1925

The properties of the fire clays used for the manufacture of zinc retorts

Adolph Harmon Kuechler

THE PROPERTIES OF THE FIRE CLAYS USED

FOR THE MANUFACTURE OF ZINC RETORTS.

-By-

Adolph Harmon Kuechler.

A

THESIS

submitted to the faculty of the

SCHOOL OF MINES AND METALLURGY OF THE UNIVERSITY OF MISSOURI

in partial fulfillment of the work required for the

DEGREE OF

MASTER OF SCIENCE.

Rolla, Missouri,

1 9 2 5.

Approved: B. M. O'Harra

Acting Superintendent of the Mississippi
Valley Experiment Station of the U. S.
Bureau of Mines.

Thesis: Properties of the fire clays used for the manufacture of zinc retorts. Kuechler. 1925.

C O N T E N T S.

I L L U S T R A T I O N S.

Page

T A B L E S.

Page

INTRODUCTION.

This thesis is presented to the faculty of the School of Mines and Metallurgy of the University of Missouri in partial fulfillment of the work required for the Degree of Master of Science. It describes experiments carried on at the Mississippi Valley Experiment Station of the United States Bureau of Mines, Department of the Interior, cooperating with the School of Mines and Metallurgy of the University of Missouri, which had for their purpose the examination of the physical and chemical properties of the refractories now used for the manufacture of zinc retorts.

I am greatly indebted to Mr. B. M. O'Harra, Acting Superintendent of the Mississippi Valley Experiment Station of the U. S. Bureau of Mines, under whose supervision this work was carried on; to Mr. E. S. Wheeler, Assistant Metallurgist and Mr. O. W. Holmes, Chemist, both affiliated with the State Mining Experiment Station of the School of Mines and Metallurgy of the University of Missouri, for their cooperation; to Mr. G. A. Bole, Superintendent of the Ceramic Experiment Station of the U. S. Bureau of Mines, for his interest and advice, and to various cooperating companies interested in the investigation.

THE PROPERTIES OF THE FIRE CLAYS USED

FOR THE MANUFACTURE OF ZINC RETORTS.

-By-

Adolph Harmon Kuechler.

Reason for Investigation.

A very important item of expense in the smelting of zinc ores is the cost of retorts. A zinc smelter of average size contains from 4,000 to 5,000 retorts, which are in continuous use when the smelter is operating to full capacity. These last from 30 to 75 days, depending upon the quality of the retorts, the kind of ore smelted, the kind of fuel used, and the type of the retort furnace. The life of the retorts is important, not only because of the cost of the retorts themselves, but also because of the absorption of zinc in new retorts, which occasions an important zinc loss, and because of the loss of capacity which results during the twenty-four hours that a new retort is in the furnace (in some plants) before it is charged.

The conditions that a zinc retort must meet are exceedingly rigorous. The retort is about eight inches in internal diameter, has walls about one inch thick, and is from fifty to sixty inches in length, and is supported at the two ends only. Besides its own weight, it carries a weight of about one hundred pounds of zinc ore and reduction fuel distributed uniformly throughout its length. It is heated to a maximum temperature of about 1400° C. on the outside (corresponding to a temperature of 1250° - 1300° C. on the inside), and during discharging and recharging is subjected to mechanical shocks and strains of no small magnitude. It must, therefore, possess high tensile strength, resistance to deformation, and resistance to shock at elevated temperatures. Charge residues are ordinarily cleaned from the retorts by inserting a pipe carrying a stream of running water to the back end of the hot retort, the residues being blown out of the retort by the steam generated, and the retort, still heated to a yellow heat, is filled with cold, damp charge. Therefore, the retort must have high resistance to sudden temperature changes. The retort is exposed to the action of more or less corrosive slags at high temperatures; therefore it must have a high resistance to the penetration and chemical action of slags. The retort must be non-porous to prevent the escape of zinc vapor from, or the entrance of air into, the retort. The tendency of the retort to absorb zinc should be as low as possible, but it is doubtful if zinc absorption can be controlled to any great extent.

Because of the rigorous conditions that zinc retorts must meet and because of the large consumption in all zinc smelters, the importance of being able to make high quality retorts at a minimum cost is apparent.

Object of the Investigation.

The ultimate object of this refractories investigation is to develop a body for zinc retorts, or changes in the method of their manufacture, that will result in better retorts than the ones now in use. In doing this, the question of permissible cost must, at all times, be kept in mind. The immediate object of the present phase of this investigation, of which this thesis covers only a part, is to determine the physical and chemical properties of the refractories (fire clays, grogs, bodies, etc.) now used for the manufacture of zinc retorts. This will be a basis for later investigations of raw materials or body mixtures that offer promise of being better than the ones now in use.

Experimental Procedure.

