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INSTRUMENTATION FOR FIELD DETERMINATION OF THE RATE OF EVAPORATION OF MOISTURE FROM PORTLAND CEMENT CONCRETE

by

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ABSTRACT

A means of rapidly estimating the rate of evaporation of moisture from a surface has been developed. The use of the evaporometer will enable field personnel to quickly determine when they must apply measures to protect freshly placed Portland Cement Concrete from excessive loss of moisture.

The report traces the development of this instrument and shows how to use it. The user is given a simple graph to convert readings from the evaporometer into the rate of evaporation. Construction details are included so that the Districts may construct the evaporometer for their field personnel.

SUMMARY

An instrument has been developed that will enable an observer to make a rapid field estimation of the rate of evaporation of water from freshly placed Portland Cement Concrete. The instrument permits field personnel to rapidly determine the evaporation rate and to anticipate when protective measures such as use of fog spray must be used.

The details of the instrument's development and theory are included. The use and operation is described and a simple graph is provided to convert the instrument reading into evaporation rate. Sketches, parts lists and construction details permit the reader to construct his own evaporometers.

IMPLEMENTATION

This instrument can be constructed in any shop for approximately five dollars. This test only takes one to two minutes depending on the weather conditions so it can be run as often as needed. Time for the complete test should not be more than a minute when the evaporation rate is near the critical rate mentioned by Portland Cement Association.

CONTENTS

Addendum To Report 3-20-70-028

"Instrumentation For Field Determination of the Rate of Evaporation of Moisture from Portland Cement Concrete"
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Field tests of the evaporometer have been run since publication of the original report in July 1974. These tests have shown the need for careful observation of additional factors such as dust, wind variation and location of the equipment. Dust blowing on the job site will adhere to the moist filter paper and could change the evaporation rate. The filter paper should be changed after each use under these conditions.

The field tests have provided data so that evaporometer values could be compared to calculated values. Table A shows these data along with calculated values of evaporation for different concrete temperatures. Chart No. 1 was prepared to replace Figure 7 (page 16) in order that these different temperature conditions could be more closely duplicated.

The calculated values show considerable variation. This can be attributed to wind gusting. Evaporometer readings should be taken during the highest wind velocity to find the maximum evaporation rates.

Chart No. 1 provides three curves for varying air-concrete temperature differentials. Curve A shows the relationship between time and the rate of evaporation when the concrete temperature is 10^{o} lower than the air temperature. Curve B shows the relationship when the temperatures are the same and Curve C shows the relationship when the concrete temperature is 10^{o} higher than the air temperature. It is recommended that the appropriate curve be used to obtain the most accurate estimation.

Readings should be taken under conditions similar to those prevailing at the concrete placement site. Temperature and wind are the major variables but shade and reflective surfaces can also affect the rate of evaporation. It is best not to put the evaporometer on a metal object because of the possibility of heat buildup.

There have been several inquiries concerning the filter paper used for the evaporometer. It is a Whatman Qualitative Grade #3 and is listed under the qualitative filter paper in chemical supply catalogs. Following are a few of the scientific products distributors and their catalog numbers for the eleven-centimeter disc Whatman filter paper #3.

Fisher Scientific Co.	9-820B
Matheson Scientific	22800-20
Sargent-Welsch Scientific Co.	S 33255-E
Curtin Scientific Co.	091-942

Table A
Field Test Data

Evaporation Rates
(Pounds Per Square Foot Per Hour)

				Calculated Evaporation Rates		
Air Temp. °F	Humidity %	Velocity mph	Evaporometer True Rate of Evaporation	Concrete Temp. at 80	Concrete Temp. at Air	Concrete Temp. Air +10 F
78	91	7	.042	0.029	0.016	0.090
		6	.040	.026	.015	.082
		5	.035	.024	.013	.073
		4	.035	.021	.012	.065
82	72	4	.054	.032	.042	.103
		3	.047	.028	.036	.090
		0	.048	.015	.020	.050
		3	.057	.028	.036	.090
83	69	2	.066	.024	.035	.082
84	66	3	.066	.029	.047	.104
		0	.062	.016	.026	.058
86	72	5	.091	.018	.054	.133
		4	.065	.016	.048	.118
		3	.066	.014	.042	.103
88	40	2.5	.084	.053	.089	.149
		0	.073	.032	.053	.089
90	50	6	.126	.052	.124	.225
		5	.109	.046	.111	.202
	55	5	.111	.035	.100	.191

Table A - Continued

Air Temp. °F	Humidity %	Velocity mph	Evaporometer True Rate of Evaporation	Calculated Evaporation Rates: Concrete Temp. at 80	Calculated Evaporation Rates: Concrete Temp. at Air	Calculated Evaporation Rates: Concrete Temp. Air + 10 F
90	55	4	.113	0.031	0.088	0.169
		3.5	.076	.028	.083	.158
		2.5	.097	.025	.071	.136
91	59	7	.272	.027	.116	.232
		5	.133	.022	.094	.188
		4.5	.139	.020	.089	.178
		4	.124	.019	.083	.167
		1.5	.091	.013	.056	.113
92	50	2	.101	.025	.078	.142
94	50	4	.133	.026	.113	.205
		2.5	.104	.021	.091	.165
		0	.067	.013	.054	.099
95	46	5	.139	.036	.142	.250
		4	.160	.032	.126	.222
		2	.133	.024	.093	.164
		0	.091	.015	.061	.107
96	37	1.5	.107	.034	.103	.170
97	66	2.5	.124	.021	.068	.151
99	59	3	.129	.016	.096	.191
		0	.097	.009	.053	.106
101	35	0	.104	.019	.090	.147

ERRATA

I. All references to a two centimeter scale change in the height of the fluid in the capillary tubing must be changed to a one-half inch scale change. In Report No. 3-20-70-028, these are:

a. Page 3, Line 3 of the second paragraph.

b. Page 9, Line 4 from top of the page.

c. Page 9, Method of Operation, Instruction #4.

d. Page 10, Figure 1, Label on X-Axis.

e. Page 11, Figure 2, Label in upper-left portion of graph.

f. Page 16, Figure 7, Label on Y-Axis.

g. Pages 19, 20 & 21, Table A, Label on column for "Time for Evaporometer."

