, tamp level using the bottom of a clean suitably sized glass beaker. Place a metal coupon onto the presaturated insulation portion and center it in a horizontal plane. Place the other presaturated 10-g portion into the crystallizing dish on the metal coupon and tamp the composite specimen (metal coupon and saturated insulation in the crystallizing dish) to assure an even distribution of this material and to assure good contact of the insulation with the metal. Exercise care in preparing the composite specimens to eliminate air pockets from forming next to the metal coupons.

9.5.2.4 Do not cover the crystallizing dish. Care should be taken to avoid evaporation from the composite during preparation or until it is placed on the testing chamber.

9.5.3 *Sample Test Cycle*—Use either a humidity chamber (Method A) or an oven (Method B) to provide for the required temperature and relative humidity exposure.

9.5.3.1 *Test Method A*—Test Method A is given to be consistent with federal standards and Test Method B is given as an alternative since the 97 ± 1.5 is an alternative requirement.

(*a*) Precondition the humidity chamber to 48.9 ± 1.7°C (120 ± 3°F) and 97 ± 1.5 % relative humidity.

(*b*) Place all six composite samples in the humidity chamber. Keep the samples in the humidity chamber 336 ± 4 h. During the test cycle, periodically monitor the temperature and humidity.

(*c*) During the test cycle, do not open the humidity chamber unless it can be determined that such openings do not adversely affect the test cycle.

(*d*) If drippings of condensate occurs within the humidity chamber, position guards over the samples to prevent the condensate from falling onto the samples.

9.5.3.2 *Test Method B:*

(*a*) Precondition the oven to 48.9 ± 1.7°C (120 ± 3°F).

(*b*) Place the crystallizing dishes containing the composite sample in separate 127-mm (5-in.) diameter containers.

(*c*) Add 70 mL of distilled water solution plus 25 g (0.88 oz) of potassium sulfate to the annular space between the crystallizing dish and the container. Use care not to add any of the solution to the composite sample. If any of the solution is inadvertently added to the composite sample, prepare a new composite.

(*d*) Loosely place the covers on the containers and preheat the containers 1 h in the oven at 48.9 ± 7°C (120 ± 3°F). After preheating, seal the containers by tightening the covers. Keep the containers in the oven 336 ± 4 h. During the test cycle, periodically monitor the temperature.

(*e*) During the test cycle, do not open the oven unless it can be determined that opening does not adversely affect the test cycle.

9.5.4 *Post-Test Cleaning of the Metal Coupons*—After completing the test cycle, disassemble the composite specimens. Thoroughly wash the metal coupons under running water and lightly brush them using a soft nylon bristle brush or equivalent to remove loose corrosion products. Remove the remaining corrosion products from the metal coupons by cleaning them as follows in a fume hood:

9.5.4.1 *Technique No. 1—Electrolytic Cleaning* (for copper, steel, and aluminum coupons). Electrolyze the coupons by making a solution containing 28 mL of sulfuric acid (sp gr 1.84), 2 mL of organic inhibitor, for example, about 0.5 g/L of such inhibitors as diorthotolyl thiourea, quinoline ethiodide, or betanaphthol quinoline, and 970 mL water. Maintain the solution at 75°C (167°F). Use carbon or lead for the anode and one metal coupon for carbon or lead. Electrolyze for 3 min at a current density of 20 A/dm^2. **Caution**: If using lead anodes, lead may deposit on the coupon. If the coupon is resistant to nitric acid, remove the lead by a flash dip in a solution of equal parts nitric acid and water. To avoid injury when mixing acid and water, for electrolytic cleaning gradually pour the acid into the water with continuous stirring, and provide cooling if necessary.

9.5.4.2 *Technique No. 2—Copper* (This technique or Technique No. 1 may be used for postcleaning only the tested copper coupons. Make a solution containing 500 mL of hydro-

chloric acid (sp gr 1.19), 100 mL of sulfuric acid (sp gr 1.84), and 400 mL of water. To avoid injury, prepare the solution by slowly adding the sulfuric acid to the water with continuous stirring. Cool, then add the hydrochloric acid slowly with continuous stirring. The solution shall be at room temperature. Dip the coupons in the solution for 1 to 3 min.

9.5.4.3 *Technique No. 3—Steel* (This technique or Technique No. 1 may be used for postcleaning only the tested steel coupons. Use one of the following two solutions:

(*a*) *Solution No. 1*—Add 100 mL of sulfuric acid (sp gr 1.84), 1.5 mL organic inhibitor, and water to make a 1-L solution. Maintain the solution at 50 ± 2°C (120 ± 35.6°F). Dip the coupons in this solution.

(*b*) *Solution No. 2* (Clarke's solution)—Add 20 g (0.71 oz) of antimony trioxide and 50 g (1.76 oz) of stannous chloride to 1 L of hydrochloric acid (sp gr 1.19). Stir the solution and use it at room temperature. Dip the coupons for up to 25 min in this solution stirring the solution at a rate so that deformation of the coupons does not occur.