Materials Used: The materials used in this investigation were collected by Messrs. G. S. Brewer, Assistant Fuel Engineer and W. E. Rice, Computer, of the U. S. Bureau of Mines, in the course of their visits to various cooperating zinc smelters. The samples collected consisted of clays, grogs and body mixtures (combinations of grog and clay). A description of these is given in tabulated form on this and succeeding pages.

C l a y s.

Sample Number	Description
1	St. Louis clay
2	Grandview clay - St. Louis
3	St. Louis clay
4	St. Louis clay
5	St. Louis clay
6	St. Louis clay
7	St. Louis clay
8	St. Louis clay
9 *	Mine run, Cheltenham clay
10 *	Cheltenham clay, lower portion of vein; pot clays taken out.

* Clays No. 9 and No. 10, Grogs No. 9 and 10, and body mixture No. 10 bear no relation to one another. Aside from this the body mixtures are all made up from the correspondingly numbered clays and grogs, i.e., body No. 1 is made up of clay No. 1 and grog No. 1, and so on.

G r o g s.

Sample Number	Description
1	1/2 volume old condenser material from jig and 1/2 volume any old burned fire clay material available around plant.
2	Adobes of Grandview clay and broken retorts from tempering kilns.
3.	1/3 volume calcined clay; 2/3 volume used retorts and tempered retorts.
4	(Synthetic-mixed in our laboratory). 1/3 Evans and Howard adobes, 1/3 calcined flint clay from Colorado, and 1/3 broken brick.
5	(Synthetic; crushed in our laboratory). Calcined clay.
6	1/2 recovered material, 1/2 calcined Big Savage flint clay from Maryland.
7	2/5 adobes from St. Louis clay, 2/5 old retorts and 1/5 bats.
8	(Synthetic; crushed in our laboratory). Broken saggers.
9 *	(Synthetic; crushed in our laboratory). Calcined flint clay.
10 *	(Synthetic; crushed in our laboratory). Burnt Cheltenham clay.

* See footnote on Page 4.

B o d y   M i x t u r e s.

Sample Number	Description
1	7 buckets clay - 8 buckets grog.
2	5 parts grog to 4 parts raw clay by volume.
3	52 parts grog to 48 parts clay (heaping bucket grog to level bucket clay).
4	10,000 pounds clay to 12,500 pounds grog.
5	1/2 clay - 1/2 grog
6	7 parts clay to 9 parts grog by volume
7	45 per cent by weight St. Louis clay; 55 per cent by weight grog.
8	50 per cent clay volume 50 per cent grog volume
10 *	Prepared mix.

---

* See footnote on Page 4.

Tests Made.

Unless otherwise noted, all tests were made according to the standard methods of the American Society for Testing Materials and the American Ceramic Society.

Chemical Analyses: Mr. O. W. Holmes determined ignition loss, silica, alumina, iron oxide, titania, lime, magnesia, Na_2O, and K_2O on all clays and grogs as shown under experimental results. In the case of the grogs, zinc was run and the carbon content was determined on body mixture No. 10, which was known to contain crushed coke.

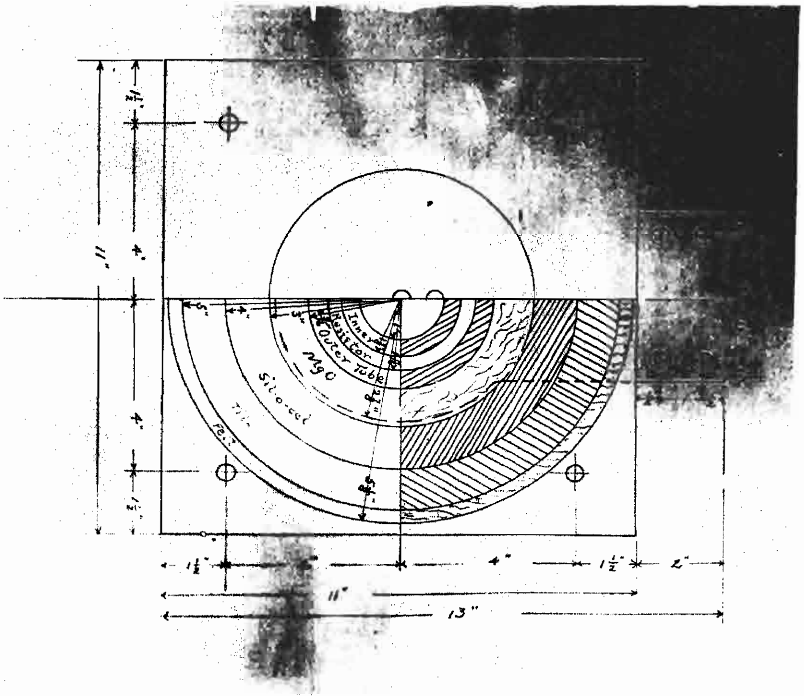
Softening Point: The softening point was determined on all clays and grogs. The sample for this test was obtained with the same care and precision as for chemical analysis, i. e., the material was crushed to 4 mesh and finer in a jaw crusher, then coned and quartered to the amount required, and finally ground in an agate mortar to pass a 65 mesh sieve. (In the case of the sample for chemical analysis, however, the material was ground to pass a 100 mesh sieve). In each case care was taken to prevent excessive reduction of the fines by frequent removal through the sieve. The test cones were moulded in steel moulds to the size and shape of the pyrometric cones as manufactured by Edward Orton, Junior. It was found necessary, however, in moulding the grogs into cones, to use an organic binder, gum arabic, to supply the deficiency in plasticity. The test cones were mounted in a circular plaque of a convenient size to insert in the furnace used. The test cones and pyrometric cones were mounted so that their numbered faces (the trowled face of the pyrometric cone) made an angle of about 75° with the plaque. The cone plaque composition used was as follows:

