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THE MEASUREMENT OF SOIL MOISTURE AND TEMPERATURE BY HEAT DIFFUSION TYPE MOISTURE CELL

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Synopsis

Procedure and materials employed in the development of soil moisture-temperature measuring equipment are described. The various stages of development are outlined briefly. Results obtained with the several types of cells investigated are presented.

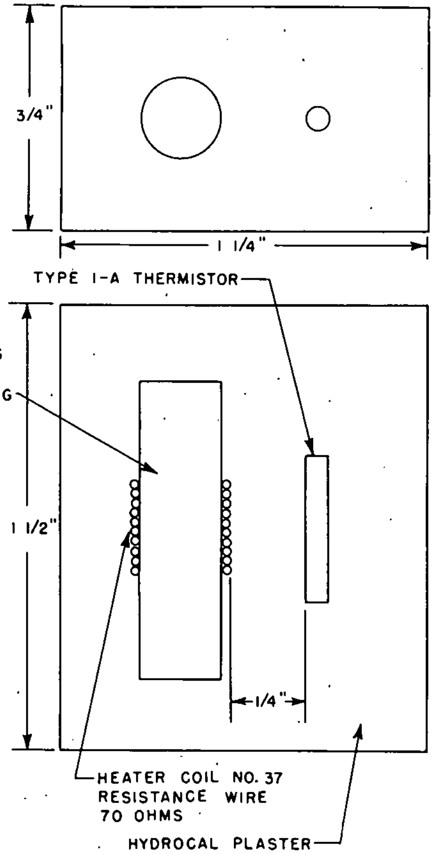
The performance characteristics of the cell in its present state of development have been investigated through the medium of laboratory-calibration test and soil-moisture determinations. The performance of the present cell is unsatisfactory when in soil at moisture content above 15 percent by dry weight and is quite variable unless positive contact with ambient soil is initially established and maintained during readings. Future improvement in design to increase operating efficiency and simplify fabrication is briefly outlined.

The significance of soil moisture as a medium for altering or modifying the structural value of foundation and paving subgrade soils is well recognized. The influence of temperature gradient on the migration of moisture vertically and laterally in the soil is generally less well understood. Facilities for observing and measuring both temperature and moisture content in existing subgrade soils under paving concurrently with weather observations are urgently needed. Such factual information obtained and compiled for various soil types over an extensive period of time and related to climatic environment, types of paving, and other pertinent physical features would be extremely useful in determining the range of moisture content to be expected. Determination of soil bearing value, shear strength and other structural properties required for rational design could thus be predicated upon definitely observed moisture content. As the supporting power of the subgrade soil directly influences the type, thickness, and character of superimposed paving provided to support the designed wheel load, the importance of authentic information on soil moisture under service conditions is obvious.

In addition to providing a means for the determination of moisture content in connection with soil bearing value, installations of cells under paving, spaced vertically at selected distances throughout the soil column, may be used to depict the directional movement of soil water together with its fluctuations and concentrations in response to temperature variations. Using this installation, the need for subdrainage in a given location can be established or the effect of existing drainage systems can be evaluated.

Investigation made preliminary to the inception of this project indicated that moisture-measuring devices had been developed for use, principally in the agricultural field. Their operation was based upon measuring the electrical resistance developed in the soil, which varies with the amount of moisture present. Reports by others investigating the application of this type of cell to subgrade-moisture measurement indicated that cell accuracy was markedly affected by slight changes in the chemical composition of the soil and that its greatest efficiency occurred at the lower range of soil moisture content. No provision had been made for obtaining soil temperature readings concurrently with moisture determination.

The evolution of the moisture cell described herein is the result of extensive study and experimentation over the past three years. As originally conceived, soil moisture content may be determined by the measurement of temperature difference resulting from the diffusion of heat from a regulated constant source



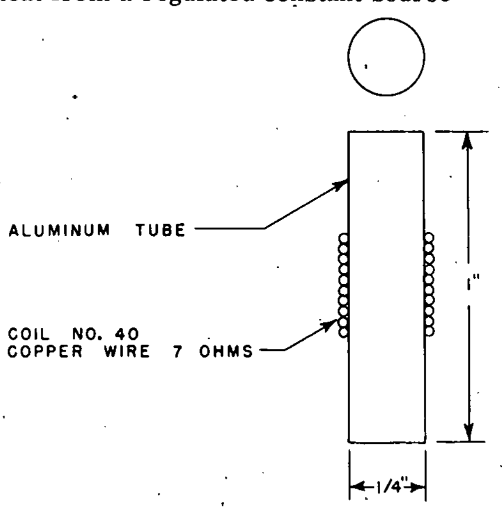
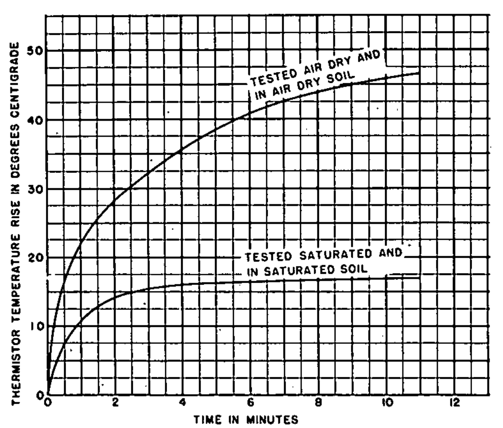


Figure 1.



Figures 2 and 2A.

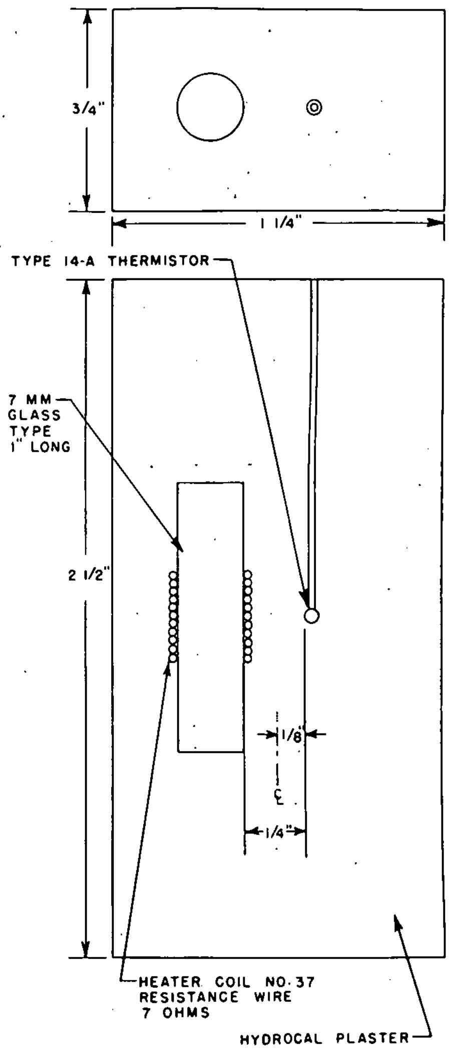


Figure 3.

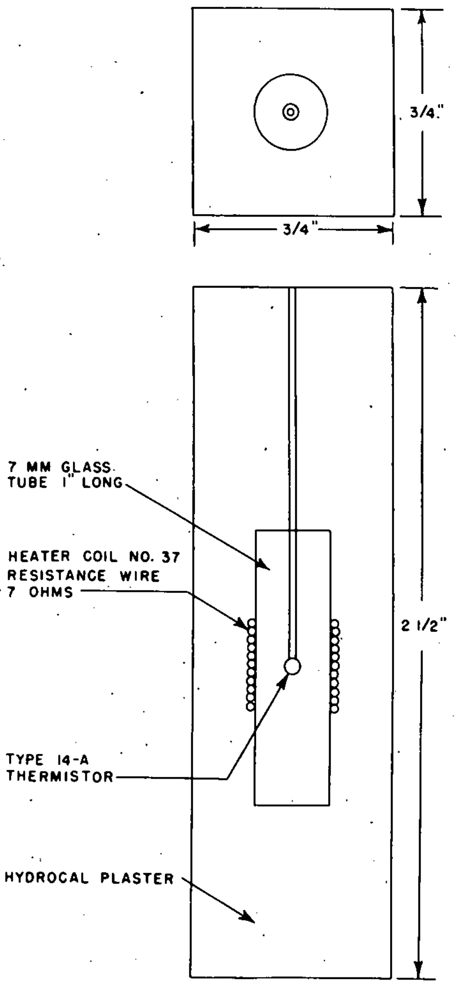


Figure 4.

into the ambient soil. Dry soil acts as a heat insulating medium. In such material a relatively large temperature rise above initial reading occurs. Conversely a wet, or saturated soil with void spaces largely filled with water conducts heat away from the cell much more readily and consequent temperature rise is quite small. Conversion of the measured temperature differential into terms of soil moisture content, through the medium of previously calibrated temperature-moisture curves is necessary to reduce the data to useable form for engineering purposes.

Moisture-Cell Development

Preliminary study indicated that the use of electrical energy for activating the moisture-cell components had distinct advantages. Use of the soil and its contained moisture as an electrolyte and depending upon its resistance or capacitance for moisture measurement in paving subgrades had not been favorably reported by other investigators. The measurement of heat transfer or diffusion from some controlled source by sufficiently accurate equipment appeared to be the method least affected by variable soil composition and electrolyte.

The thermistor element employed in this cell as a means of measuring existing soil temperature and temperature rise in the body of the cell after the heating coil has been energized is a standard product of the Western Electric Company and has been used extensively in other commercial and scientific work. It is a selected combination of at least two metallic oxides which, when properly combined, compressed, and sintered, becomes a temperature-measuring instrument of extreme sensitivity. Its peculiar ability to change its electrical resistance with temperature over a range of 0 to 3000 ohms is a highly advantageous attribute. The uniformity and reproducibility of its performance is essential in order to obtain minor temperature variations which accompany very slight changes in the moisture content of the ambient soil. It might be well to add further that the potential of the thermistor has not been fully developed in connection with its application to moisture measurement, and present indications are that it will become an increasingly useful medium in future moisture-cell development.

Figure 1 indicates the type and character of the initial cell. A wire coil was used for heat source. Its change in resistance was correlated with temperature. This type was abandoned due to insulation difficulty, heat control, and variable heat dissipation.