9.5.4.4 *Technique No. 4—Aluminum* (This technique or Technique No. 1 can be used for postcleaning only the tested aluminum coupons.) Make a 1-L solution by adding 20 g (0.71 oz) of chromic acid and 50 mL of phosphoric acid (sp gr 1.69) to water. Maintain the solution at 80 ± 2°C (176 ± 35.6°F). Dip the coupons in this for 5 to 10 min. If a film remains, dip the coupons in nitric acid (sp gr 1.42) for 1 min. Repeat the chromic acid dip. If there are no deposits, use nitric acid alone.

9.5.5 *Inspection*—After cleaning the metal coupons, examine the coupons over a 40-W light bulb for perforations. Ignore notches that extend into the coupon 3 mm (0.04 in.) or less from any edge.

9.6 *Report*—The report shall include the following:

9.6.1 Description of the insulation tested.

9.6.2 ASTM method used.

9.6.3 The absence or presence of perforations of or by the metal coupons. Notches extending into the coupon 3 mm or less from any edge shall be ignored. The absence or presence or perforation by type of metal coupon may also be reported.

9.7 *Precision and Bias*—A precision and bias statement is not applicable to this test method because the test produces pass/fail results, not numerical results.

Standard Specification for
MINERAL-FIBER BLANKET THERMAL INSULATION FOR LIGHT FRAME CONSTRUCTION AND MANUFACTURED HOUSING[1]

This standard is issued under the fixed designation C 665; the number immediately following the designation indicates the year original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reappro A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

Subcommittee C16.23 is currently balloting a revision to delete "density" from 9.2.1 of this standard because density is not genera required.

1. Scope

1.1 This specification covers the composition and physical properties of mineral-fiber blanket insulation used to thermally or acoustically insulate ceilings, floors, and walls in light frame construction and manufactured housing. The requirements cover fibrous blankets and facings. Values for water-vapor permeance of facings are suggested for information that will be helpful to designers and installers.

1.2 The values stated in inch-pound units are to be regarded as the standard.

Standard Specification for
MINERAL FIBER LOOSE-FILL THERMAL INSULATION[1]

This standard is issued under the fixed designation C 764; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification covers the composition and physical properties of nodulated mineral fiber thermal insulation for use in attics or enclosed spaces in housing and other framed buildings.

1.2 The values stated in inch-pound units are to be regarded as the standard.

13.8 *Corrosiveness:*

13.8.1 *Scope*—This method provides a qualitative measure of the corrosiveness of mineral-fiber insulation by comparison to a control.

13.8.2 *Summary of Method:*

13.8.2.1 Five each of specially cleaned steel, copper, aluminum, and galvanized steel test plates are individually sandwiched between pieces of insulation. The insulation is uniformly held against each side of the test plate with wire screens and rubber bands.

13.8.2.2 An equal number of cleaned metal test plates are sandwiched between pieces of washed sterile cotton in an identical manner.

13.8.2.3 The samples are suspended vertically in a humidity test chamber at 95 ± 3 % relative humidity and 120 ± 3°F (49 ± 2°C) for time periods determined by the type of metal being tested. Steel is tested for 96 ± 2 h. Copper, aluminum, and galvanized steel are tested for 720 ± 5 h.

13.8.2.4 After the appropriate test period, the test plates exposed to the insulation are compared to the control plates exposed to sterile cotton for severity of corrosion. The insulation is considered to have passed this test if the corrosion attributed to the insulation is not significantly worse than that of the washed sterile cotton controls. The criterion for acceptance is predetermined through the use of non-parametric statistics and a 90 % confidence level ($\alpha = 0.10$).

NOTE 3—A task group of Subcommittee C 16.31 is developing a more quantitative insulation corrosiveness test method that when available will be considered for adoption in this specification.

13.8.3 *Significance and Use:*

13.8.3.1 The fiber composition and the type of binder used in the manufacture of mineral fiber insulation can sometimes create a potential for corrosion on certain metals in the presence of water or water vapor.

13.8.3.2 This method is used to determine the relative corrosion potential of mineral fiber insulation on specific metals under high humidity conditions.

13.8.4 *Apparatus*

13.8.4.1 *Test Plates*—The dimensions of all metal test plates shall be 1 by 4 ± ¼ in. (25 by 100 ± 6.3 mm):

(*a*) *Steel Plates,* shall be 0.02 ± 0.005 in. (0.5 mm ± 0.13 mm) thick, bright No. 2 finish, cold-rolled low-carbon strip steel, quarter hard, temper No. 3.

(*b*) *Aluminum Plates,* shall be 0.025 ± 0.005-in. (0.6 ± 0.13 mm) thick, Type 3003-0.

(*c*) *Copper Plates,* shall be 0.032 ± 0.005-in. (0.8 ± 0.13 mm) thick, ASTM B 152 Type ETP, No. 110 soft copper.

(*d*) *Galvanized Plates,* shall be 0.034 ± 0.005-in. (0.9 ± 0.13 mm) thick (22 gage), hot-dipped galvanized sheet steel, ASTM 446 Standard Grade A or B with a total zinc coating of 9 ± 1 oz/ft^2 (2755 ± 28 g/m^2), with at least 40 % of the total zinc content on each side.