1/2-pound - No. 2 St. Louis Plastic Fire Clay

1/4-pound - Calcined Flint Clay

1/4-pound - Alundum.

In the softening point determinations, Fulton's grananular resistance furnace was used, a drawing of which appears as Figure 1. This furnace was used on one phase of a three phase 220 volt A. C. circuit. It was in series with 2200-220 volt transformers, a voltage regulator and panel board allowing a voltage variation from 17 to 300 volts giving a very accurate temperature control. It will be noted from Figure 1 that a hole was drilled in the bottom of the furnace. This hole gave rise, by natural draft, to a circulation of air which apparently was insufficient to appreciably cool the furnace, but was sufficient to maintain an oxidizing atmosphere around the cones. The cones were set on a cylindrical support a couple of inches above the bottom of the furnace; the air coming in at the bottom came up around the periphery of this support and was preheated to the temperature of the furnace before coming in contact with the cones. The



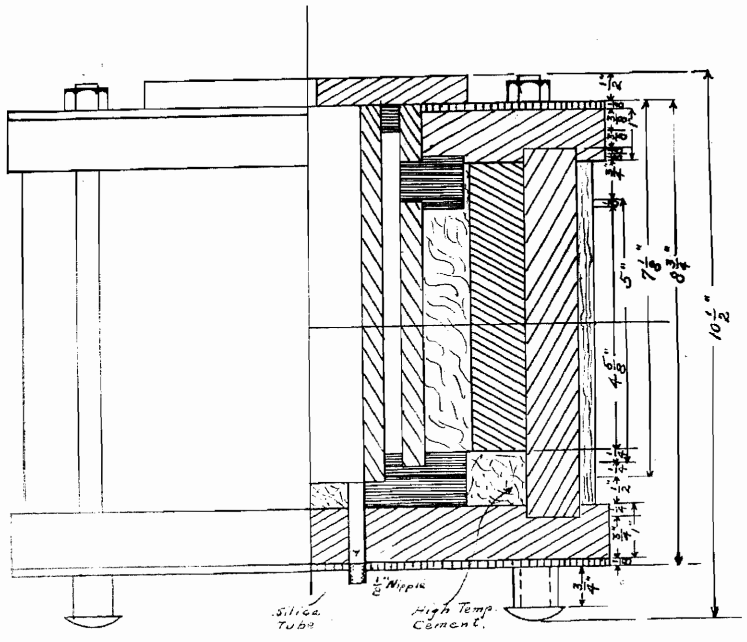


Figure 1.

Fulton's Granamular Resistance Furnace.