II. Appendix Two, Page 23, Materials List. Change size of Capillary Tubing to read:

8 inch x 1 $\pm$ 1/4 mm I. D.

Page 24, Change second sentence in Instruction #3 to read: "Markings are made every quarter-inch and numbered every one-half inch."

Many methods are available for use by biologists and weather service personnel for measuring daily evaporation rates. Most of these were not adaptable to the Highway Department's field operations since results must be available in minutes rather than days or hours. The goal of this study was to find such a device capable of performing within these limitations.

The simplest and most logical approach appeared to be the modification of existing devices. Evaporation pans such as the ones used by the weather service could not be adapted because of their size and method of measurement. A change in the water level in the pan is measured by using a caliper with a hook on it. The caliper scale could not be reduced sufficiently for THD use. A Livingston Sphere uses a porous bulb connected to a bottle by a glass tube. This might have worked but was judged too fragile for field use. A Piche Evaporometer and the Atmometer as described in ASTM Test Method C 157, "Test for Length Change of Cement Mortar and Concrete," were tried during the course of this study. The Atmometer was made from molded epoxy, fabricated metal parts, and flexible tubing. Several versions were tried but they failed due to poor liquid flow to the Atmometer. In the method described by ASTM C 157, capillary action and surface tension of the water on the evaporating paper draw the water to the Atmometer. The altered units were unable to use the same capillary action and have rapid readability at the same time.

The use of the Piche Evaporometer (Figure 4, p. 13) was the most successful concept tried. This instrument is similar to an inverted test tube with filter paper held to its mouth. Water feeds by gravity to the filter paper where it evaporates. Air bubbles pass through the filter paper to relieve the vacuum from the displaced water. The instrument was modified so that the internal diameter of the tube was reduced to provide a faster visual indication of the evaporation rate. There is only a small volume of water in the capillary tubing. When it evaporates from the large surface area of the filter paper a distinguishable height change in the water column results. The first modification (Figure 5, p. 14) admitted air to the unit in the manner described. Due to the small internal diameter of the tubing, these bubbles would block the passage and stop the water flow. A water solution using a wetting agent was developed that alleviated this problem. This solution produced smaller bubbles that did not cling to the tubing. This unit was tested under various temperatures, relative humidity settings and different wind velocities. It was found that at high evaporation rates the filter paper evaporating surface began to dry from the edges toward the center. The resulting height change in the column then indicated a lower evaporation rate than the true rate. This apparently was caused by air bubbles being unable to enter the tube fast enough to relieve the partial vacuum caused by the rapid evaporation. Several variations were made in the water feeding system and in the filter paper diameters but no satisfactory solution was reached.

The modified Piche evaporometer was then inverted, a new base made, and the stopper for the filler tube eliminated. In the present modification (Figure 6, p. 15), surface tension of the water on the evaporating surface, draws the water up the capillary tubing. Since there are no bubbles in this unit, tap water can be used. Distilled water is best because it will not leave mineral deposits that could interfere with water flow and vary the evaporation rate.

Experimentation showed that three centimeters was a good diameter for the #3 grade filter paper. The larger diameters tended to flutter in wind currents and gave erratic readings. Filter paper is available in larger sizes and must be cut to a three centimeter diameter. These discs should be replaced after three or four uses to keep a clean evaporating surface.

Evaporation tests were made in an environmental room where different weather conditions could be simulated by changing wind velocity, temperature and relative humidity. Readings would fluctuate slightly during individual runs because the room controls could control the humidity only within a 6% range. The overall readings, however, appeared quite stable and consistent.

Two sets of data were obtained using different methods for measuring wind velocity. A wind velocity meter such as the type used for air conditioning measurements was used for the first set of data. This only measured velocities up to 11 miles per hour and covered too large an area for good accuracy. The second device used was an inclined manometer used with a pitot tube. With the manometer, accurate wind velocity readings could be made exactly at the evaporometer filter paper. Higher wind velocities could also be measured.

Many readings were made over a range of conditions so that evaporation rates could be correlated with their calculated values. The data from the first method was not used in this report since the wind velocity meter shows an average for an area and was not as accurate as the second method. The regression curve shape is only very slightly different but the numbers in the equation change noticeably. The points were plotted and a curve drawn showing the full range of agreement (Figure 2, p. 11). From this, another chart (Figure 7, p. 16) was derived. This relates evaporation rate of the evaporometer to approximate field evaporation rates. Since the evaporometer readings do not include a temperature differential between air and pavement, a higher rate is used in the graph to give a safety factor.

No field trials have been performed as of the date of this report. These tests are being planned. A supplemental report will be made upon completion.

A materials list and instructions for the construction of the instrument in its final state are shown in Appendix II.

VII. OPERATION

This device is simple to operate. A large evaporating surface is provided by a piece of filter paper. A limited supply of water for evaporation is held in the capillary tubing. The movement of the meniscus in the tubing allows measurement of the evaporation rate. This movement is timed over a two centimeter interval and the evaporation rate is determined from the calibration curve (Figure 7, p. 16).

The Method of Operation is as Follows:

1. A three centimeter diameter, #3 grade, filter paper disc is placed between the glass rod and the capillary tube.

2. The device is inverted and distilled water is poured into the plastic tubing.

3. Separate the glass rod and the glass tubing slightly so that the water will fill the capillary tube and wet the paper. By allowing the meniscus to drop down to the edge of the capillary tube, the surplus water can be removed from the filter paper after the paper is saturated.

4. Now the device is turned upright and readings made. When the meniscus passes a mark, time its movement for the next two centimeters.