13.8.4.2 *Woven Wire Screen,* 1½ ± ¼ by 4½ ± ¼ in. (38 ± 6.3 by 114 ± 6.3 mm), made of Type 304 stainless steel, 0.063 ± 0.005-in. (1.60 ± 0.13-mm) wire, 7/16 ± 1/16-in. (11 ± 1.6-mm) open-square grid.

13.8.4.3 *Rubber Bands,* No. 12.

13.8.4.4 *Humidity Test Chamber,* clean, well maintained, and capable of controlling temperature at 120 ± 3°F (49 ± 2°C), and humidity at 95 ± 3 % relative humidity.

13.8.5 *Test Specimens*—Two pieces of the material to be tested shall comprise one specimen. Each piece shall measure 1½ ± ¼ by 4½ ± ¼ in. (38 ± 6.3 by 114 ± 6.3 mm) by ½ ± ⅛ in. (13 ± 3.2 mm) thick, when compressed against the metal test plates. As a guideline, cut board type insulations to a thickness of ½ ± 1/16 in (12.7 ± 1.6 mm); cut blanket type insulations to a thickness of 1 ± 1/16 in. (25.4 ± 1.6 mm). For each type of metal tested, make five specimens out of test insulation and five control specimens out of washed sterile cotton.

13.8.6 *Procedure:*

13.8.6.1 The metal test plates shall be cleaned until the surface is free of water breaks. Take care to avoid excessive handling of the surfaces of the metal plates. Do not touch them at all once completing the final cleaning step. The use of plastic surgical gloves or their equivalent are recommended to facilitate the handling of the plates. *Specific cleansing instructions for each type of metal is as follows:*

(*a*) *Steel and Galvanized Steel*—First clean the test plates by vapor degreasing for 5 min using 1-1-1 trichloroethane or chloroprene. After degreasing, wipe the residue from both sides of the coupons using paper laboratory wipes. Next, immerse for 15 min in a hot caustic solution (15 % potassium hydroxide (KOH) by volume), rinse thoroughly in distilled water, and immediately dry using paper laboratory wipes.

(*b*) *Copper*—Degrease the test plates in the same manner as the steel plates, then clean again in a hot acidic solution (10 % nitric acid by volume) for 15 min. Then rinse and dry the copper plates in the same manner as described in 13.8.6.1 (*a*).

(*c*) *Aluminum*—Clean the test plates with a 5 % solution of all-purpose laboratory detergent and water, then rinse in distilled water and dry with laboratory wipes.

(*d*) *Wire Screens*—The wire screens should also be cleaned before use in the same manner as the aluminum plates, that is, washed in detergent, rinsed in distilled water, and dried.

13.8.6.2 Make five test specimens, each one consisting of one piece of metal placed between two pieces of insulation. Next, compress this assembly between two pieces of woven wire screen and secure near each end with a No. 12 rubber band or other means to ensure that the compressed thickness of this assembly measures 1 ± ⅛-in. (25 ± 3 mm).

13.8.6.3 Assemble 5 control specimens, each consisting of one piece of metal placed between two 1½ by 4½ by ½-in. (38 by 114 by 13-mm) pieces of sterile cotton. The sterile cotton shall have previously been solvent extracted in ACS reagent grade acetone for 48 h, and then vacuum dried at low heat. Identify the outer surface of the cotton as rolled. After cleaning, place the outer cotton surface against the metal coupons in the same manner as the insulation specimen. Then compress and secure these specimens in exactly the same manner as the insulation test specimens using wire screens and No. 12 rubber bands or other suitable means to maintain sample thickness.

[5] Wittes, J., and Furk, A., "The Selection of Judges for Odor Discrimination Panels," *Correlation of Subjective-Objective Methods in the Study of Odors and Taste, ASTM STP 440,* ASTM, 1968, pp. 49–70.

13.8.6.4 Vertically suspend the five test specimens and the five control specimens in an atmosphere free of contaminants, having a relative humidity of 95 ± 3 %, and a temperature of 120 ± 3°F (49 ± 2°C) for the specified test period (96 ± 2 h for steel, and 720 ± 5 h for copper, aluminum, and galvanized steel). If possible, close the humidity chamber for the entire test period. If the chamber must be opened, take care to ensure that the relative humidity does not rise sufficiently high to cause condensation within the chamber. At the conclusion of the test period, remove the specimens from the chamber, disassemble and mark them to distinguish individual plates from each other.

13.8.6.5 Closely examine the surfaces of each of the test and control plate for the following characteristics:

(*a*) *Steel*—The presence and relative severity of red rust and pitting. Surface blush should not be weighed strongly.

(*b*) *Aluminum*—The presence and relative severity of pitting, scaling, or other evidence of attack. The generation of oxide is a protective mechanism of aluminum and should be disregarded. The oxide can be removed by scrubbing with a nonabrasive implement of rubber under running water or immersing into a 70 % solution of nitric acid.