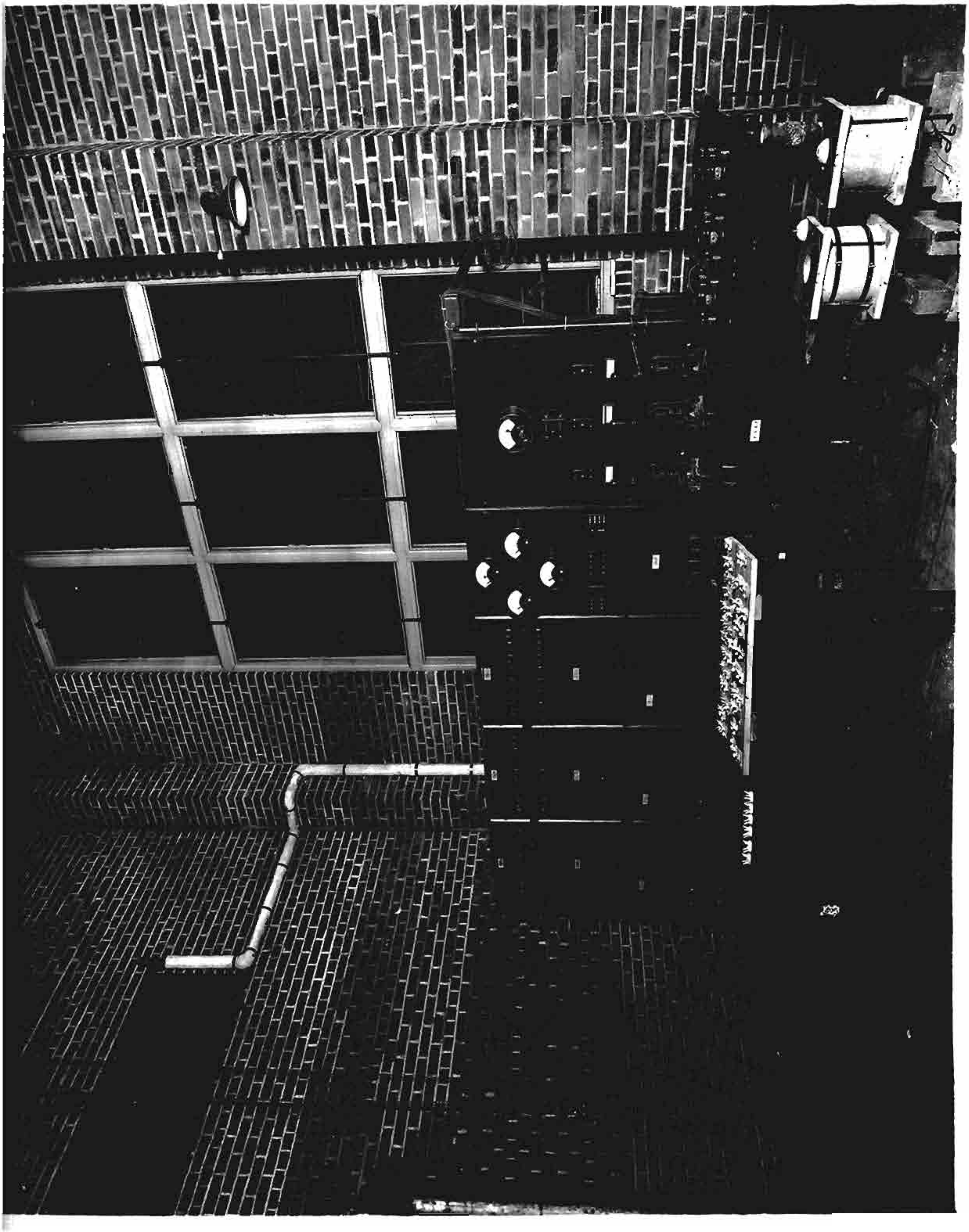


Figure 2.

Switch Board with Fulton's Grananular Furnaces Attached.

rate of heating was approximately 50° C. per five minutes after 800° C. was reached. The softening point of a cone is indicated by its tip bending over and touching the plaque and is reported as the serial number of the standard pyrometric cone which softens at the same temperature.

Drying Shrinkage: The clays were crushed to pass a 20 mesh sieve and thoroughly kneaded with water to form a mixture of soft plastic consistency. This test also was used on body mixtures except that they were not crushed before working with water. The test pieces were then formed in a steel mould measuring 1-1/8" x 1-1/8", cut into 1-7/8" lengths. The plastic volume was then determined in a Schurecht overflow volumeter. Kerosene was used as the measuring fluid and the volume was read to the nearest 0.1 cc. After determining the plastic volume, the test pieces were dried with a cloth to remove the film of kerosene, and allowed to dry at room temperature until air dry, 24 to 36 hours. They were next dried at a temperature of 64° to 76° C. for at least five hours, then at 110° C. to approximately constant weight and finally cooled in a dessicator. The dry test pieces were then soaked in kerosene for at least 12 hours, after which the dry volume was obtained in the same manner as the plastic volume. The per cent volume shrinkage was calculated as follows:

$$\text{Per cent volume shrinkage} = \frac{\text{Plastic Volume} - \text{Dry Volume}}{\text{Dry Volume}} \times 100.$$

Water of Plasticity: The test pieces were approximately of the same size and shape and made in the same manner as those for the drying shrinkage tests. The plastic test piece was weighed on a balance to an accuracy of 0.1 gram, dried according to the method outlined above for the drying shrinkage tests and was weighed with the same accuracy as before. The water of plasticity was calculated as follows:

$$\text{Per cent Water of Plasticity} = \frac{\text{Plastic Weight} - \text{Dry Weight}}{\text{Dry Weight}} \times 100.$$