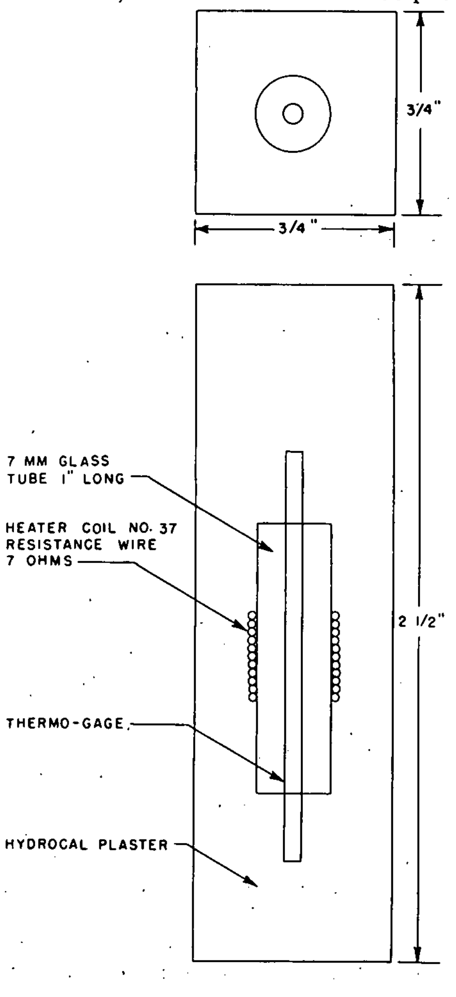


Figure 5.

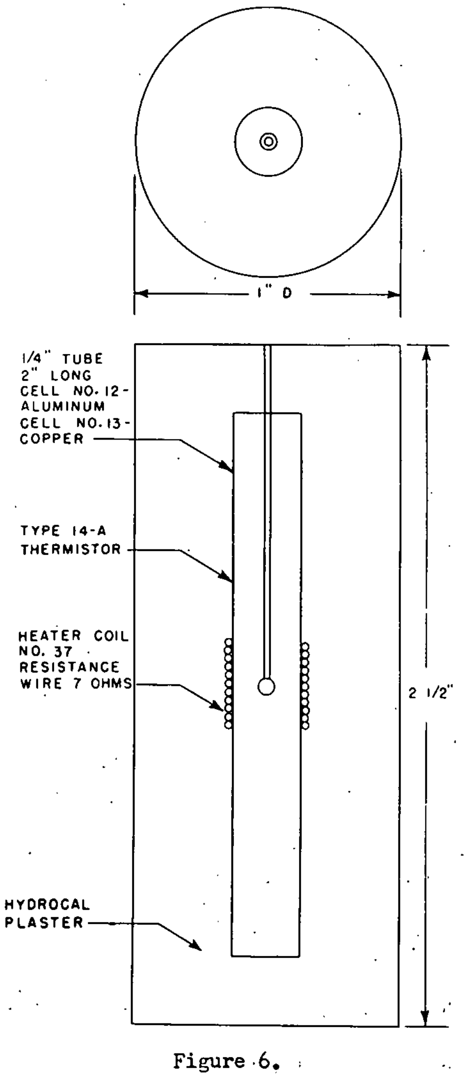


Figure 6.

Figures from 2 to 13 inclusive* are sketches of cells constructed during the progressive stages of development when a moisture conducting medium (hydrocal plaster) was employed as a bedding material and a protective cover for the electrical elements. Figure 2A indicates graphically the time-temperature rise relationship of cells in this series.

The use of the plaster block was also considered advantageous due to the relatively constant properties of the material itself. Its particle size, chemical composition, and affinity for water could be readily determined. The dry density, volume of voids, thermal conductivity, specific heat, and physical dimensions of the fabricated block appeared to offer a material of uniform quality which would have only one variable,

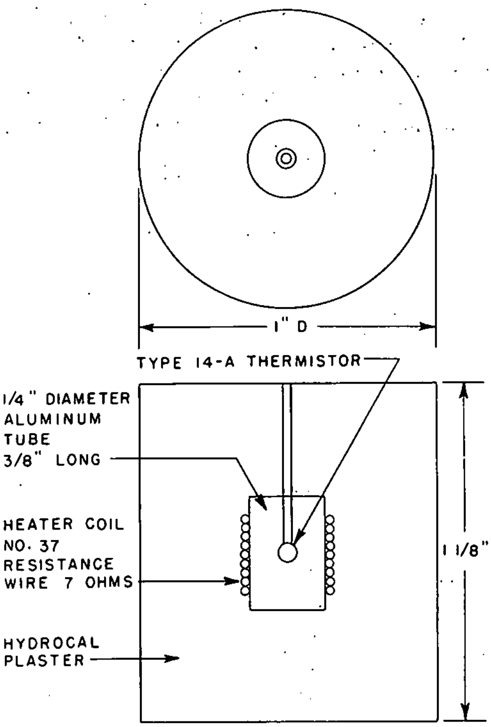


Figure 8.

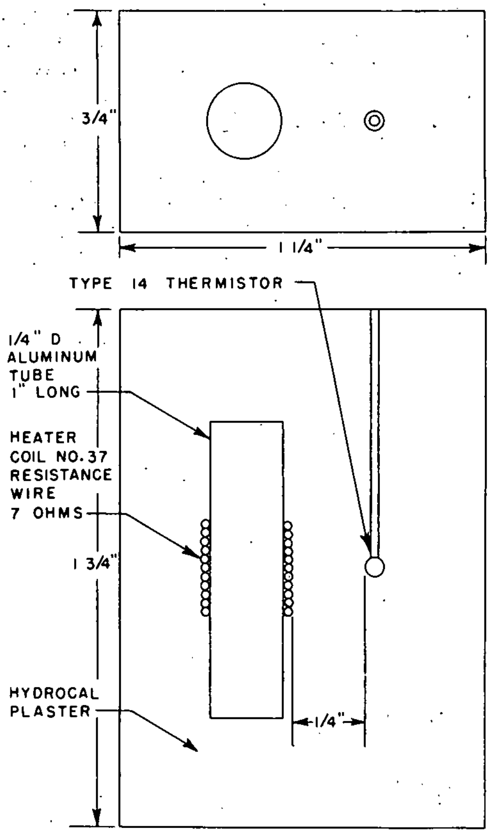


Figure 9.

namely, moisture content. If block and soil moisture varied directly, or in some ratio, the block's constant and reproducible characteristics offered a more desirable medium in which to measure moisture than the soil itself. This type of block material failed to follow soil moisture closely or rapidly. For that reason, its use was limited only to this transition period in which it served its best purpose in the determination of the best type of thermistor and the most efficient relative location of the heater coil and thermistor. Of the cells tested in this series, the best performance was obtained from the one illustrated in Figure 13.

As it was then believed that a uniform material of known density, void space, and heat conductivity would be preferable to the natural soil as the medium for the passage of heat generated in the cell, arrangements were made with the Norton Company, Worcester, Massachusetts, for the design and fabrication of Alundum porous blocks for this purpose. A mixture was selected which, when molded, compressed, and fired,

*Figure 7 is not shown.

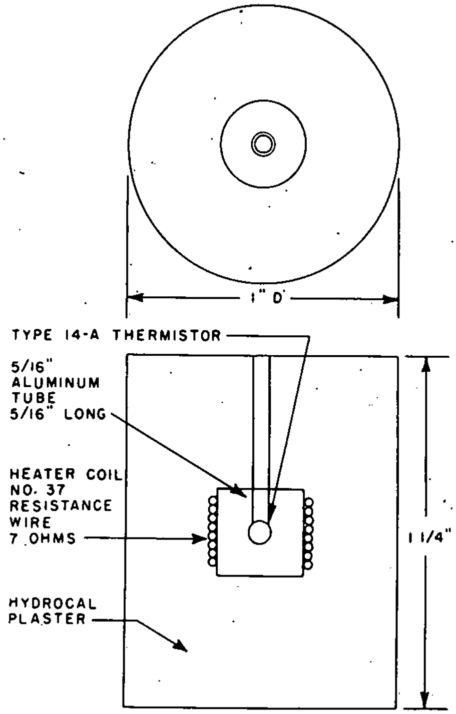


Figure 10.

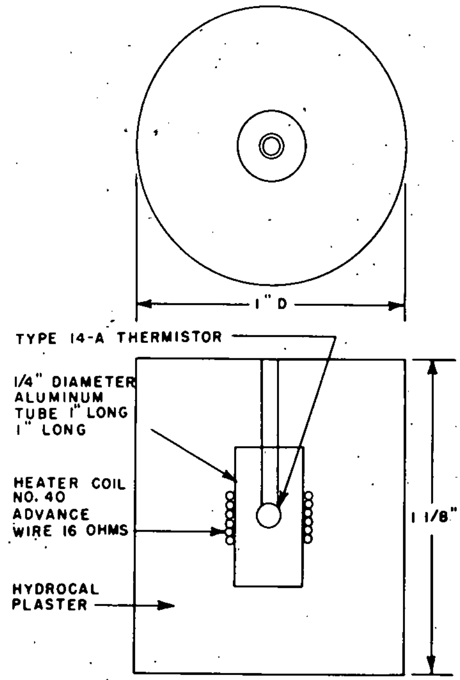


Figure 11.

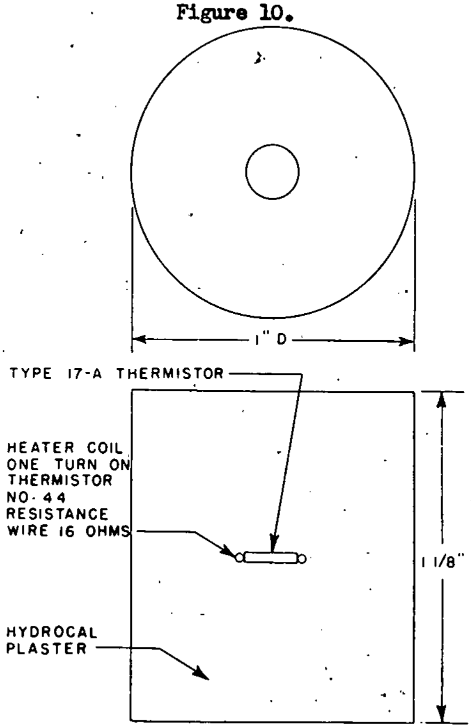


Figure 12.