5. The time is then entered on the graph in Figure 7 and the evaporation rate is read directly in pounds of water per square foot surface area per hour. After the evaporation rate has been found, the decision as to when to take protection steps may be made.

Power Curve Regression Analysis

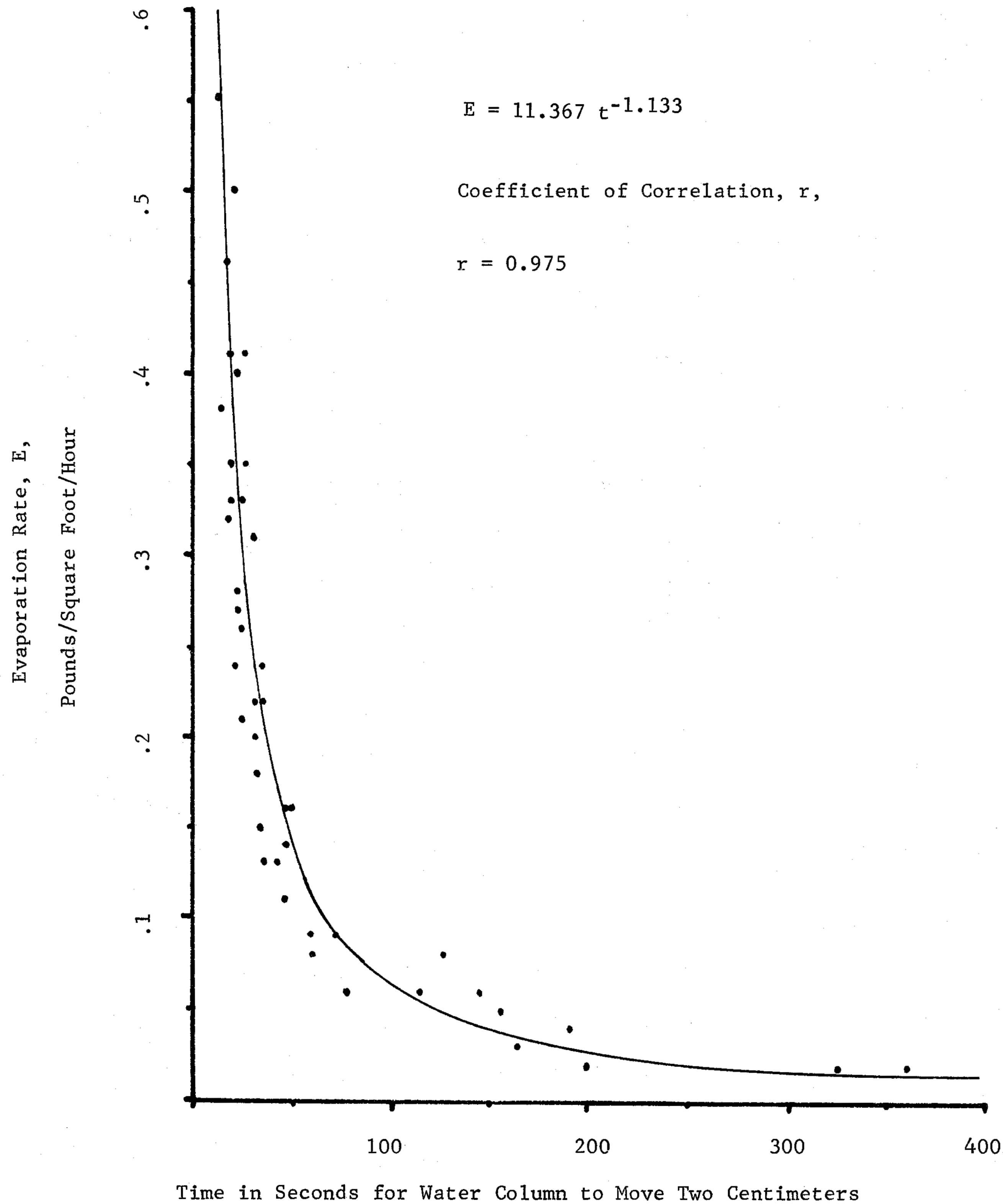
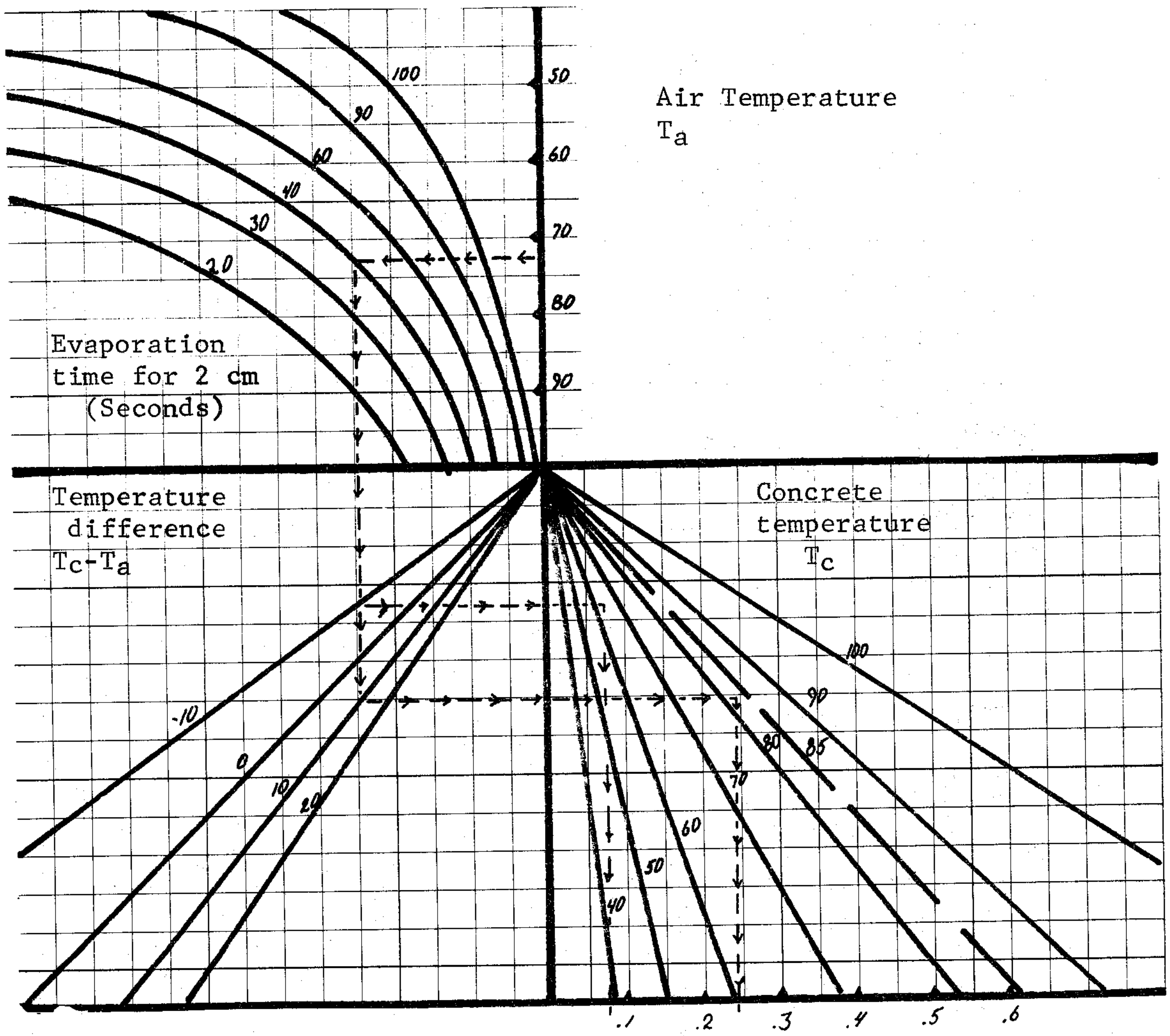