Firing Behavior: The test pieces were formed and the dry volume and weight determined as described under drying shrinkage. The test pieces were then placed in a test kiln, a view of which is shown in Figure 3. This kiln is oil fired and has a remarkably uniform temperature distribution. The temperature is controlled by both Orton cones and a platinum, platinum-rhodium thermocouple. The temperature, however, is reported in terms of cones. The heating rate was approximately 50° C. per hour. Test pieces were drawn at 800° C., Cone 6, Cone 8, Cone 12, Cone 14 and Cone 16 and immediately immersed in hot sand to prevent too sudden cooling. When cool enough to handle the test pieces were put into a dessicator to cool to room temperature and then the fired weight determined by weighing on a balance to an accuracy of 0.1 gram. The weighed test pieces were placed in distilled water and boiled for two hours, cooled to room temperature and the saturated weight determined by

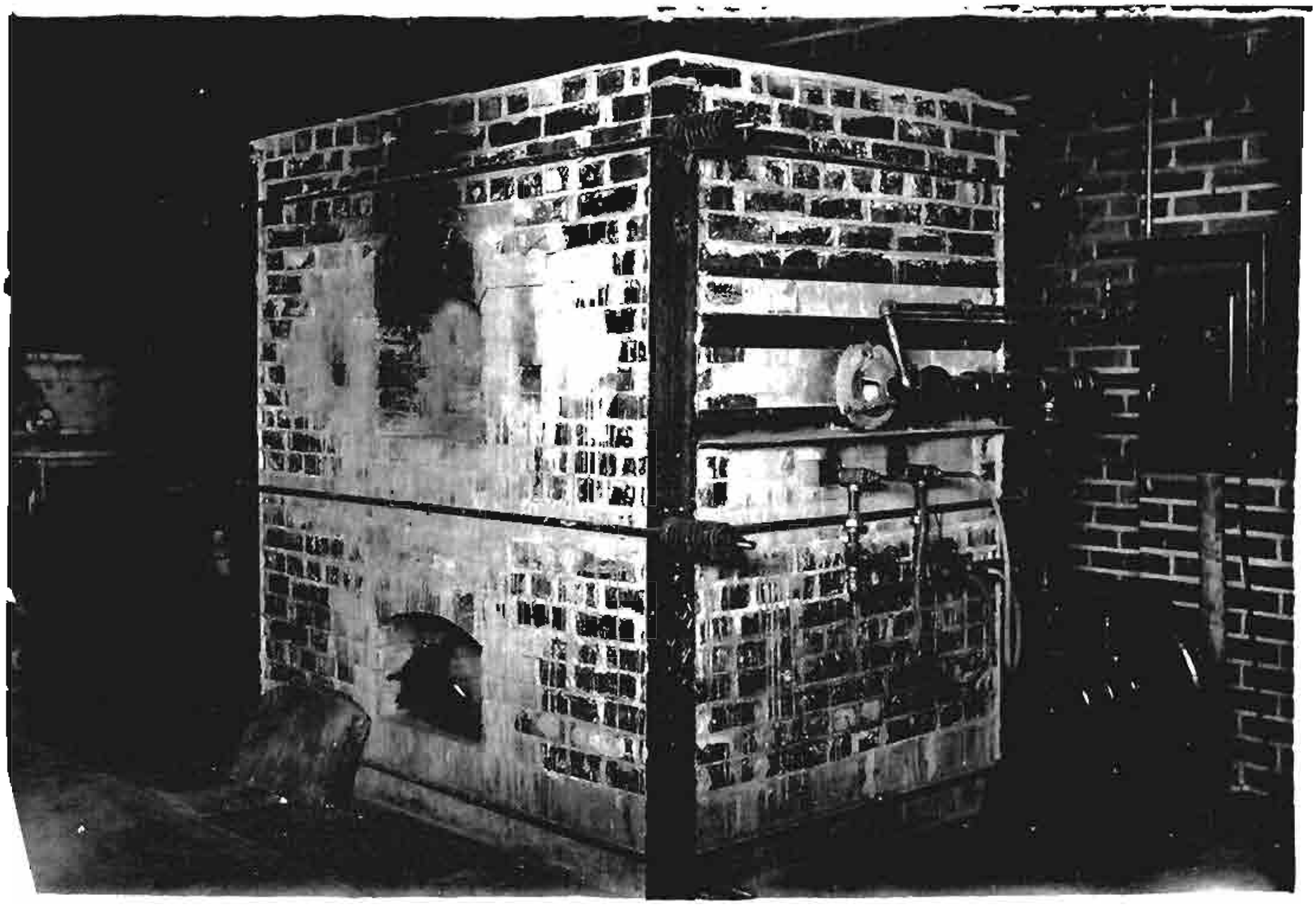


Figure 3.