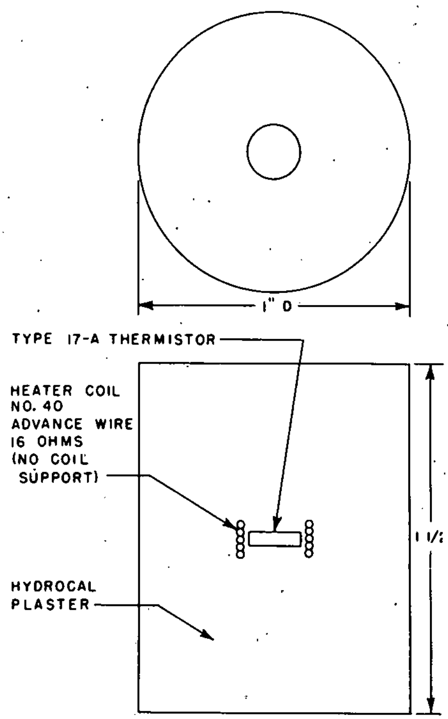


Figure 13.

closely duplicated the composition and grain-size of average sandy-clay soil. This was considered desirable in order that the capillary potential of the porous block be of similar magnitude to that of the soil in which it was to be placed.

This type of block absorbed moisture from ambient material quite readily when

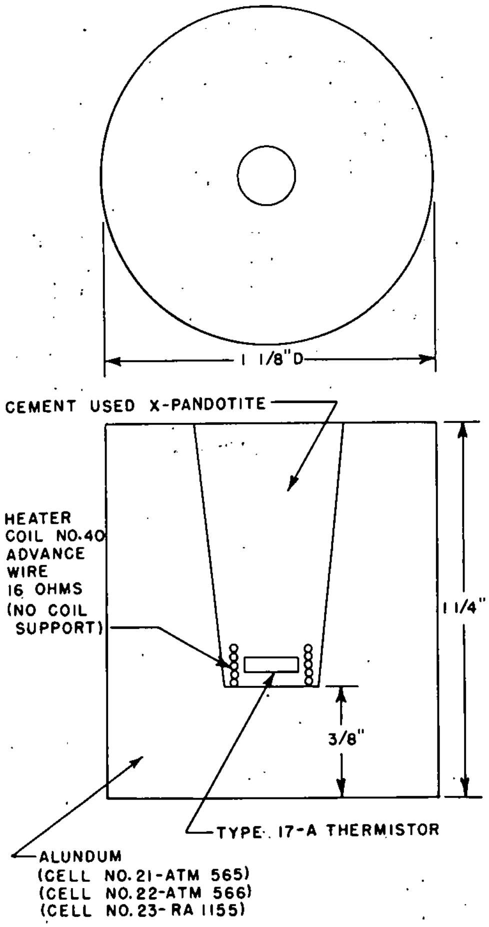
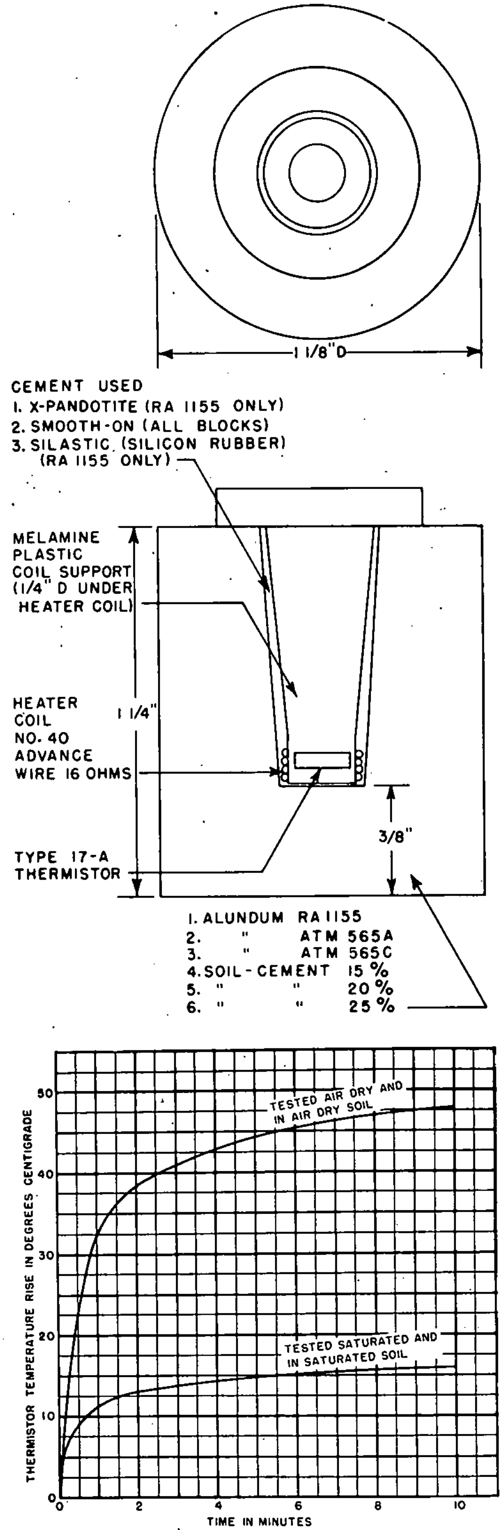


Figure 14.

moisture content of such material was relatively high. Considerable lag was evident before the moisture content of block and surrounding soil were in equilibrium at low and medium moisture. This was particularly noticeable with fine-grained, high-capillary soils. Better performance was obtained from a wetting cycle than from a drying cycle in all soils.

Figure 14 illustrates the general form



Figures 15 and 15A.

of this type cell and the location of the component parts. Different mixtures were used in each block as noted. Such mixtures produced blocks of different densities and consequent rates of absorption of moisture. The block composed of mixture RA-1155, having voids in the order of 50 to 55 percent proved to be the most satisfactory. As shown in the sketches the thermistor and coil were placed in a circular hole located in the center of the block. The locations of the coil and thermistor were such that they were practically equidistant from the sides and bottom of the blocks. They were insulated against moisture by being dipped into liquid plastic which was cured by drying at low temperature in an oven. The electrical elements were secured against movement in the hole by the use of X-Pandotite cement.

The first extensive experimentation and testing was undertaken with cells of this type. Insulation of the electrical components against moisture was extremely difficult. It was also apparent that the use of the X-Pandotite cement for securing the coil and thermistor in the block provided an unsatisfactory heat transfer medium due to the difficulty of placing it in the restricted space to relatively the same density. The above disadvantages coupled with the cost of winding the coil and insulating it with the liquid plastic are the reasons for the abandonment of this type of construction.

The continued and consistent difficulty with insulation of the electrical components against moisture in vapor or liquid form and prevention of shorting between the elements themselves stimulated the design and fabrication of the cells as illustrated in Figure 15. Figure 15A shows time-temperature rise characteristics.

The cell assembly consisted of a mandrel of melamine plastic in the form of a cylinder having the top end open. The inside diameter of this cylinder very closely approximated the diameter of the thermistor unit. This unit was placed inside this plastic tube at a selected location where the wall thickness of the tube was 0. 015 in. The thermistor was secured in place through the use of liquid plastic, which solidified at approximately 150 F. The coil was wound around the outside of the tubing and was located symmetrically with respect to the thermistor. Thus the two elements were separated by a plastic wall of 0. 015-in. thickness. Tests prior to assembly indicated that relatively good heat transfer was possible through the plastic medium, and as the material used for cementing purposes was to be kept to a minimum thickness, no trouble was anticipated due to its heat insulating effect.

As shown by Figure 15, the plastic mandrel, complete with thermistor and cell units, was inserted into a cylindrical hole located at the center of the porous block. As previous test results made the use of X-Pandotite cement questionable from the standpoint of waterproofing and thermal conductivity, additional types of material were employed as potting compounds or cements to secure the plastic mandrel. Several of the typical materials investigated are noted on the sketch.

This test series was further utilized to investigate block material other than Norton Company Alundum Block RA 1155. Norton materials designated as ATM 565A and ATM 565C were used. The density and void space of these latter two blocks were modified from that of the RA 1155 and a considerable amount of ferrous material was incorporated with the alundum. Soil of the same type employed for testing the cells was combined with Portland cement to provide soil cement mixtures from which blocks were fabricated, using 15 percent, 20 percent, and 25 percent cement based upon the dry weight of the soil. soil.

Figure 16 is an illustration of the meter with wiring diagram employed for measuring the heater-coil input and recording the flow of electrical current through the thermistor element. Figure 17 shows the supplemental equipment required for preparing the soil specimen and container for holding the selected soil at controlled moisture content. Figure 18 illustrates the component parts and assembled cell as employed in this series.

Exploratory Testing of Porous Block Cells

The testing operations referred to in the following paragraphs, the type of equipment and cell construction employed, and the results obtained are important chiefly because


RANGE CALIBRATION
HEATER CURRENT
PRECISE CURRENT INDICATOR
CELL SELECTOR
COARSE
FINE
HEATER SUPPLY
PUSH TO READ
TEMPERATURE RANGE
TEMPERATURE METER SUPPLY
PUSH TO READ

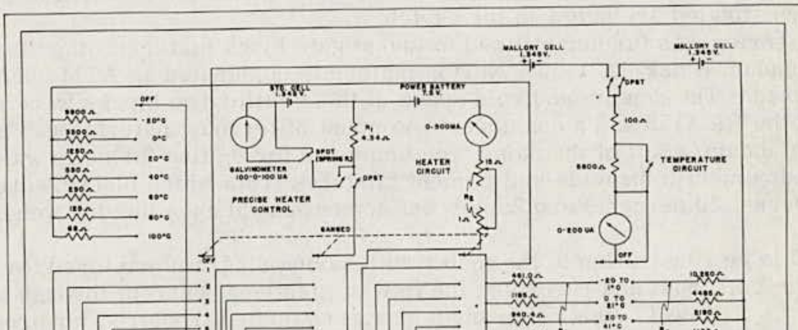

MALLORY CELL
MALLORY CELL
POWER BATTERY
GALVANOMETER
PRECISE HEATER CONTROL
HEATER CIRCUIT
TEMPERATURE CIRCUIT
TO THERMISTOR AS SELECTED
TO HEATER COIL AS SELECTED
HEATER COIL RETURN
TO THERMISTOR AS SELECTED
WIRING DIAGRAM

Figure 16.

of the influence they exercised upon subsequent investigations.

The performance of these cells under test conditions emphasized the need for extensive improvement in electrical insulation and further indicated that such insulation must have high thermal conductivity. Variation in density and structure of the potting and cementing material employed to secure the electrical elements in place and provide insulation against moisture was found to be the cause of unfavorable and erratic cell performance. The random occurrence of air voids in the media surrounding the therm-

Figure 17. Assembled Moisture Cell.

ister and heating coil adversely affected the reliability and reproducibility of results.