(*c*) *Copper*—Presence and relative severity of scaling, pitting, deposits or encrustation, severe discolorations, or general uniform attack. Surface blush and slight discolorations should be ignored and can be removed by scrubbing with a nonabrasive implement of rubber under running water or immersing into a 10 % solution of sulfuric acid.

(*d*) *Galvanized Steel*—Presence and relative severity of loss of coating thickness, red rust, or obvious signs of attack. The plates can be cleaned by scrubbing with a nonabrasive implement of rubber under running water.

NOTE 4—Additional guidance for evaluating the plates can be found in Practice G 1.

13.8.7 *Interpretation of Results:*

13.8.7.1 Because of the subjectivity inherent in the judging of these plates, nonparametric statistical methods are employed to identify those materials that are conclusively more corrosive than sterile cotton.

13.8.7.2 The ten metal plates (5 test, 5 control), should be examined by at least four judges with experience in corrosion evaluation. Each judge should independently rank all ten plates in order from least severe corrosion to most severe corrosion. The judges should receive no indication as to which plates are control and which are test specimens. The judges' rankings should be based on their own best estimate of the severity of the corrosion visible on each plate.

13.8.7.3 Upon completion of the judges' ratings, the arithmetic sum of all of the rankings for each plate should be calculated. These sums should then be ranked from 1 (lowest total) to 10 (highest total), with any ties being assigned the arithmetic mean of the rankings involved (for example, 2 plates tied for third = (3 + 4)/2 = 3.5; 3 plates tied for fourth = (4 + 5 + 6)/3 = 5). The new rankings thus established should then be totaled for the control plates only; if this sum is less than 21, then the control plates are judged to be significantly better than the test plates and the insulation tested is considered to have *failed* the test. Any sum of the rankings for the five control plates ≥ 21 indicates that there is no statistical difference between the control and test plates, and the insulation is considered to have *passed*.

13.8.8 *Precision and Bias*—Assuming that there is no bias involved in the judges' rankings, this method will identify those materials that are significantly worse than sterile cotton with a statistical confidence of $\alpha = 0.10$. This means that a material that is judged to be more corrosive to a metal than sterile cotton has at most a 10 % chance of being incorrectly failed. This method can make no estimate of the probability than an insulation that is more corrosive than sterile cotton will not be identified as such.

APPENDIX II

ESTIMATION OF TEMPERATURE AND VAPOR PRESSURE PROFILES IN TEST WALL

An estimation of the possible temperature and vapor pressure profiles through the test wall were calculated using the method described in the ASHRAE Handbook: *Fundamentals*, American Society of Heating, Refrigeration and Airconditioning Engineers, 1977, Chapter 21.

First the temperature profiles were calculated assuming the wall components form a series of thermal resistances. The temperature at each interface can be calculated as the temperature drop through each component is proportional to its resistance. The values for resistances were taken from the above reference and are listed below. Once the temperature profiles are known, the saturation vapor pressure profiles can be calculated or read from psychrometric tables. The actual vapor pressure profiles were calculated based on inside and outside vapor pressures and the vapor resistances of each wall component are used to calculate the pressure drop across each component. These values were also obtained from the ASHRAE Handbook and are given below. The calculated profiles are shown in the figure. It can be seen that the estimated vapor pressure profiles cross the saturation pressure profile inside the wall cavity for both types of outer sheathing. This suggests that condensation was possible with both plywood and foil-faced foam as an outer sheathing under the environmental conditions of this test.

In order to estimate the moisture accumulation rate, an assumption was made that condensation occurred at the inside surface of the sheathing. The condensation plane estimated above was very close to this point and the inside sheathing surface would therefore most likely be the nucleation point for moisture. The vapor pressure profile was recalculated assuminmg condensation. Assuming only diffusion as the mode of moisture migration, the rate of moisture transport to the condensation plane was calculated as well as that from the condensation plane to the outside of the wall. From this the accumulation rate was estimated. This is given on the figure. It can be seen that accumulation was approximately twice for the half of the wall with the plywood sheathing compared to that with the foam. Due to the assumptions used in the above calculations, the results can only be considered an approximate guide to the possibilities for condensation.

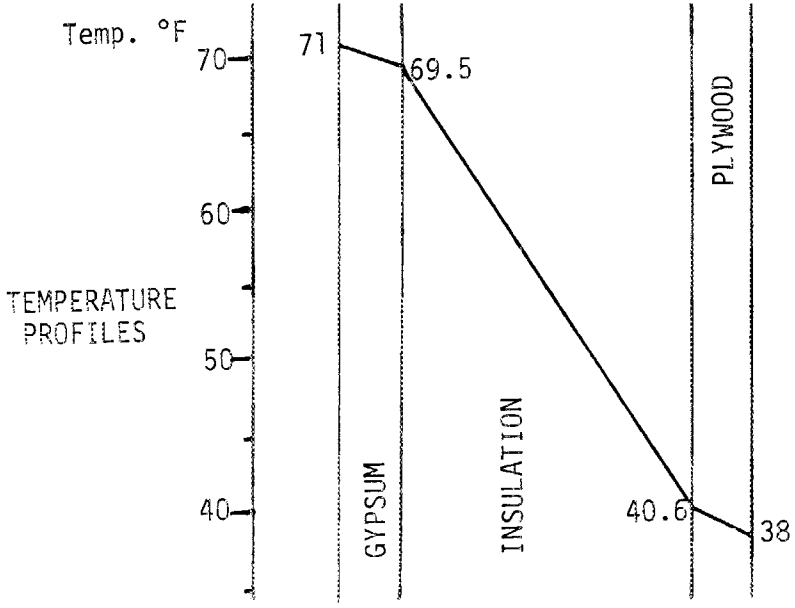
Handbook Data Used in Calculation [10]