Test Kiln.

weighing to the accuracy of 0.1 gram. The fired volume was next determined in a volumeter using distilled water as the measuring fluid. The following data were then calculated as indicated:

$$\text{Per cent Porosity} = \frac{\text{Saturated Fired Weight} - \text{Fired Weight}}{\text{Fired Volume}} \times 100$$

$$\text{Per cent Volume Change} = \frac{\text{Dry Volume} - \text{Fired Volume}}{\text{Dry Volume}} \times 100$$

$$\text{Apparent Specific Gravity} = \frac{\text{Fired Weight}}{\text{Fired Volume} - (\text{Saturated Fire Weight} - \text{Fired Weight})}$$

$$\text{Bulk Specific Gravity} = \frac{\text{Fired Weight}}{\text{Fired Volume}}$$

$$\text{Per cent Absorption} = \frac{\text{Saturated Fired Weight} - \text{Fired Weight}}{\text{Fired Weight}} \times 100.$$

Transverse Strength: The samples used in this test were crushed to pass a 20 mesh sieve and very intimately mixed with an equal amount, by weight, of standard silica sand, sized to pass a 20 mesh sieve and to be retained on a 35 mesh sieve. The mixture was brought to a soft, plastic consistency with water, formed in a steel mould one inch by one inch in cross section, and cut into seven-inch lengths. The test pieces were dried by the standard method described before, care being taken to keep the drying uniform in the early stages by turning every twelve hours. The test pieces were broken on a machine, shown in Figure 4, having knife edges of one-fourth inch radius and five inches apart. An automatic feed was used for the shot used to weight the test bar, the rate of feeding being twelve pounds per minute.

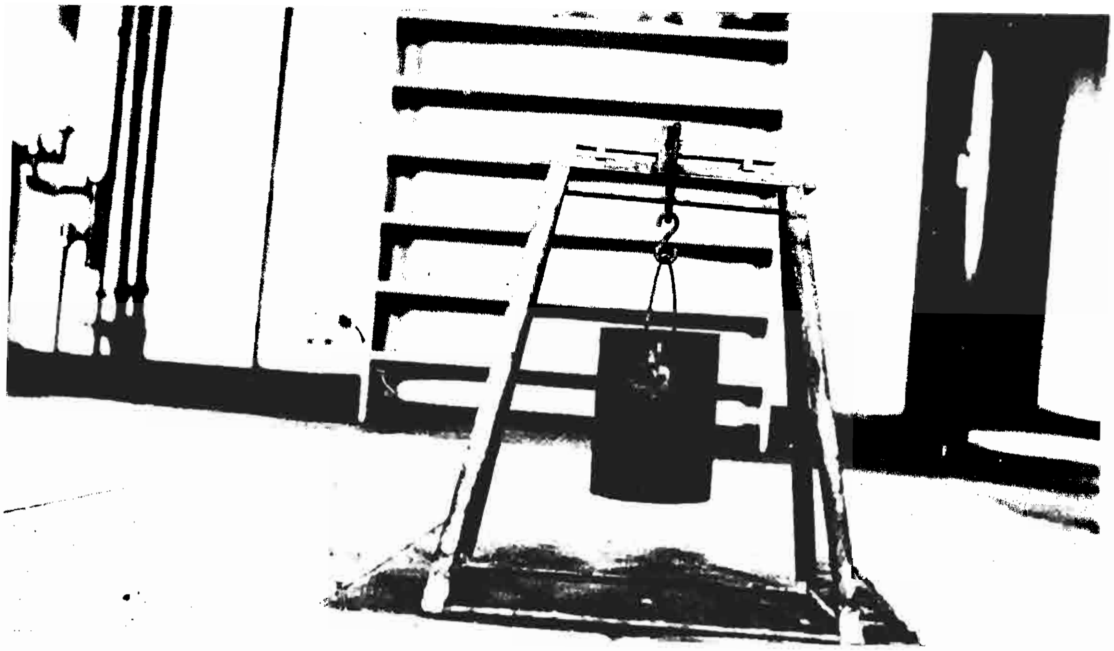


Figure 4.

Transverse Strength Testing Machine.

The depth and width of the bar were taken at the break, together with the breaking load in pounds. The modulus of rupture was calculated by the following formula:

$$\text{Modulus of Rupture} = \frac{\text{Breaking Load X distance between knife edges X 3}}{\text{Breadth of bar X depth of bar squared X 2}}$$

Slaking Test: The test pieces used were made of a mixture of 50 per cent by weight of powdered flint and 50 per cent of the clay to be tested, which had been crushed to pass a 28 mesh sieve. The cubes were one inch on an edge in the plastic state. They were dried and slaked on a 3 mesh sieve, the temperature of the water being held at 25° C, $\pm 1^{\circ}$ C. The slaking time noted was the time required for the whole of the test piece to slake and settle through the screen.