Test data indicated that the moisture content of the ambient block material, while quite readily measurable by the heat diffusion method, was too frequently dissimilar to that of the soil in which it was placed. As tests progressed and results were studied, it became apparent that comparable capillary potential between the block and the surrounding soil was necessary to facilitate interchange of moisture. To provide this necessary attribute the blocks would need void space closely identical with the various types of soil in which they were to be placed. From a practical standpoint this would be untenable.

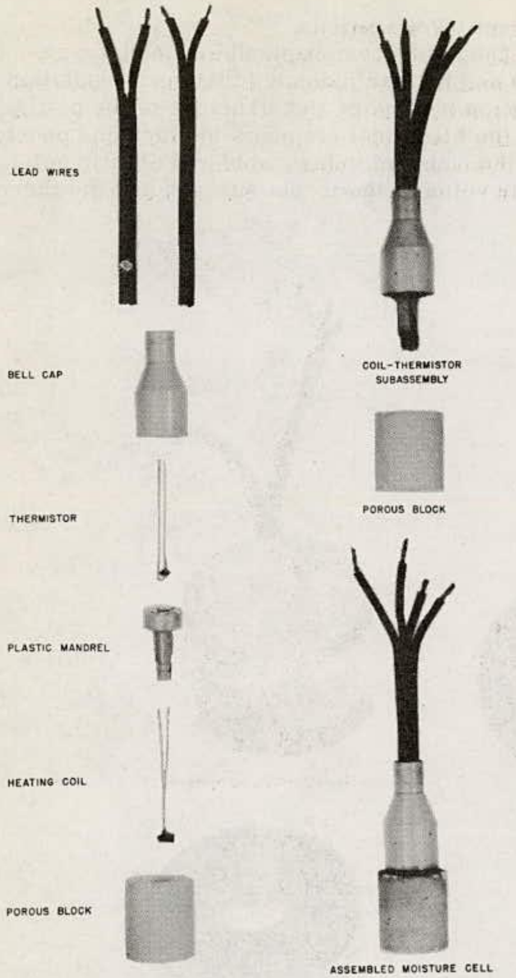


Figure 18.

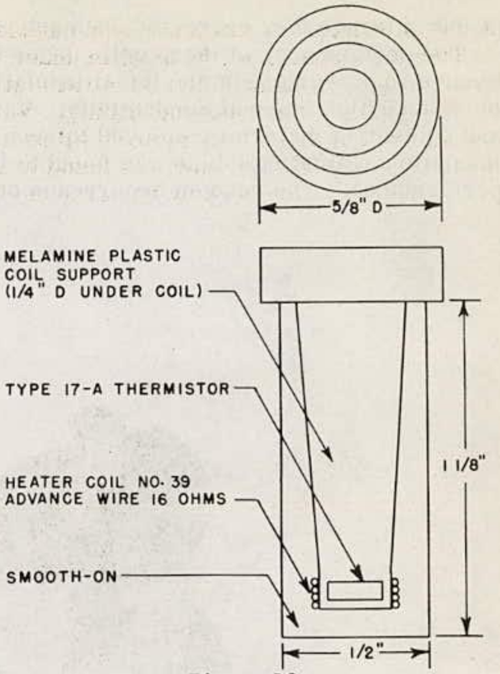


Figure 19.

Development of Direct-Contact Moisture Cells

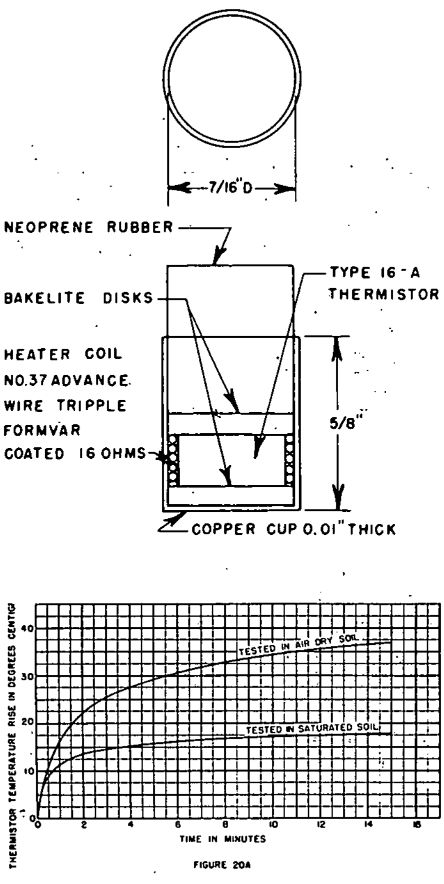
In order to remedy the deficiencies in the initial cells as demonstrated by previous tests, the development of a direct-contact moisture cell was initiated. The porous block was replaced by a protective coating material having good thermal conductivity and waterproofing properties and which would be capable of establishing intimate contact with the electrical elements to the extent that detrimental air voids or spaces adjacent to the heater coil or thermister could be eliminated.

Direct-Type Metal Encased Cell

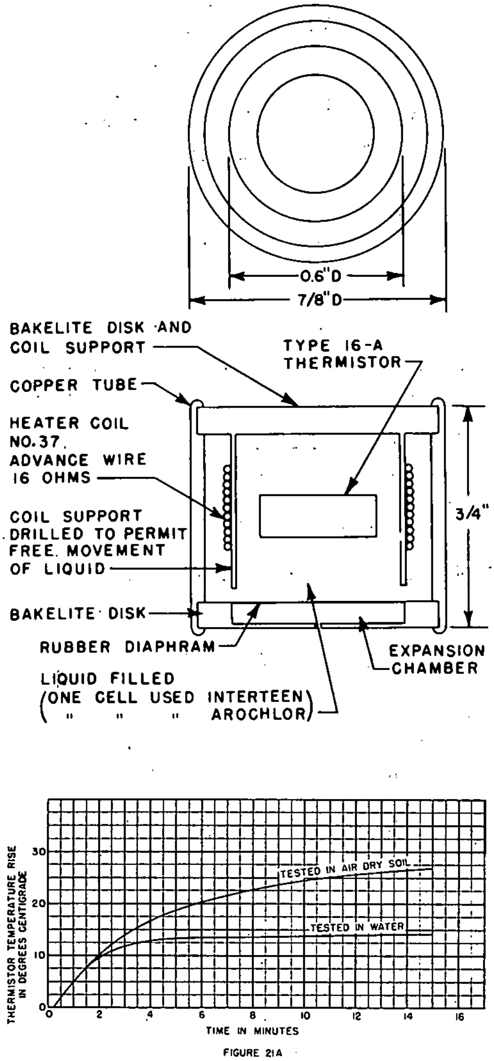
The decision to concentrate on the direct-contact moisture cell entailed a considerable amount of special investigation relative to thermistor dimensions and characteristics and electrical resistance properties. It was necessary to obtain added information with respect to the heater-coil requirements, e. g. , type of winding, wire-size applicable, and thermal conductivity of available insulating material. Extraneous air voids occurring within the cell structure proved troublesome and to overcome this difficulty, a study was made on the adaptability of various inert fillers. The diameter, wall thickness, and heat conductance of the mandrel was investigated, and heat concentration areas within the cell were investigated in an effort to eliminate them. The moisture resistance of the several surface coatings for covering electrical components was explored. During such investigation, the special applications of conventional equipment and its calibration were of special significance with respect to test results. Complete coverage of these essential tests and pertinent detail is presented in Appendix I.

Figure 19 illustrates the first direct-type cell fabricated. The electrical elements were encased and supported by one of the melamine plastic mandrels. The protective covering employed was a metallic cement having the trade name of "Smooth-on." It has been used as heat conducting material in many industrial applications and was generally considered as a satisfactory waterproofing medium. Tests indicated that it would not fulfill our requirements and the coating of the cells with this material was discontinued.

Figure 20 indicates the initial direct-contact cell employing a thin-wall copper cup to cover the heater coil and thermistor. Figure 20A illustrates its time versus temperature rise characteristics. In this assembly, bakelite discs were cemented on both ends of the thermistor. The diameter of these discs equalled the diameter of the thermistor plus double the thickness of the insulated wire used for winding the heater coil and greatly facilitated winding of the coil directly on the thermistor. The insulating effect provided by the bakelite discs tended to channel the flow of heat between heating coil and center of thermistor. The circular rubber plug was provided with four separate holes through which the heater coil and thermistor lead-in wires were passed. The copper cup had an inside diameter adequate to just permit a slip fit over the electrical element assembly, and all small air voids were to be filled with Formvar insulating plastic. With this design it appeared that previous difficulty caused by infiltration of moisture had been over-



Figures 20 and 20A.



Figures 21 and 21A.

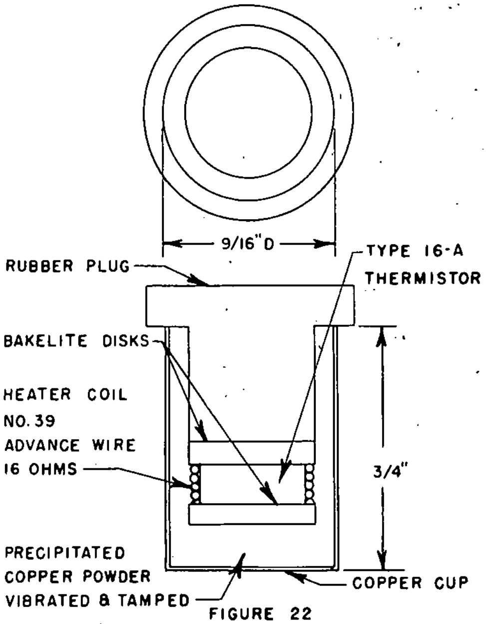
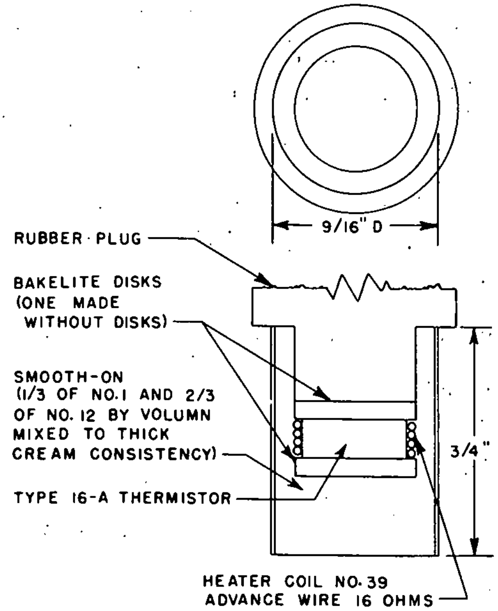


FIGURE 22



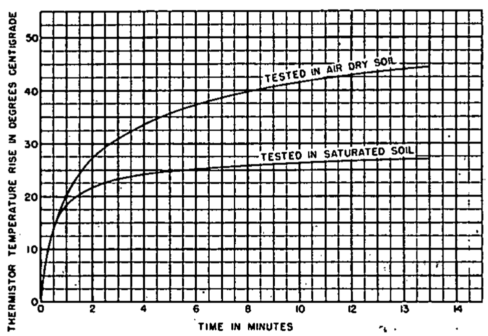


FIGURE 22A

Figures 22 and 22A.