Figure 1

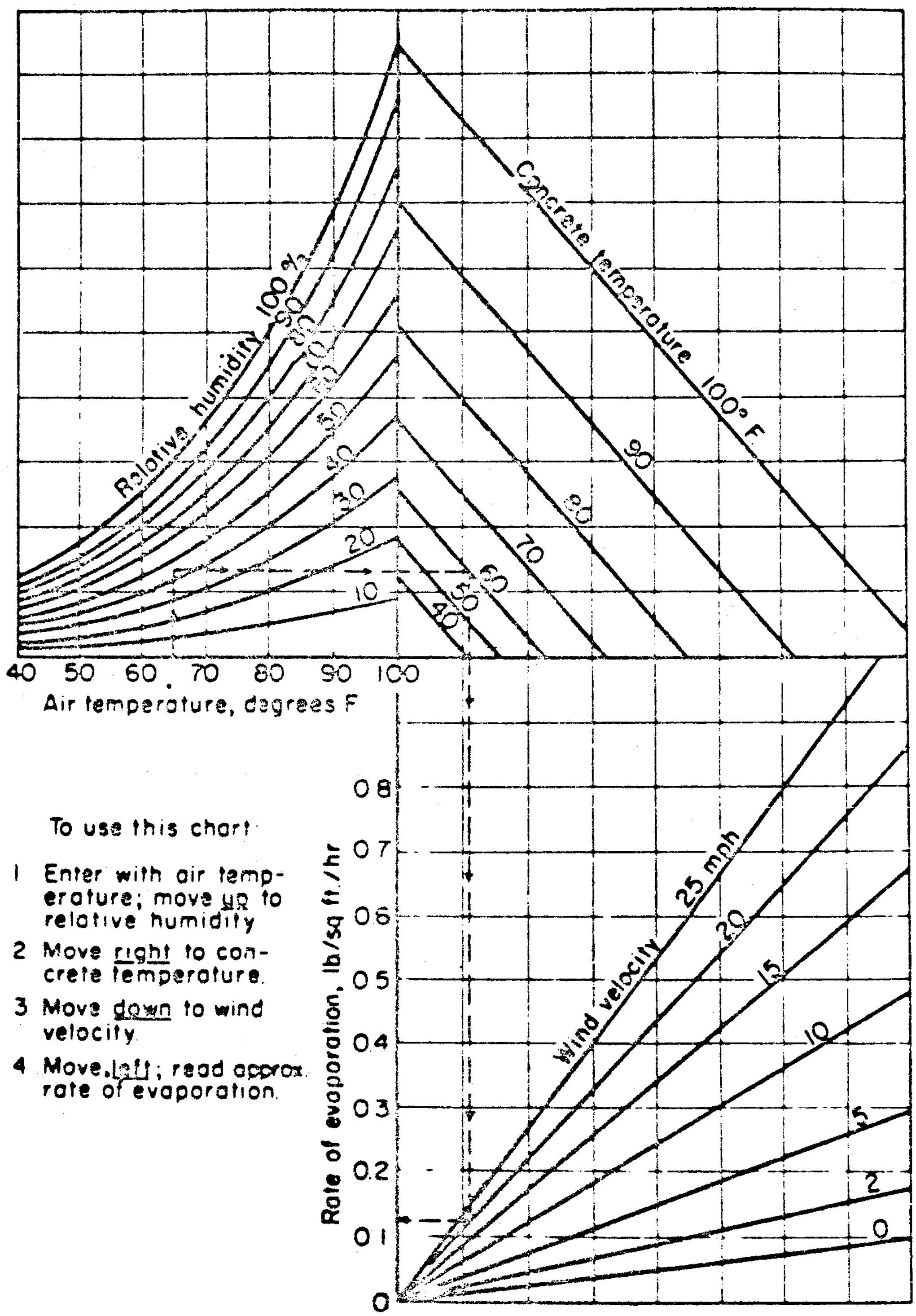
Original Evaporation Chart Showing
the Effects of Temperature Variations



Evaporation Rate
(lbs./sq. ft./hr.)