Material	Thermal Resistance (R)	Vapor Resistance (Rep)
Gypsum (0.5"	0.56	0.03
Plywood (0.5")	0.77	2.80
Al-foil Faced DoM	3.25	20.00
Insulation	11.00	0.03

Units

R = foot^2 • °F • hour • Btu^{-1}.

Rep = inch Hg • foot^2 • hour • grain^{-1}


Temp. °F
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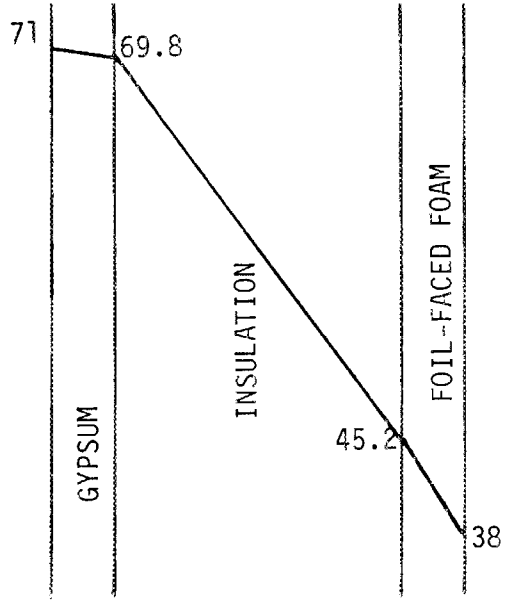
60
50
40
TEMPERATURE PROFILES
71
69.5
40.6
38
GYPSUM
INSULATION
PLYWOOD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69.8
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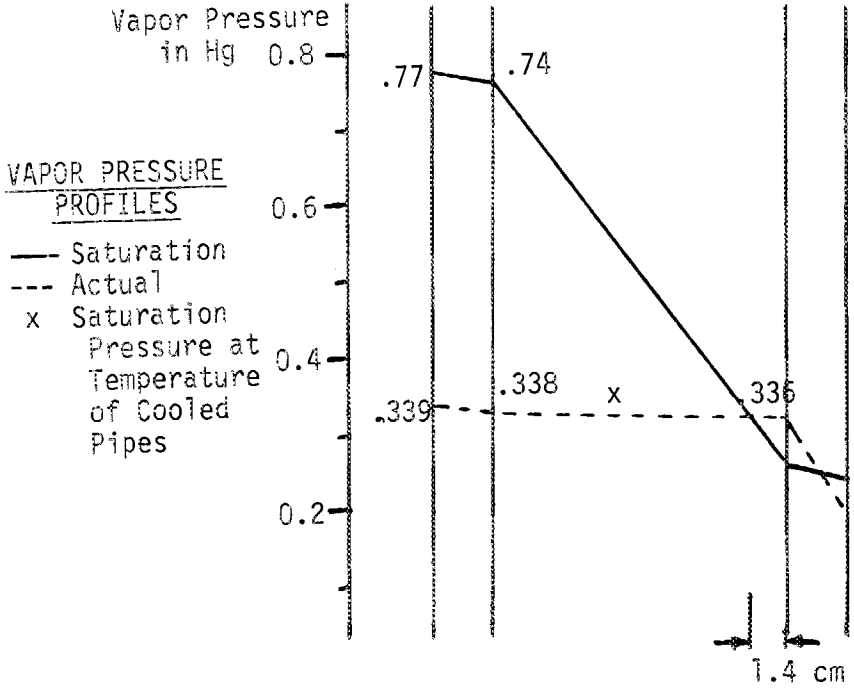
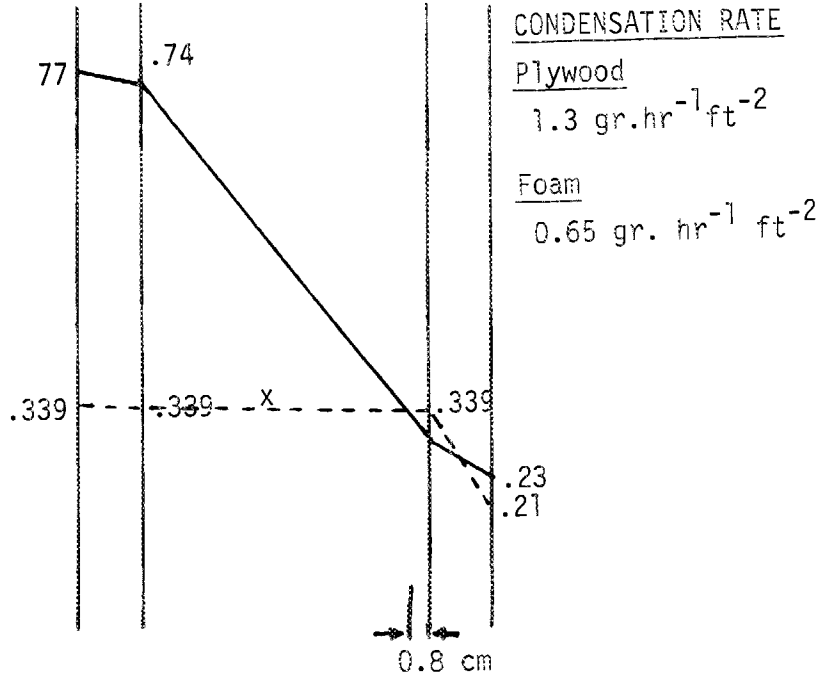
GYPSUM
INSULATION
FOIL-FACED FOAM