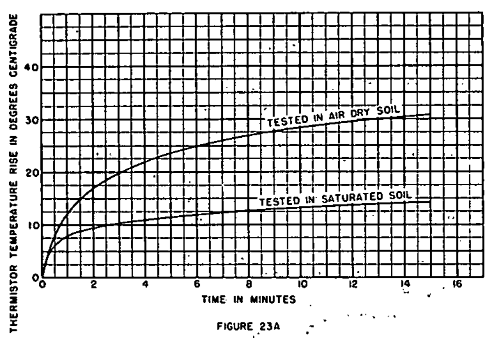


FIGURE 23A

Figures 23 and 23A.

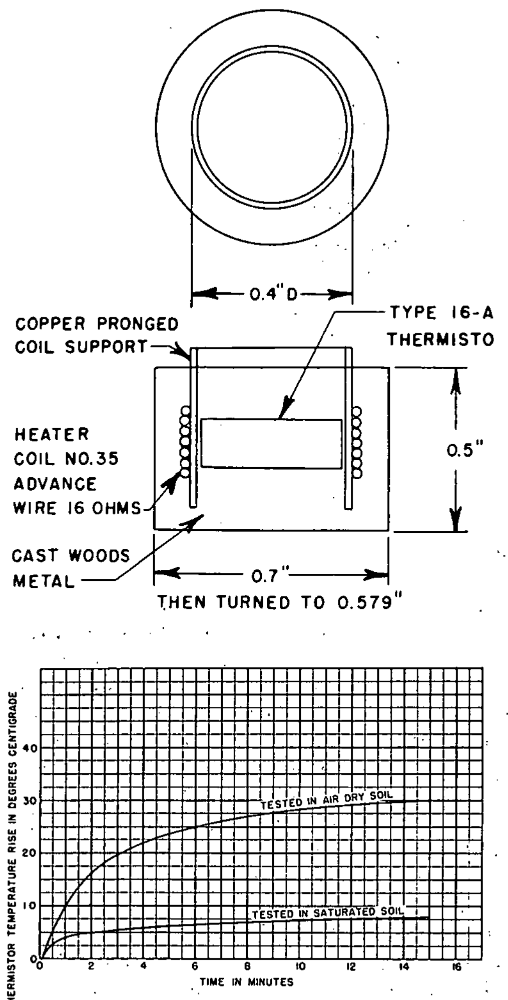
come.

Testing operations confirmed the opinion that moisture infiltration had been minimized, but the presence of variable air voids, which remained unfilled with the plastic or were created when the solvent in the plastic evaporated, caused extreme variation in temperature rise readings between cells of presumably identical fabrication. In the cell design a larger thermistor unit was first employed. This unit was approximately 0.400-inches in diameter and 0.200 inches thick. It was found that by use of larger thermistor and consequently larger coil and attendant construction, and possibly also due to the location of the plastic insulation and cement, the time required for attaining equilibrium condition in temperature rise increased to approximately five minutes as against two minutes with the previous cell assembly. For reasons indicated, investigation was continued to obtain more acceptable operating characteristics.

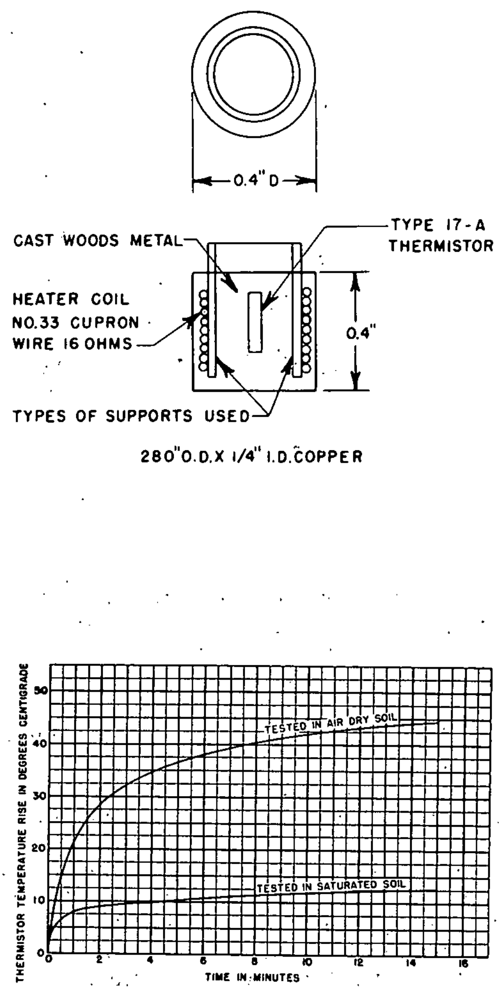
As the copper cup provided a heat conducting material of superior character as well as a durable medium in contact with the soil, it was retained in the cell illustrated in

Figure 21. Time versus temperature rise characteristics are shown on Figure 21A. The basis for design and use of liquid heat-transfer media was to provide for the elimination of detrimental air bubbles and provide a constant contact material. It may be noted that the thin-wall, perforated plastic mandrel projects from the upper plastic disc. This provided a circular tube upon which the heater coil could be wound, and it was so located as to make the heater coil equidistant from the copper tube and the thermistor. At normal room temperature the liquid filled the cell; when heated, its expansion was provided for by a very thin, rubber diaphragm. The liquids used were electrical transformer fluids, specially selected for their ability to transmit heat. The time required for heat transmission through the liquid proved to be excessive and the difficulty of providing for its expansion eliminated this design from further consideration.

Figure 22 illustrates a cell of the same type shown in Figure 21 with the exception that finely-ground copper powder was used as heat-conducting material. Figure 22A demonstrates the detrimental effect of this combination in that a very narrow spread



Figures 24 and 24A.



Figures 25 and 25A.

was obtained between dry and saturated soil conditions. This powder was well vibrated and tamped when placed and apparently provided a continuous metal phase between the outer copper shell and the electrical elements. The infinitely large number of air voids present in finely dispersed material detrimentally affected heat transfer and indicated that air spaces, even when present in one of the best heat conducting materials, were sufficient to seriously affect its thermal conductance. This cell consequently received no further consideration.

Figure 23 illustrates a cell of similar construction using Smooth-on as the heat transfer medium. Figure 23A illustrates time-temperature rise performance. Smooth-on is a relatively well-known metallic cement consisting largely of minute iron particles, graphite, and a paste vehicle. From available literature, it has previously been employed as a heat conductor in various industrial installations. Its performance in this

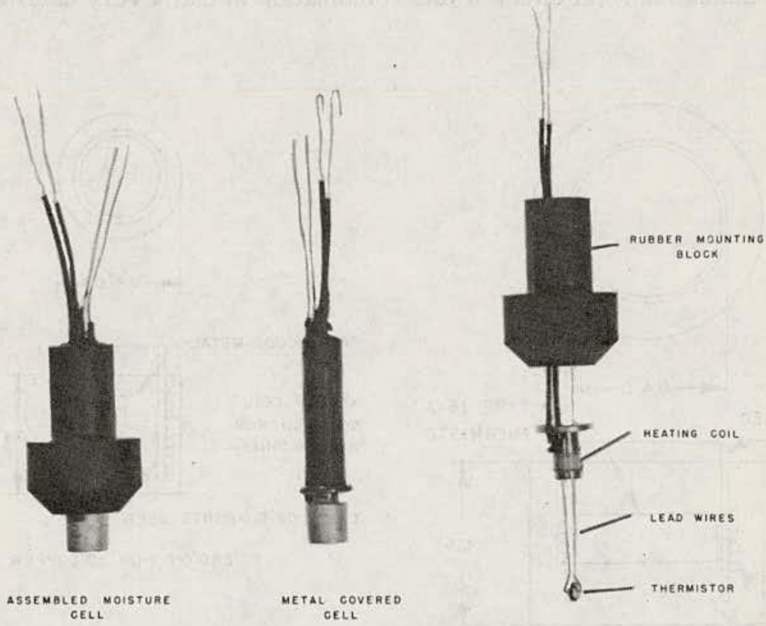


Figure 26.

respect was very unsatisfactory and therefore its further use was not considered.

Figure 24 is a line sketch showing the essential component parts and their arrangement employed in the fabrication of the direct cell having its electrical components encased in Wood's metal. This first cell was equipped with the large thermistor unit, which had a thickness of 0.170-inch and a diameter of approximately 0.400-inch. It may be noted that a thin-wall-tube copper mandrel was used upon which the wire coil was wound and into which the thermistor unit was placed. The thermistor itself was insulated electrically by repeated immersion in Formvar diluted with solvent to 10 percent solids. From 8 to 12 dips and subsequent baking periods were required. The coil wire was insulated by Ceroc-Teflon application and after its winding was coated with Formvar. The prepared assembly was centered in a mold and liquid Wood's metal heated to approximately 120 C. was poured to the depth indicated on the sketch. As past experience had indicated the importance of eliminating air bubbles to insure constant heat conductance, the lower portion of the copper mandrel upon which the heater coil was wound was slotted, thus providing six prongs to support the coil and grasp the thermistor, leaving adequate space between each prong for the hot metal to flow in and around the thermistor and heating coil. Originally the thickness of the

Wood's metal surrounding the coil was 0. 100-inch. Preliminary inspection and test indicated that this provided more mass than was required and the cell was turned down to a final diameter of approximately 0. 579-inch which provided about 0. 050-inch cover over the electrical components. Figure 24A illustrates the time versus temperature rise characteristics of this type cell. The effect of unnecessary total mass is quite evident as shown by the continued temperature rise when tested in dry soil and the relatively narrow spread between saturated and dry curves.