Figure 2

Nomograph From Item 420 THD Special Provisions



Effect of concrete and air temperatures, relative humidity, and wind velocity on the rate of evaporation of surface moisture from concrete.

Figure 3

The Piche Evaporometer

Figure 4

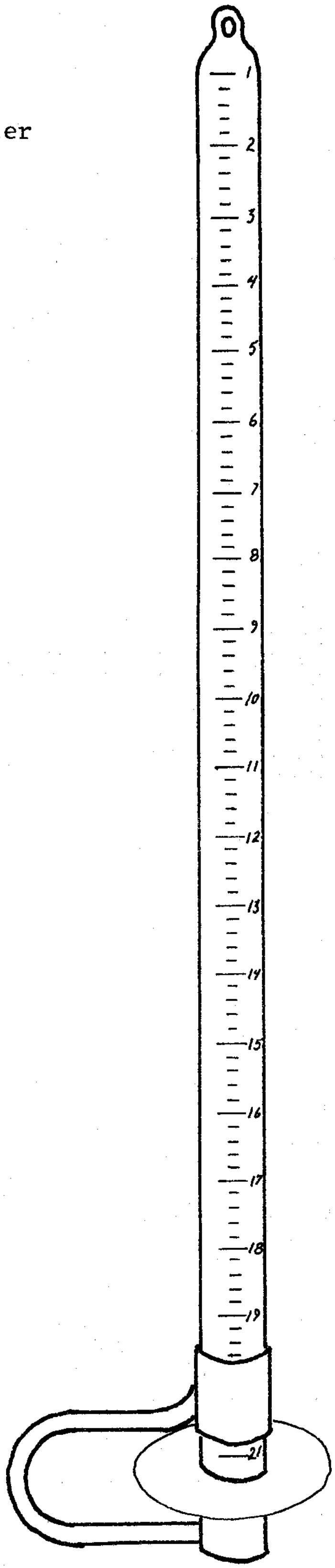
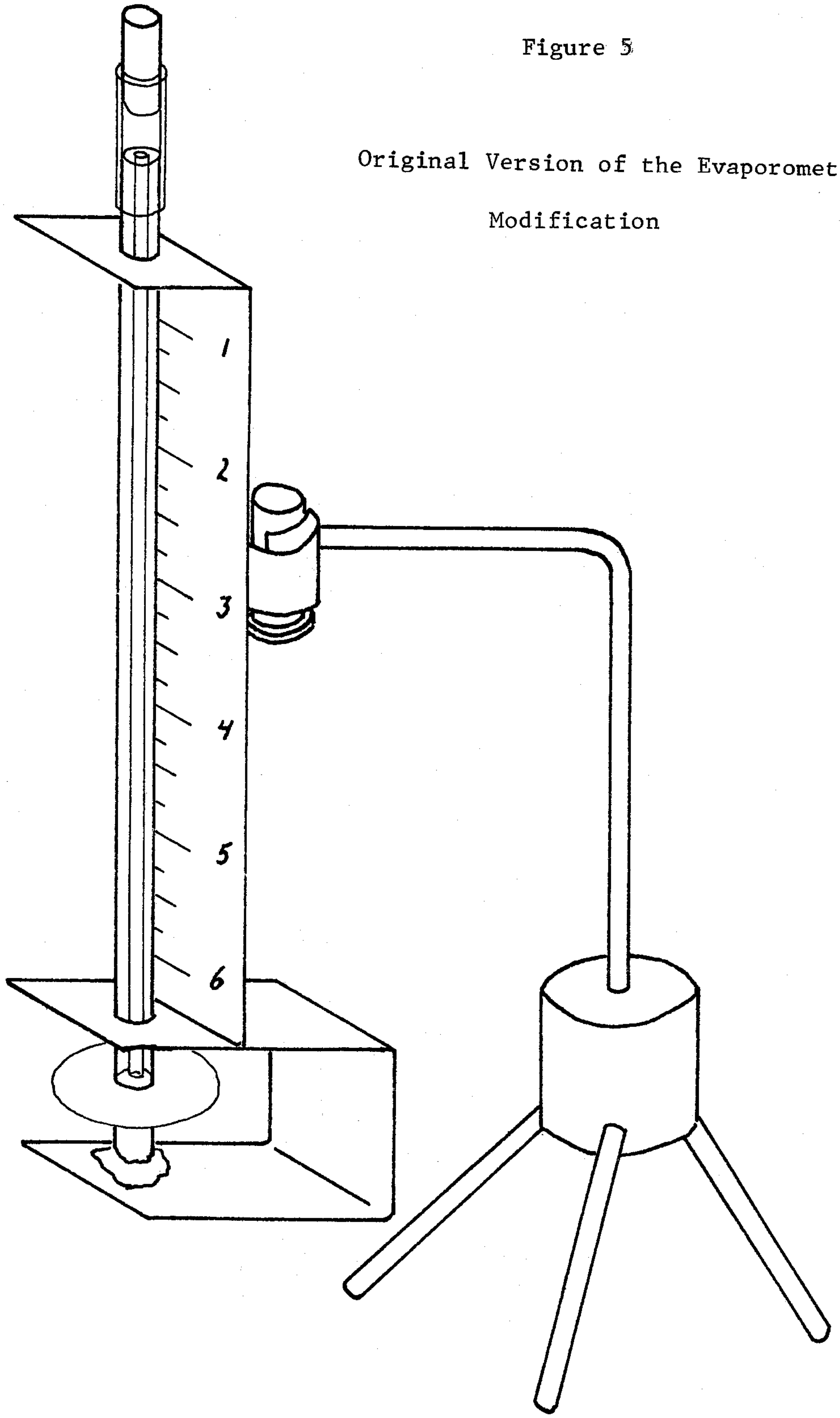