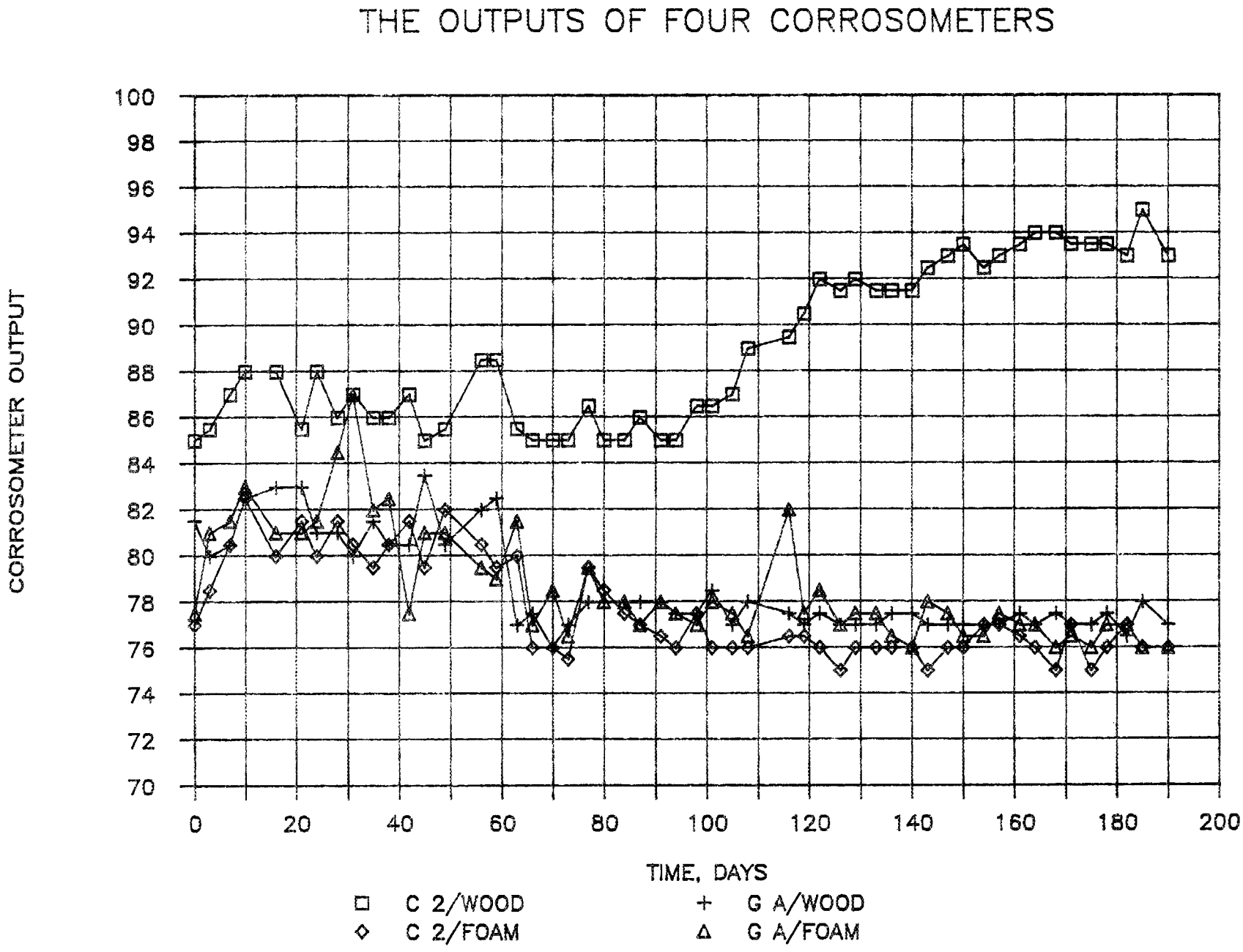

Vapor Pressure in Hg
0.8
0.6
0.4
0.2
VAPOR PRESSURE PROFILES
—— Saturation
--- Actual
x Saturation Pressure at Temperature of Cooled Pipes
.77
.74
.339
.338
x
.336
1.4 cm