Figure 25 illustrates the component parts and their arrangement for the direct-type-metal-encased cell as developed up to the present time. The copper mandrel is a tube having an outside diameter of 0. 280-inch and an inside diameter of 0. 250-inch. The heater coil is of No. 33 Cupron wire covered with Ceroc insulation and later treated with Formvar plastic insulating material. The thermistor element is a Western Electric 17A thermistor having a diameter of 0. 200-inch and a thickness of approximately 0. 03125-inch. This thermistor is dip-treated with Formvar plastic insulation. When tested by immersion in water the application is capable of developing a resistance of from 10 to 30 megohms. The entire electrical and mandrel assembly are rigidly supported in a mold and the molten Wood's metal is poured around it. Attention is called to the position of the thermistor element in this cell. Placing it on edge within the copper mandrel facilitates the passage of the molten metal and successfully insures against the undesirable formation of air pockets in this critical location. Figure 25A indicates the improvement effected by the use of a cell having relatively small mass, as indicated by the relatively large spread between the curves representing values in the dry and saturated condition.

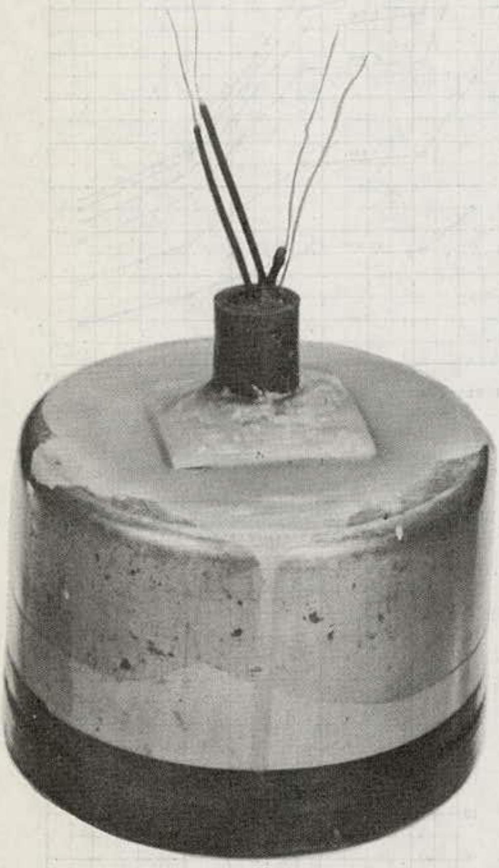


Figure 27.

Calibration Tests - Direct Type Moisture Cell

The method of testing the metal-encased direct-type cells followed previous laboratory procedure. The equipment used for molding the soil samples to the desired density and moisture content has been previously illustrated on Figure 17. The soil is combined with the desired percentage of moisture and allowed to slake in sealed cans for approximately two weeks prior to its use for test. The ointment can, with the circular hole in the bottom, is placed in the specimen mold, the correct amount of moistened soil placed therein and compacted by static pressure through the medium of a small Carver press. The top of the can is then applied and tightly sealed. The moisture-cell assembly is inserted through the circular opening into a somewhat undersized hole bored in the soil. The slight pressure required to introduce the cell is necessary to establish intimate contact with the soil. The square aluminum flat is provided with a hole only slightly larger than the barrel of the moisture cell, and the remaining openings are tightly sealed with a hot mixture of beeswax and paraffin. In this manner, both the soil and moisture cell are sealed inside the impervious metal container, and variations in soil moisture are largely eliminated.

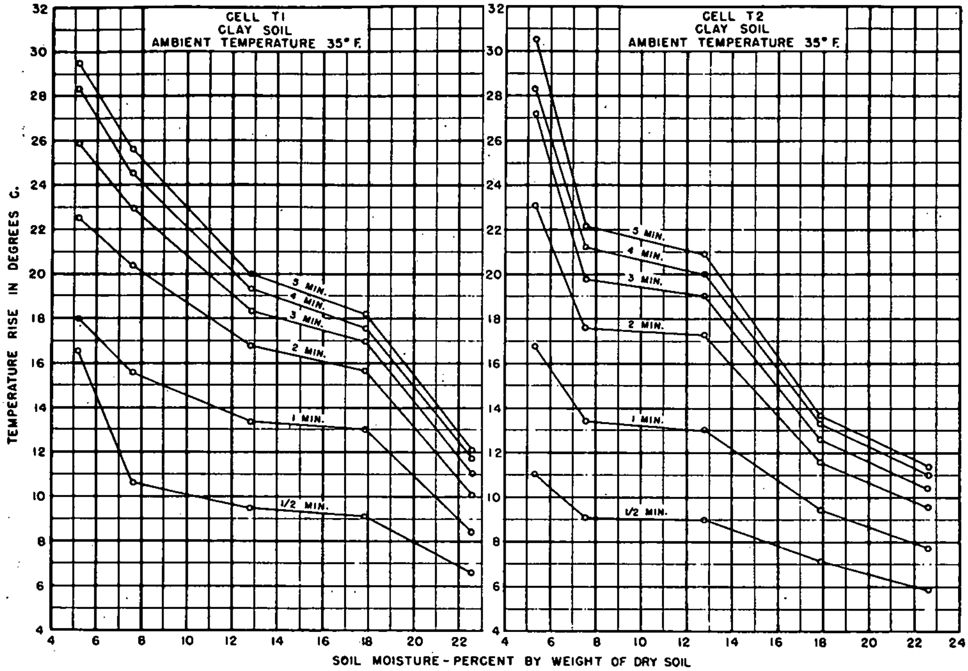


Figure 28.

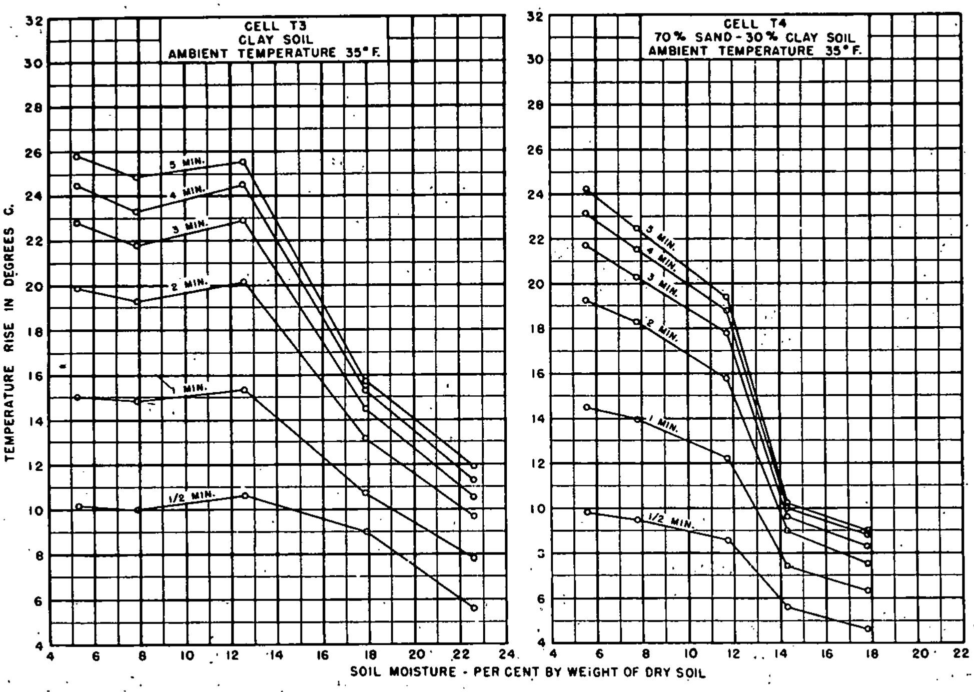


Figure 29.

Characteristics of Soil Specimens
Used in Moisture Cell Calibration

Cell T1 Clay Soil
Ambient Temperature at 35° and 70°

% Moisture	Wet Density	Dry Density
5.0	106.20	101.14
7.43	108.58	101.07
12.13	114.07	101.73
15.40	116.38	100.85
17.48	118.62	101.06
20.29	121.80	101.26
22.99	122.87	99.90

Cell T4 70% Sand-30% Clay Soil
Ambient Temperature at 35° and 70°

% Moisture	Wet Density	Dry Density
5.23	115.50	109.76
7.63	117.94	109.58
11.46	123.18	110.51
13.88	126.55	111.24
14.46	125.55	109.69
17.18	125.55	107.14
17.65	128.04	108.83

Cell T2 Clay Soil
Ambient Temperature at 35° and 70°

5.41	106.39	100.93
6.51	109.01	102.35
12.18	113.94	101.57
15.84	116.38	100.47
17.57	119.37	101.53
20.52	121.87	101.12
22.47	122.80	100.27

Cell T5 - 70% Sand-30% Clay Soil
Ambient Temperature at 35° and 70°

5.19	115.75	110.04
7.58	117.87	109.56
11.55	123.99	111.15
14.25	126.55	110.77
14.45	124.68	108.94
17.70	127.80	108.58
19.78	126.73	105.80

Cell T3 Clay Soil
Ambient Temperature at 35° and 70°

5.05	107.08	101.93
7.52	108.51	100.92
12.59	113.82	101.09
15.48	116.19	100.61
17.84	118.93	100.92
21.00	121.18	100.15
22.88	123.43	100.45

Cell T6 - 70% Sand-30% Clay Soil
Ambient Temperature at 35° and 70°

5.49	115.63	109.61
7.33	118.25	110.17
11.45	122.99	110.35
14.20	126.61	110.87
18.03	126.67	107.32
18.32	127.86	108.06

The picture of the moisture cell appearing on Figure 17 was the initial plastic mandrel-porous block assembly initially reported. The exploded view of the first of this series, and as assembled, is shown on Figure 26. View of the assembled container, as used in test, is shown on Figure 27.

In order to compare cell performance under different temperature conditions, each cell of a given series was exposed to ambient temperatures of 35 and 70 F. One soil was a silty clay, while the other was a mixture of 70 percent fine sand and 30 percent silty clay. By this arrangement it was possible to differentiate between the effect of temperature and soil-particle size upon the performance of the cell. The results obtained are illustrated graphically in Figures 28 to 33. The relationship between temperature rise as recorded by the thermistor element and the concurrent soil moisture content has been determined for various heating periods of the electrical coil, ranging from 1/2 to 5 min. In all cases, it may be noted that a minimum period of 2 min. is required to develop a satisfactory slope of the curves to permit ready location of the intercept defining temperature rise and moisture content relationships. More positive definition is possible when the 5-min. curve is employed.