Figure 5

Original Version of the Evaporometer

Modification



Final Version of the Evaporometer

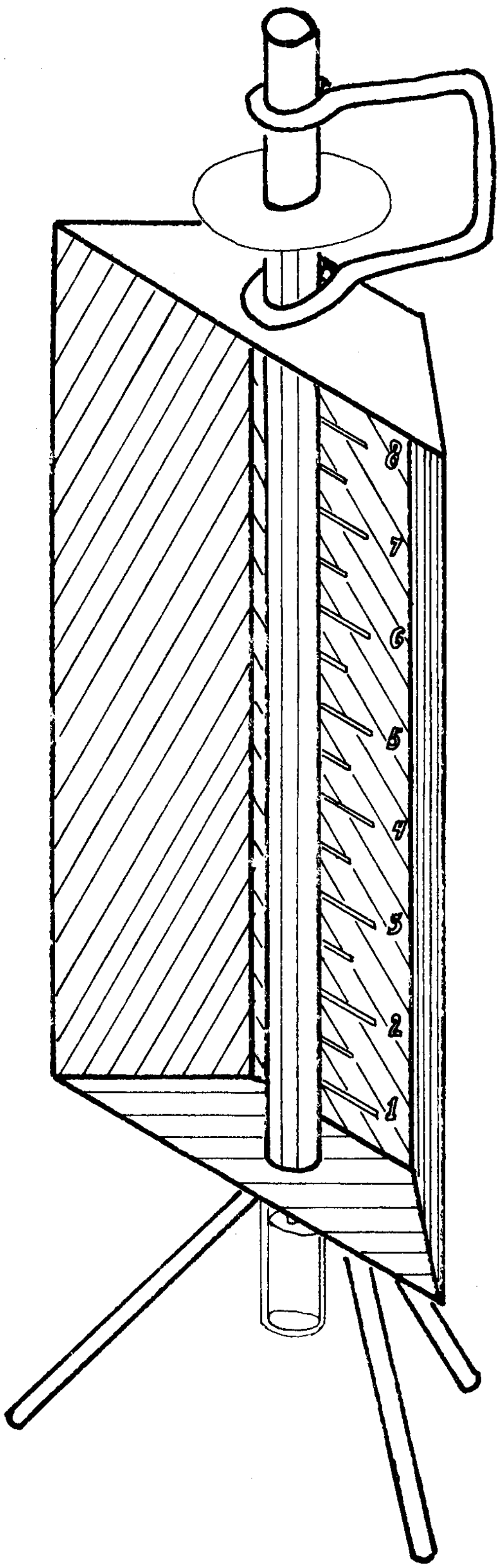
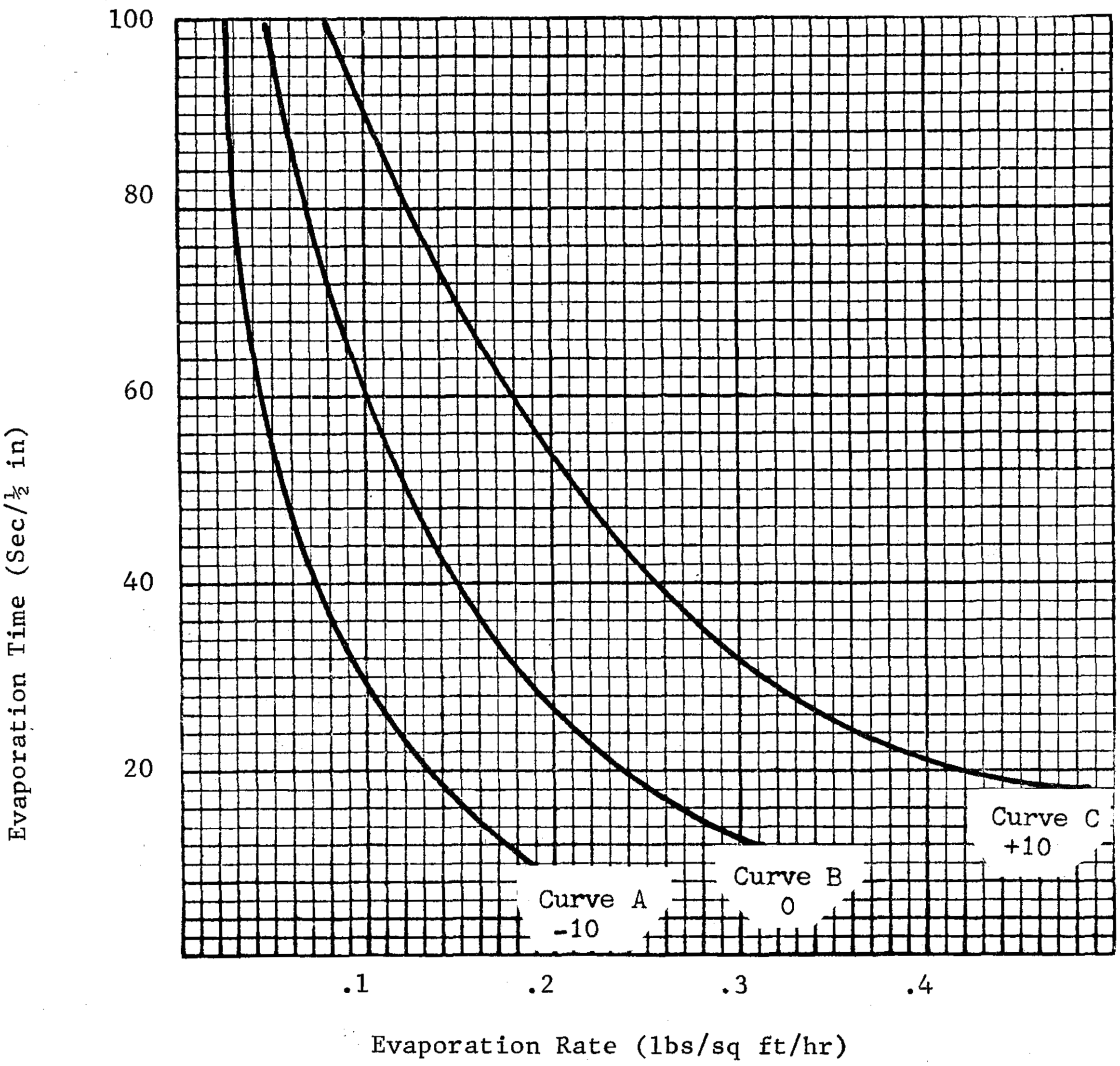