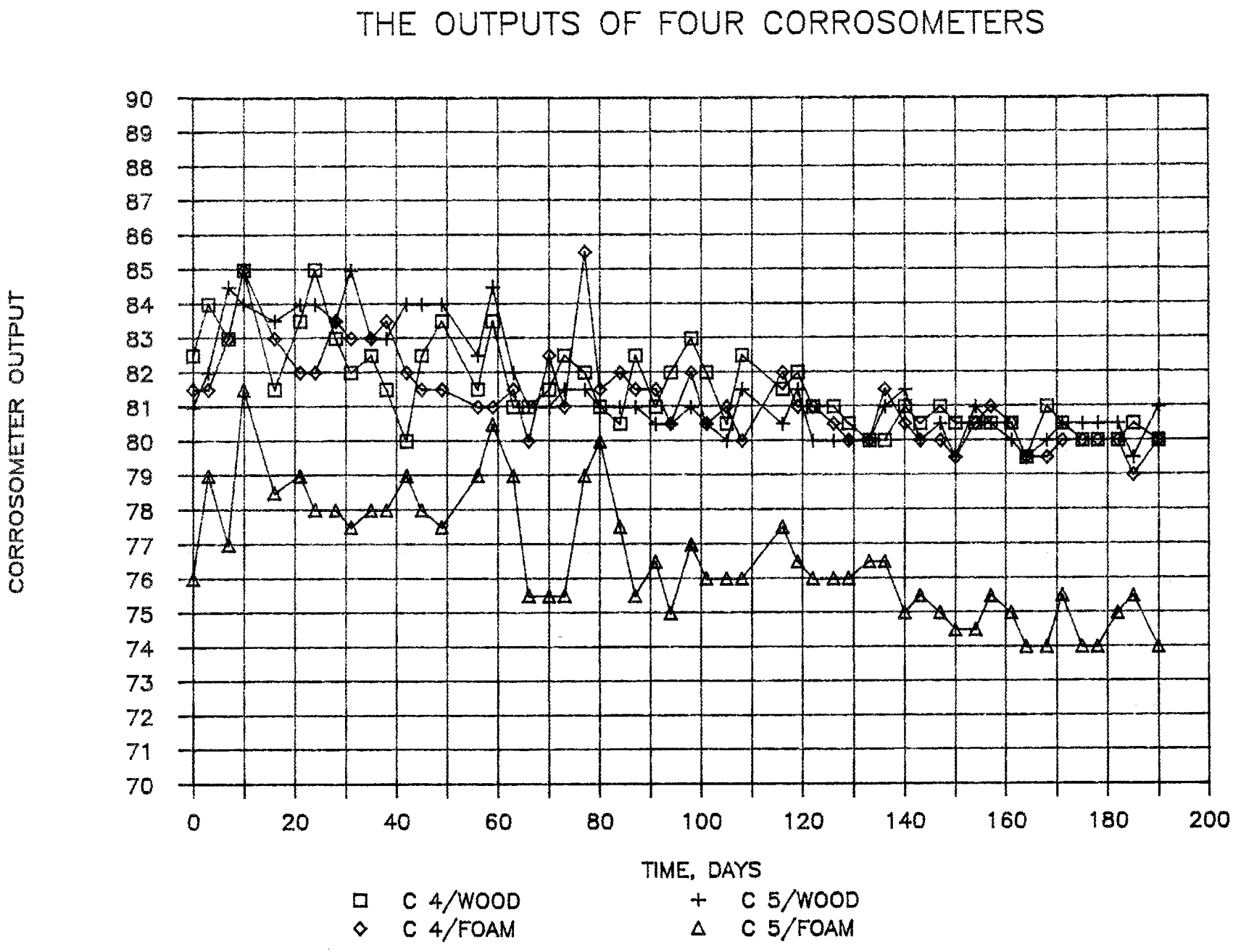

77
.74
.339
.339
x
.339
.23
.21
0.8 cm
CONDENSATION RATE
Plywood
1.3 gr.hr^{-1}ft^{-2}
Foam
0.65 gr. hr^{-1} ft^{-2}