Based upon test results, the cell performance cannot be considered satisfactory. While a perfectly smooth alignment cannot be expected, the presence of sharp breaks or relatively level position of the line between points of different moisture is undesirable and is believed to indicate poor contact between the exterior of the cell and the adjacent soil. The importance of positive contact has been long recognized and was fully intended to be attained. When an air space intervenes between the moisture cell and the ambient soil, especially when the soil moisture is relatively low, a heat insulating effect is produced which results in abnormally high temperature rise. As an illustration, cell T1, clay soil, 70 F. ambient temperature, indicates a relatively high

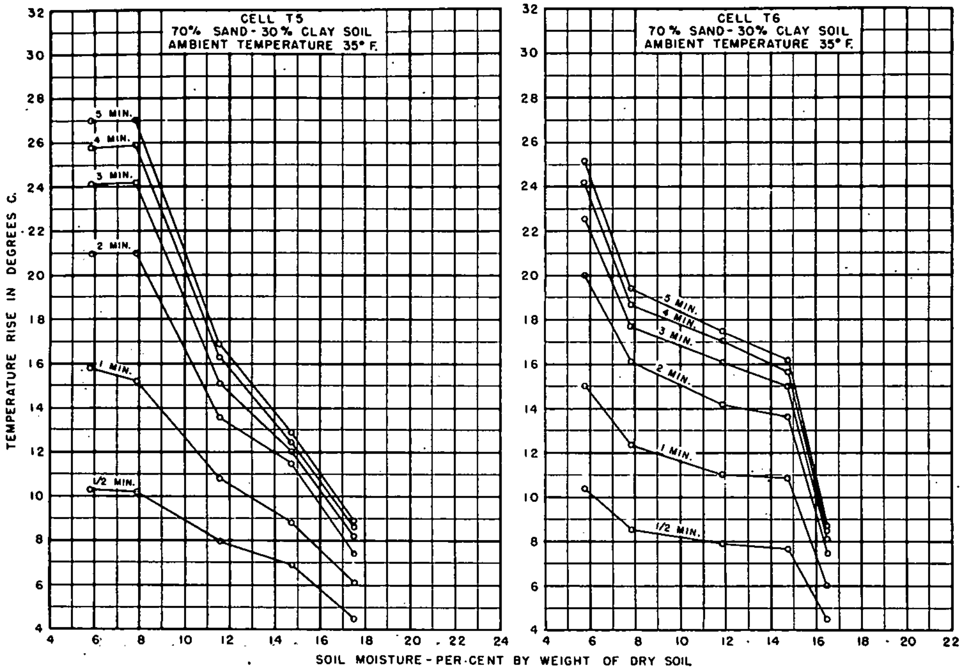


Figure 30.

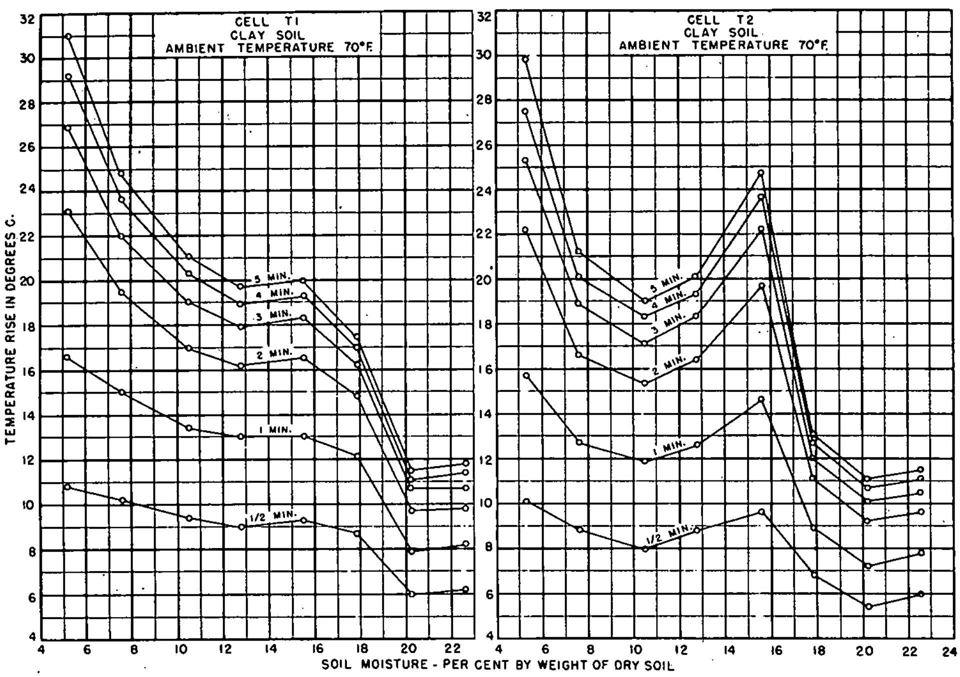


Figure 31.

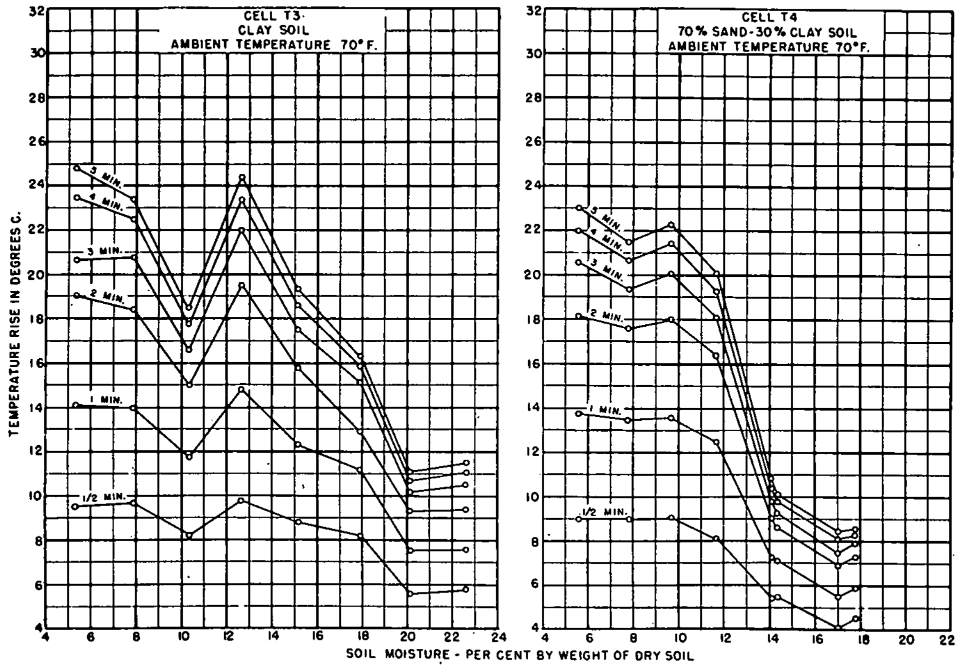


Figure 32.

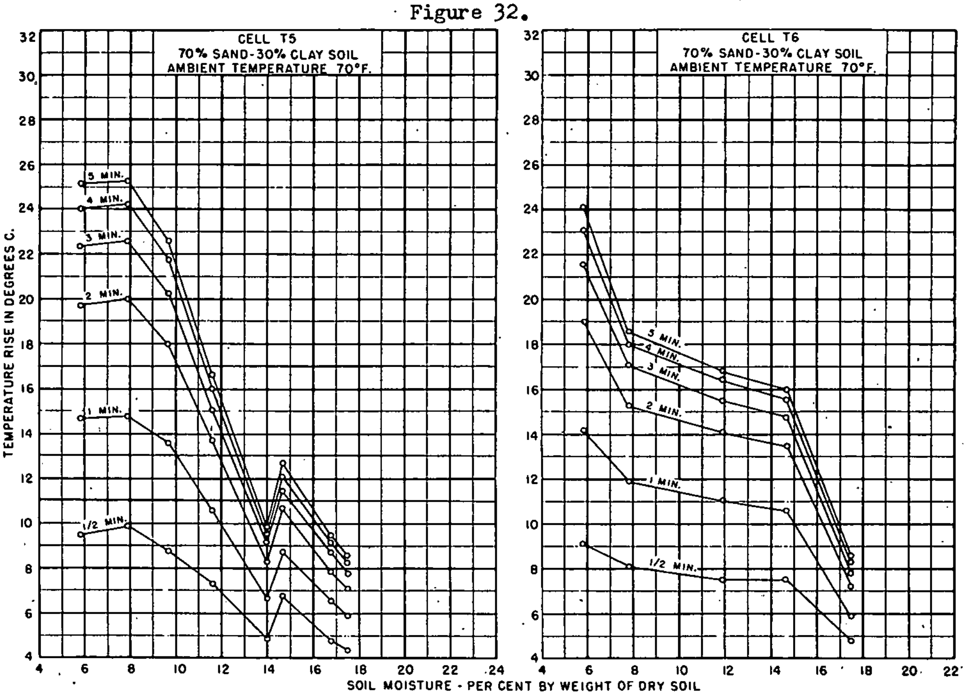


Figure 33.