Figure 6

Chart 1
(Replaces Figure 7)



Curve A shows the correlation when concrete temperature is 10 degrees less than air temperature.

Curve B shows the correlation when concrete temperature is the same as air temperature.

Curve C shows the correlation when concrete temperature is 10 degrees higher than air temperature.

BIBLIOGRAPHY

1.) C. Abbe, "The Piche Evaporometer," Monthly Weather Review, Vol. 33, 1905.

2.) Design and Control of Concrete Mixtures, Portland Cement Association Engineering Bulletin #3, July 1968.

3.) R. E. Horton, "A New Evaporation Formula Developed," Engineering News Record, Vol. 18 #4, April 1917.

4.) R. K. Kinsley, M. A. Kohler and J. L. Paulhus, Applied Hydrology, McGraw Hill Book Co., New York, 1949.

5.) M. A. Kohler and T. J. Norde, "Evaporation from Pans and Lakes," Weather Bureau Research Paper #38, May 1955.

6.) H. L. Pinman, "Natural Evaporation from Open Water, Bare Soil and Grass," Proceedings of the Royal Society of London, Ser. A, Vol. 198 #1032, April 1948.

7.) C. Rohwer, "Evaporation from Free Water Surfaces" U. S. Department of Agriculture Technical Bulletin #271, December 1931.

8.) C. W. Thornthwaite, "Measurement of Evaporation Land and Water Surfaces," U. S. Department of Agriculture Technical Bulletin #817, 1942.

APPENDIX I

Table A

Comparison of Evaporative Rates at Various Ambient Temperatures

Temperature °F	Variables Wind Velocity mph	Relative Humidity %	Calculated Evaporation lbs/sq ft/hr	Time For Evaporometer 2 cm Change seconds	Evaporometer Evaporation lbs/sq ft/hr
110	35	18	1.62	8	.83
110	26	18	1.24	10	.67
110	14	18	.74	12	.55
100	35	22	1.21	9	.74
100	26	22	.93	11	.62
100	14	22	.55	13	.51
96	35	50	.69	12	.55
99	30	38	.80	14	.48
99	25	40	.66	15	.44
100	21	45	.50	17	.40
99	18	45	.46	17	.39
99	11	54	.26	24	.28
97	6	44	.20	31	.22
99	0	44	.08	126	.05
90	35	27	.83	10	.67
90	26	27	.64	12	.55
90	14	27	.38	14	.47
90	35	55	.50	21	.32
92	30	58	.41	26	.26
91	25	58	.35	27	.24
89	21	42	.41	18	.37

Table A - Continued

Temperature °F	Variables Wind Velocity mph	Relative Humidity %	Calculated Evaporation lbs/sq ft/hr	Time For Evaporometer 2 cm Change seconds	Evaporometer Evaporation lbs/sq ft/hr
89	18	45	.33	24	.28
90	11	44	.24	35	.19
90	6	44	.16	46	.14
89	0	42	.06	144	.05
80	35	50	.40	22	.30
80	30	50	.35	26	.25
80	25	48	.31	30	.22
79	21	46	.27	22	.30
81	18	32	.32	18	.36
81	11	32	.22	32	.21
81	6	32	.14	47	.14
80	0	41	.05	156	.04
80	35	72	.22	34	.19
80	25	80	.16	49	.14
80	0	80	.02	361	.02
70	35	38	.35	18	.38
71	30	34	.33	19	.36
71	25	37	.28	22	.30
70	21	36	.24	21	.32
73	17	43	.21	25	.26
73	11	46	.13	42	.16
73	6	48	.08	60	.11
70	0	43	.03	164	.04

Table A - Continued

Temperature °F	Variables Wind Velocity mph	Relative Humidity %	Calculated Evaporation lbs/sq ft/hr	Time For Evaporometer 2 cm Change seconds	Evaporometer Evaporation lbs/sq ft/hr
70	35	80	.11	46	.14
70	25	80	.09	59	.11
70	0	77	.01	326	.02
70	35	90	.06	114	.06
70	25	90	.04	190	.03
70	0	90	.01	602	.01
62	35	59	.18	32	.21
62	30	59	.15	34	.19
62	25	59	.13	35	.19
60	11	45	.09	72	.09
60	6	48	.06	77	.09
61	0	39	.02	199	.03

APPENDIX II

MATERIALS LIST

Quantity	Size	Description
1 each	3 x 8 inch	18 gauge aluminum or steel
1 each	1 x 3 inch	18 gauge aluminum or steel
1 each	8 inch x 1-1/4 mm I.D.	Capillary tubing
1 each	1 inch x 1/4 inch diameter	Solid glass rod
1 each	6 inch 1/8 inch diameter	Brass rod
1 each	1-1/2 inch x 1/4 inch I.D.	Tygon plastic tubing
3 each	8 inch x 1/8 inch diameter	Steel rods
1 each	1 x 6-1/2 inch	Colored paper
2 each	6-32 x 1/2 inch	Machine screws w/nuts or 1/8 inch pop rivets
	3 cm diameter	#3 Grade filter paper (cut from larger stock)

EVAPOROMETER CONSTRUCTION

Figures 8 and 9 show the parts and layout for construction.