Screen Analysis: Screen analysis was run on all grog samples using Tyler standard screens. Approximately a 1000-gram sample was shaken in a nest of screens on a Ro-Tap machine for fifteen minutes. The screens used and the diameter of the openings are as follows:

Mesh	Diameter of Openings
6	.131 inch
8	.093 inch
10	.065 inch
14	.046 inch
20	.0328 inch
28	.0232 inch
35	.0164 inch
48	.0116 inch
65	.0082 inch
100	.0058 inch
150	.0041 inch
200	.0029 inch

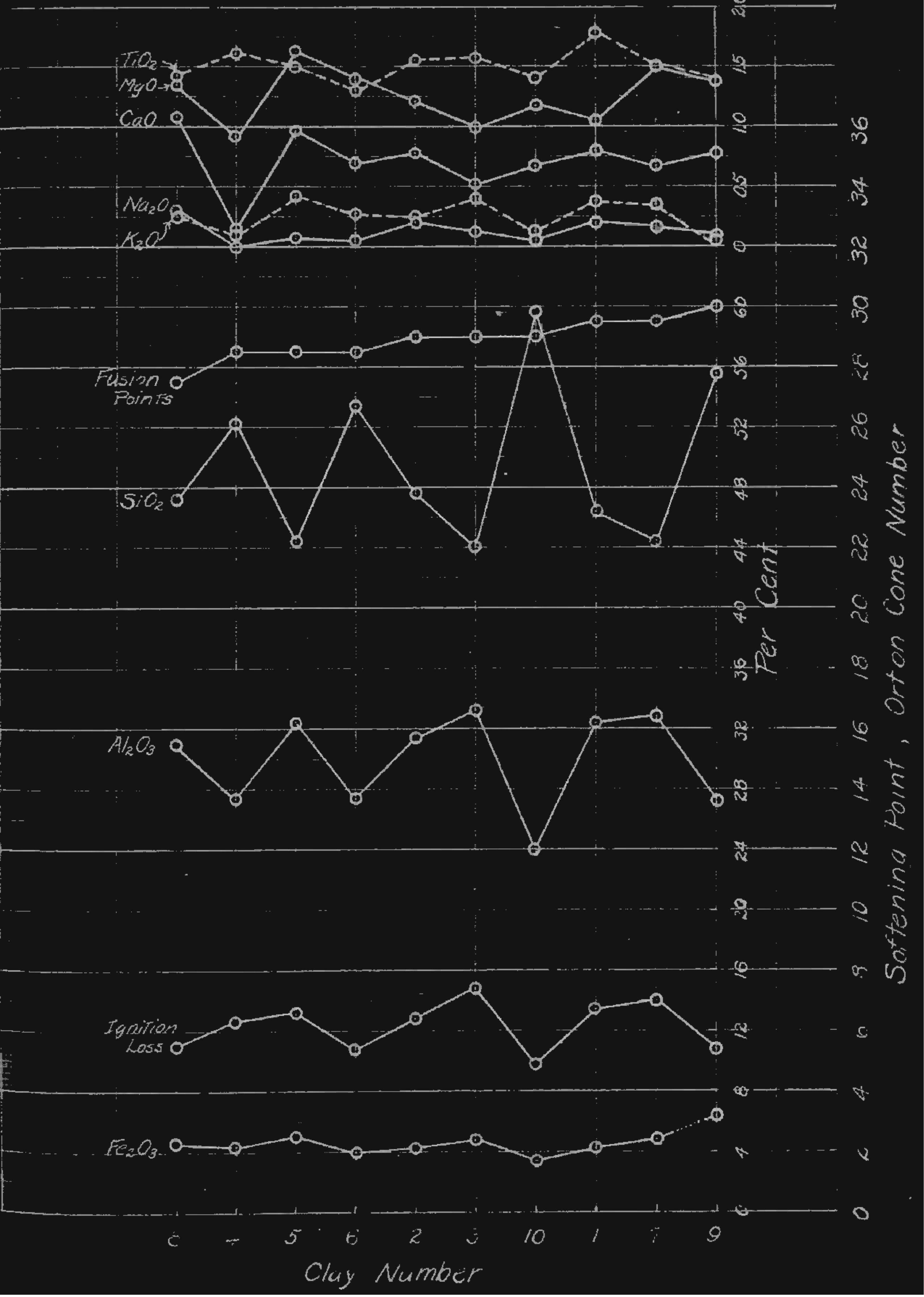
Experimental Results.

On the following pages will be found the tabulated results of the tests made on the various clays, grogs and body mixtures, together with the curves plotted therefrom.

Table I.

Chemical Analyses and Softening Points of Clays.