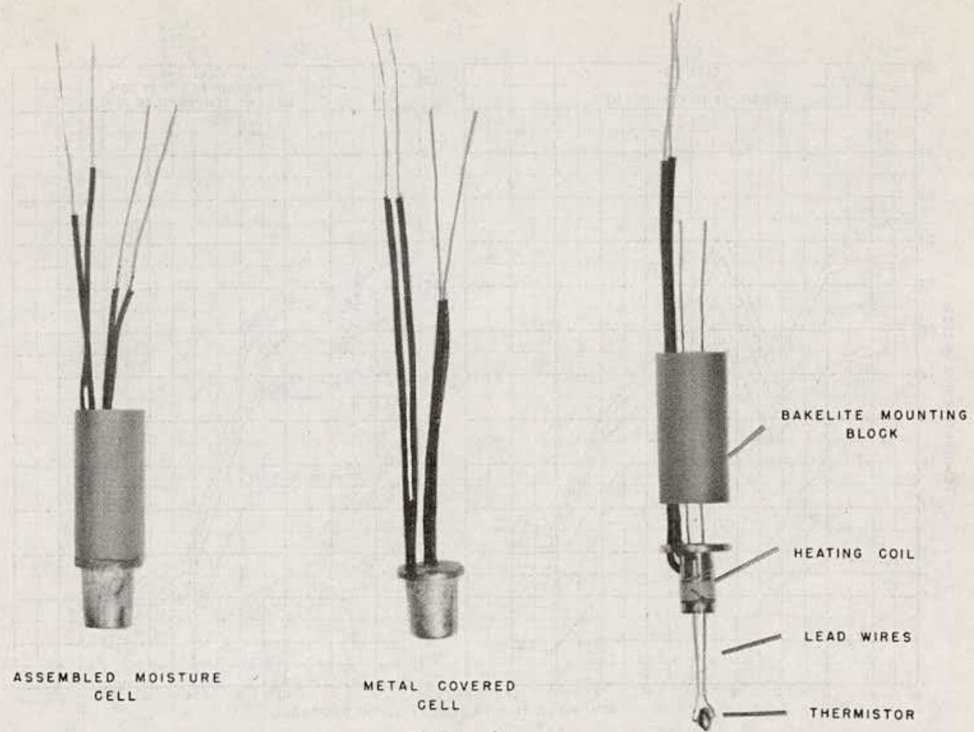


Figure 34.

temperature rise in soil having 5 percent and again at 17. 9 percent moisture. From past observations both of the values of temperature rise for such moisture content should be lower, which would have produced better alignment between respective points. Curves representing the performance of cell T1 for 35 F. , obtained using the same soil sample, produce the same relative position of the plotted points, and appear to further confirm the opinion that the internal components of the cell are functioning in practically an identical manner irrespective of the ambient temperatures.

An examination of the cell shown in Figure 26, as assembled and used in the tests under discussion, indicates the cause of the difficulty. The active portion of the cell which projects below the beveled bottom of the rubber mount is essentially a right cylinder with a flat base, the top of which extends into the rubber mounting piece to allow the upper disc to fit into a groove molded in the rubber container. It is possible, when the metal encased portion of the cell is inserted into the prepared undersized hole in the soil, that the soil scraped from the sides of the prepared opening in the soil builds up on the bottom edges of the metal cylinder and prevents complete seating or contact of the bottom of the cylinder with the underlying soil, or that it has not been possible to seat the assembly properly and eliminate air space at the point where the walls of the cylinder and the base of the rubber mount occur. The presence of undesirable air space at either or both points would minimize heat transfer and thus account for abnormal temperature rise.

A solution to this difficulty, which appears feasible, is the elimination of the rubber mount, with its overhanging section, to facilitate soil contact at the top of the cell and the use of greater side taper between top and bottom to produce more favorable embedment in the soil. The cell, as revised, is illustrated in Figure 34. Due to limited time it has not been possible to include the data obtained as the result of testing the modified cell as illustrated in Figure 34.

APPENDIX

TECHNICAL DATA RELATIVE TO COMPONENT PARTS OF DIRECT CONTACT TYPE MOISTURE CELLS

The subject matter covered in this appendix is information relative to the component parts of the direct-contact moisture cell.

To facilitate cell operation heat generated in the cell must be rapidly transmitted to surrounding material. It is further essential that the coil wire be insulated electrically from other material or elements with which it is in contact. The most efficient type of insulation for this purpose would be one having good electrical insulating properties combined with good heat conductance. In our investigation coils were fabricated from identical wire covered with various types of insulating material. These coils were wound over thermistors and energized for short periods of time and the time rate of change of temperature ($\frac{dT}{dt}$) as detected by the thermistors was recorded for each of the insulating materials. The one showing the most acceptable performance characteristics was selected for our purpose. The data as obtained by tests are reproduced herewith. Examination shows that the material tested falls into the following order with respect to heat conductance:

1. Ceroc No. 200
2. Triple Formvar
3. Formvar
4. Double Silk

The nomenclature employed in the formation of the tabular data which follow is set forth below:

<u>Nomenclature for Data:</u>

t - Time in seconds
r - The Resistance of the thermistor as read on the Brown Electron Instrument in Millivolts (R x E)
Δ R5 - The change of resistance in Millivolts in five seconds
Δ R15 - The change of resistance in Millivolts in fifteen seconds
Av. Δ R5 - The average change of resistance in Millivolts in five seconds
Av. Δ R15 - The average change of resistance in Millivolts in fifteen seconds

Values that were recorded using Brown Electronic Instrument.

Amount of Heat Transferred

Triple Formvar #37

t sec	Run 1 ΔR	Run 1 ΔR5	Run 1 ΔR15	Run 2 ΔR	Run 2 ΔR5	Run 2 ΔR15	Run 3 ΔR	Run 3 ΔR5	Run 3 ΔR15	Ave. ΔR5	Ave. ΔR15
0	.46			.42			.32				
		1.50			1.48			1.54		1.51	
5	1.96			1.90			1.86				
		1.18			1.20			1.14		1.17	
10	3.14		3.74	3.10		3.48	3.00		3.58		3.56
		1.06			.80			.90			
15	4.20			3.90			3.90				
		.64			.86			.88			
20	4.84		.70	4.76		1.90	4.78		2.00		1.90
		.56			.63			.62		.60	
25	5.40			5.39			5.40				
		.50			.41			.50		.47	
30	5.90			5.80			5.90				
			1.10			1.12			1.10		1.11
45	7.00			6.92			7.00				
			.74			.76			.72		.74
60	7.74			7.68			7.72				

Glass #37

t sec	Run 1 ΔR	Run 1 ΔR5	Run 1 ΔR15	Run 2 ΔR	Run 2 ΔR5	Run 2 ΔR15	Run 3 ΔR	Run 3 ΔR5	Run 3 ΔR15	Ave. ΔR5	Ave. ΔR15
0	.27			.30			.24				
		1.49			1.40			1.36		1.42	
5	1.76			1.70			1.60				
		1.14			1.10			1.30		1.18	
10	2.90		3.53	2.80		3.52	2.90		3.66		3.57
		1.10			1.02			1.00		1.04	
15	3.80			3.82			3.90				
		.8			.8			.76		.79	
20	4.60			4.64			4.66				
		.68	1.96		.7	1.98		.72	2.04		1.99
25	5.28			5.50			5.38				
		.48						.56			
30	5.76			5.80			5.94				
			1.12			1.10			.98		1.10
45	6.88			6.90			6.92				
			.80			.80			.76		.79
60	7.68			7.66			7.68				

Amount of Heat Transferred (Cont'd)

Formvar #37

t	Run 1 ΔR	Run 1 ΔR5	Run 1 ΔR15	Run 2 ΔR	Run 2 ΔR5	Run 2 ΔR15	Run 3 ΔR	Run 3 ΔR5	Run 3 ΔR15	Ave. ΔR5	Ave. ΔR15
0	.77			.60			.80				
		1.53			1.60			1.62		1.57	
5	2.30			2.20			2.42				
		1.34			1.10			1.18		1.21	
10	3.64		3.69	3.30		3.60	3.60		3.78		3.69
		.82			.90			.98		.90	
15	4.46			4.20			4.58				
		.78			.88			.82		.83	
20	5.24		1.82	5.08		1.98	5.40		1.87		1.89
		.66			.58			.60		.61	
25	5.80			5.66			6.00				
		.68			.52			.45		.55	
30	6.28			6.18			6.45				
			1.08			1.02			1.05		1.05
45	7.36			7.20			7.50				
			.66			.74			.64		.68
60	8.02			7.94			8.14				

Double Silk #27

t	Run 1 ΔR	Run 1 ΔR5	Run 1 ΔR15	Run 2 ΔR	Run 2 ΔR5	Run 2 ΔR15	Run 3 ΔR	Run 3 ΔR5	Run 3 ΔR15	Ave. ΔR5	Ave. ΔR15
0	.63			6.00			.64				
		1.37			1.30			1.48		1.38	
5	2.00			1.90			2.12				
		1.10			1.08			1.18		1.12	
10	3.10		3.43	2.98		3.39	3.30		3.56		
		1.04			1.01			.90		.98	
15	4.06			3.99			4.20				
		.72			.83			.80		.78	
20	4.78			4.82			5.00				
		.60	1.74		.66	1.87		.60	1.80	.62	1.80
25	5.38			5.48			5.60				
		.42			.38			.40		.40	
30	5.80			5.86			6.00				
			1.10			1.04			1.02		1.05
45	6.90			6.90			7.02				
			.76			.76			.76		.76
60	7.64			7.64			7.78				

Amount of Heat Transferred (Cont'd)

Ceroc #37

t	Run 1 ΔR	Run 1 $\Delta R5$	Run 1 $\Delta R15$	Run 2 ΔR	Run 2 $\Delta R15$	Run 2 $\Delta R15$	Run 3 ΔR	Run 3 $\Delta R15$	Run 3 $\Delta R15$
0									
5	1.60			1.80			2.20		
		2.00			1.90			2.00	
10	3.60			3.70			4.20		
		1.50			1.50			1.40	
15	5.10			5.20			5.60		
		1.10			1.18			1.00	
20	6.20		2.60	6.38		2.48	6.60		2.38
		1.10			.76			.80	
25	7.10			7.14			7.40		
		.60			.54			.58	
30	7.70			7.68			7.98		
			1.26			1.32			1.12
45	8.96			9.00			9.10		
			.64			.74			.70
60	9.70			9.74			9.80		

THE MEASUREMENT OF SOIL MOISTURE AND DENSITY BY NEUTRON AND GAMMA-RAY SCATTERING

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Over a span of approximately 50 years the records and literature on the subject of soils contain descriptions of various apparatus developed for determining soil moisture. The lack of knowledge in the field of soil moisture can be attributed to a lack of adequate means of measurement rather than a lack of interest. Because of the limitations of moisture measuring devices little is known, in a definite sense, of the movement of moisture in soils. This is particularly true in unsaturated soils. The movement of moisture through soil by percolation, by capillary action, and by vapor transfer is little known except by analogy and inference. When in the frozen state, the soil conditions defy study.

An essential to the satisfactory study of values and trends in soil moisture is the need for continuing observations of the same soil throughout its seasonal cyclic changes. Destructive sampling with an auger introduces many uncertainties in most soil formations because of their heterogeneous nature. This type of an investigation, although simple, is expensive and also lacks continuity, especially over critical periods of rapid rise and fall of the ground-water table. To date, the problem of installing measuring devices without materially altering the adjacent soil conditions has been met with but limited success.

Most of these early instrument methods have been related to the variations in electrical resistance offered by soils in varying degrees of saturation. In general, these have presented overwhelming difficulties, particularly in the calibration of the equip-