APPENDIX III

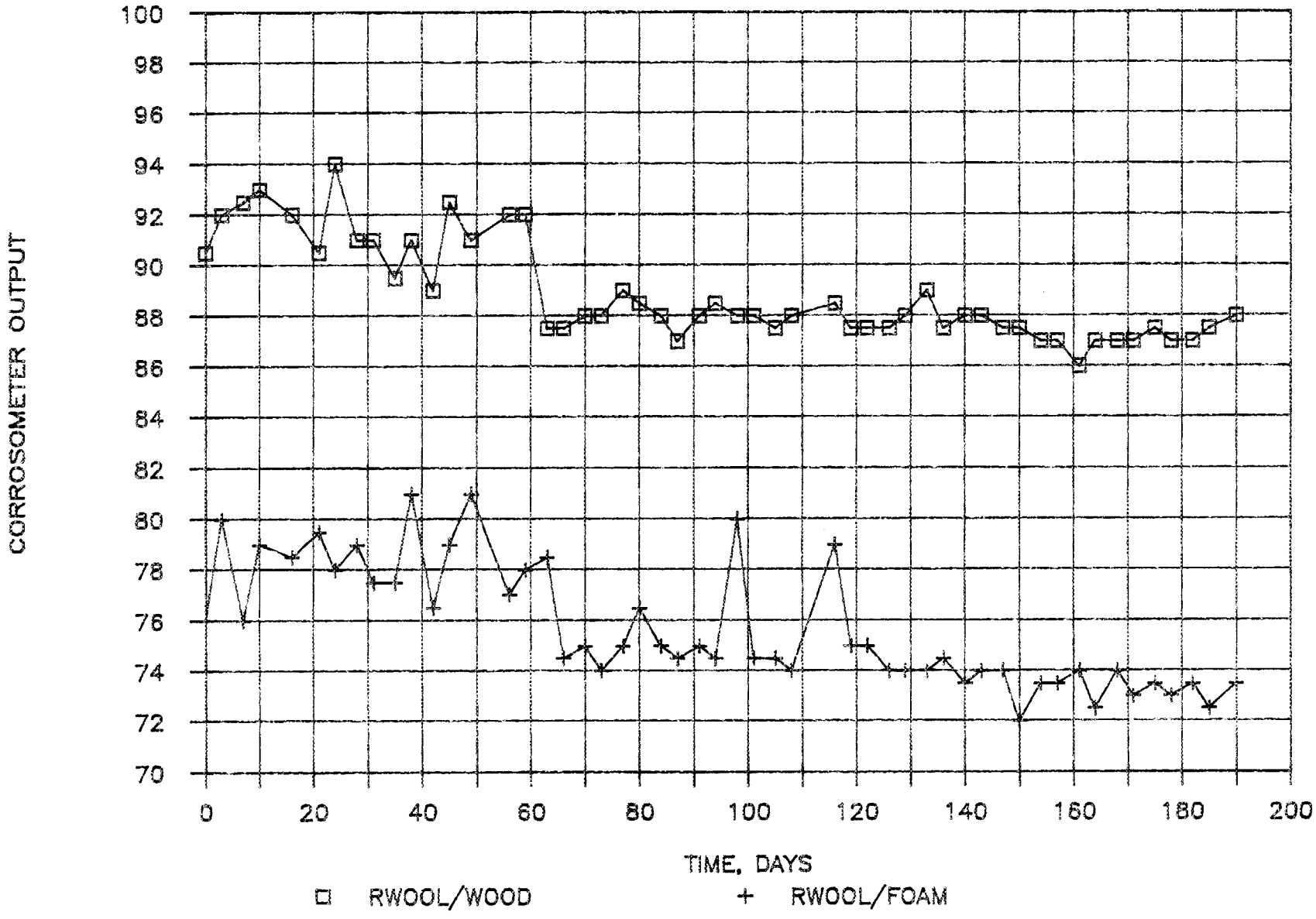
DATA FROM ELECTRICAL-RESISTANCE PROBES (CORROSOMETER)

The following three pages of graphs show the output of the electrical resistance probe monitoring device. This device uses a bridge circuit to record the difference in electrical resistance between two identical metal films. One is exposed to the environment, the other is protected. As corrosion of the exposed element occurs, its thickness will be reduced and its resistance will increase compared to the protected element. From the change in resistance one can calculate a corrosion rate if loss of metal is assumed to be uniform over the exposed metal surface. The corrosion rate will be proportional to the slope of the output from the bridge circuit versus time. In the data shown, there are sharp fluctuations from one reading to the next primarily due to experimental error in obtaining a reading from the measuring device. If one examines the average slope from start to finish of the test period, one observes no significant increase in slope except for the steel probe in Cellulose 2 in the cell having the plywood sheathing. This probe showed a small increase in resistance over the test period. On examination very little corrosion of the surface was observed. The legend for the curves shows the type of insulation - C representing cellulose, G representing glass fiber and Rwool representing rockwool. Also given is the sheathing type either Wood (plywood) or Foam (foil-faced polyisocyanurate).


THE OUTPUTS OF FOUR CORROSOMETERS
CORROSOMETER OUTPUT
100
98
96
94
92
90
88
86
84
82
80
78
76
74
72
70
0
20
40
60
80
100
120
140
160
180
200
TIME, DAYS
C 2/WOOD
C 2/FOAM
G A/WOOD
G A/FOAM


THE OUTPUTS OF FOUR CORROSOMETERS
CORROSOMETER OUTPUT
90
89
88
87
86
85
84
83
82
81
80
79
78
77
76
75
74
73
72
71
70
0
20
40
60
80
100
120
140
160
180
200
TIME, DAYS
C 4/WOOD
C 4/FOAM
C 5/WOOD
C 5/FOAM

THE OUTPUTS OF TWO CORROSOMETERS



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