1. The frame (A) is made of 18 gauge aluminum or similar strength metal. Drill the holes, make the cuts and bend into shape as shown in Figure 9.

2. Make the bracket (B) of the same material. It is cut out, drilled, bent as shown, and then fastened to the frame by rivets or 6 x 32 screws.

3. The scale (S) is drawn on paper and then glued onto the frame. Markings are made every centimeter and numbered every two centimeter A dark or colored paper helps the meniscus to be more visible. The paper used should be sprayed with clear Krylon to protect it from the weather.

4. An eight (8) inch length of 1-1/4 millimeter internal diameter capillary tubing (C) is ground flat at one end with 320 wet sand-paper. Wet grind to prevent glass dust from getting into the air.

5. A one (1) inch length of 1/4 inch diameter glass rod (D) is ground flat on one end. Wet grind to remove sharp edges on the other end.

6. A six (6) inch length of 1/8 inch diameter brass rod (E) is bent into a U shape. Both ends are then bent for one turn around a 1/4 inch rod.

7. Cut a 1-1/2 inch length of 1/4 inch internal diameter plastic tubing (F) such as Tygon.

8. The capillary tubing (C) is epoxied to the frame with the metal rod (E) on one end and the plastic tubing (F) on the other. After the epoxy has cured, the solid glass rod (D) is epoxied to the bent metal rod (E) so the glass surfaces of the rod and capillary tubing are flush.

9. Make the stand of three metal rods; each 1/8 inch in diameter and 8 inches long. Braze the rods together at one end and bend the free ends to form a tripod.

10. Cut a 3 centimeter diameter disc (H) from larger sheets of #3 grade filter paper. This can be done by marking a circle and then cutting it.

11. Insert the tripod base (G) into the slot between the frame (A) and the bracket (B).

Expanded Evaporometer View

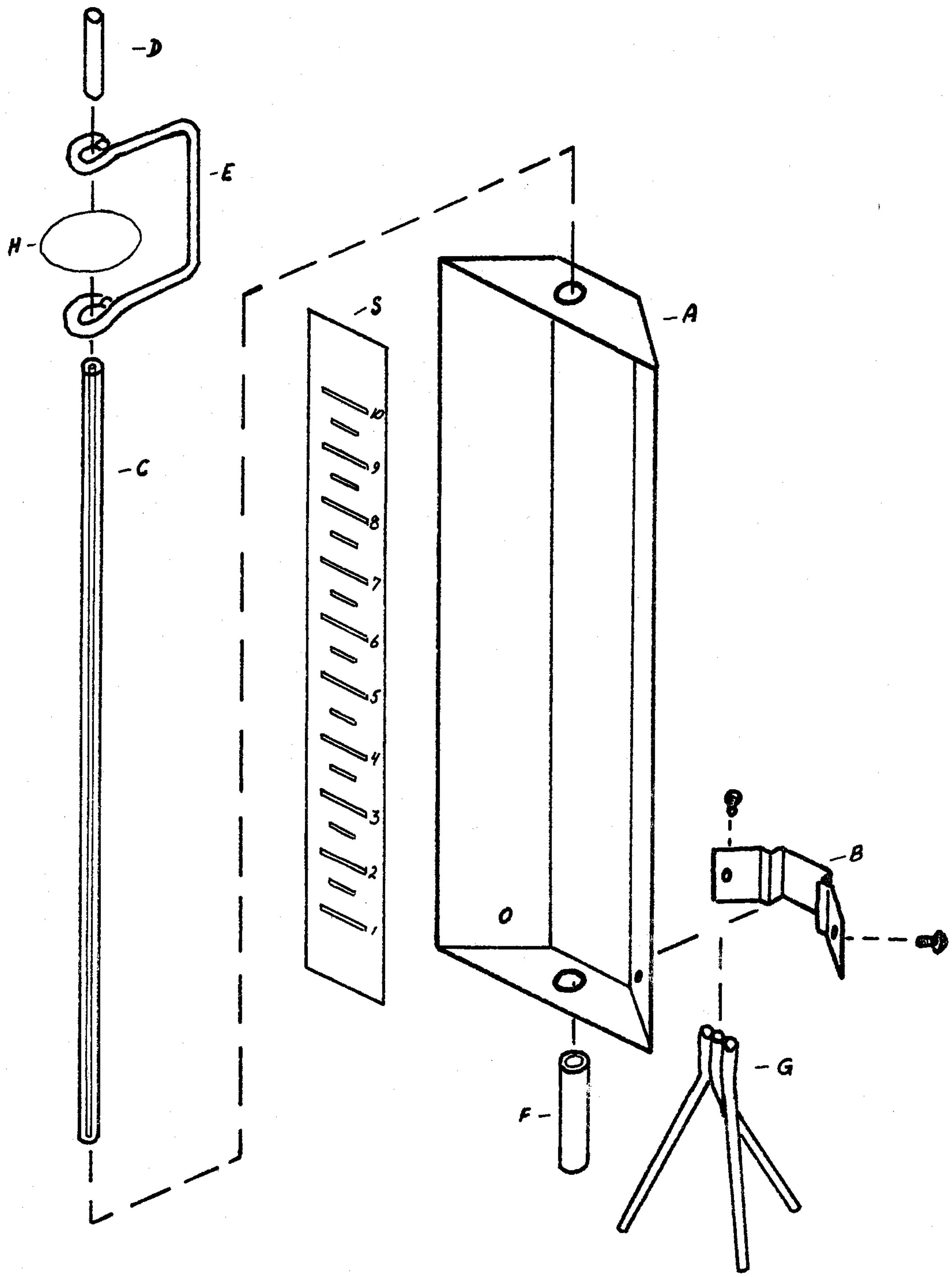


Figure 8

Figure 9

Evaporometer Parts A&B Pattern