Clay Number	1	2	3	4	5	6	7	8	9	10
Per cent SiO_2	46.49	47.66	44.11	52.21	44.35	53.40	44.51	47.52	55.52	59.67
Per cent Al_2O_3	32.33	31.35	33.34	27.41	32.51	27.38	32.73	31.09	27.31	24.10
Per cent Ignition Loss	13.44	12.70	14.76	12.54	13.07	10.78	13.95	11.90	10.71	9.82
Per cent Fe_2O_3	4.27	4.20	4.72	4.42	5.08	4.04	4.79	4.60	3.47	3.40
Per cent TiO_2	1.78	1.54	1.58	1.60	1.49	1.31	1.47	1.42	1.41	1.41
Per cent MgO	1.05	1.21	1.00	.93	1.62	1.41	1.51	1.34	1.38	1.17
Per cent CaO	.79	.77	.52	.15	.97	.70	.69	1.08	.77	.67
Per cent Na_2O	.20	.21	.13	.00	.18	.06	.17	.03	.09	.05
Per cent K_2O	.38	.24	.40	.11	.42	.28	.34	.26	.03	.13
Softening Point	29-30	29	29	28-29	28-29	28-29	29-30	27-28	30	29



TiO2
MgO
CaO
Na2O
K2O
Fusion Points
SiO2
Al2O3
Ignition Loss
Fe2O3
Per Cent
Softening Point, Orton Cone Number
Clay Number
5
6
2
10
1
7
9

Figure 5.

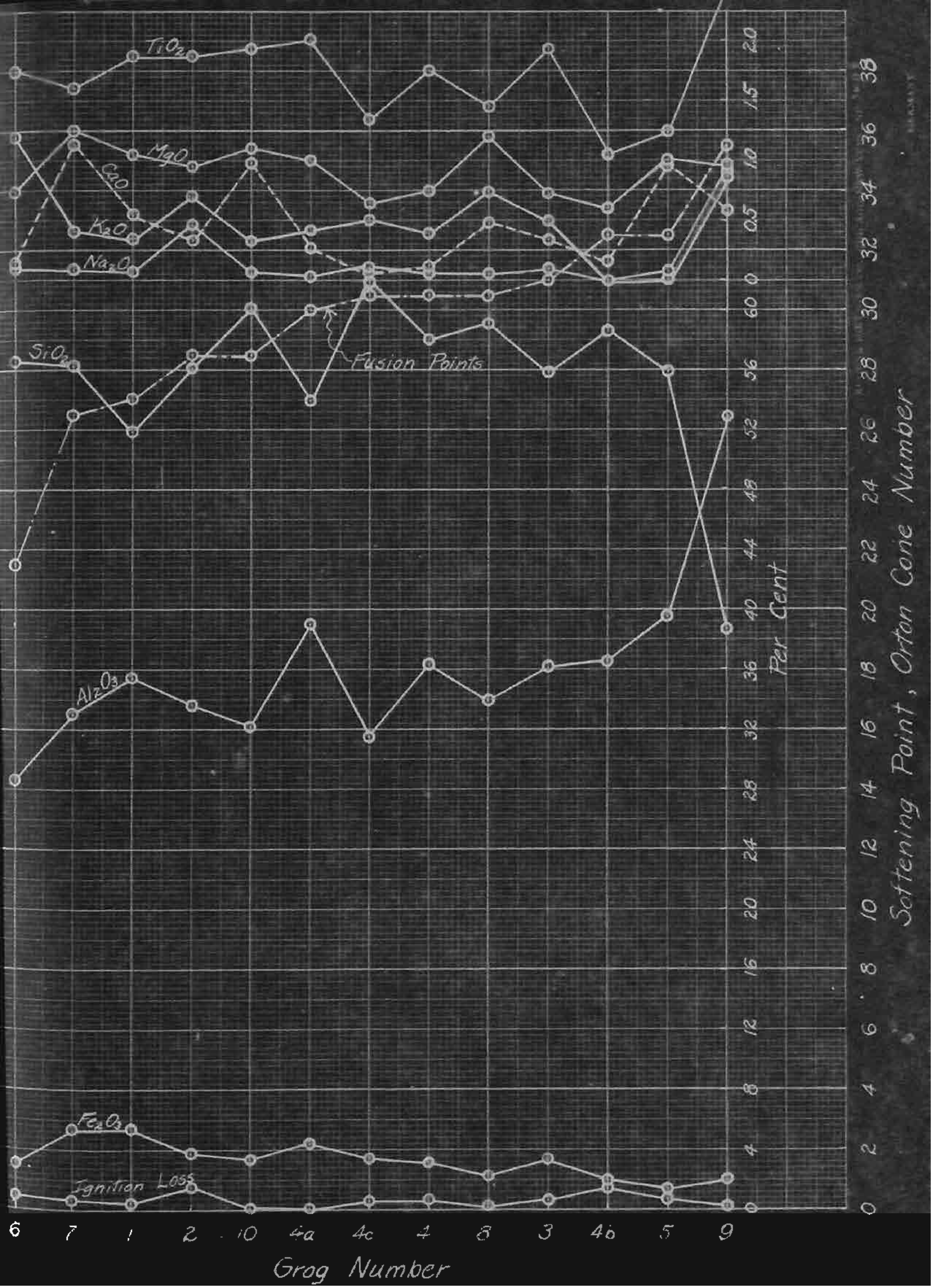
Chemical Analyses and Softening Points of Clays.

Table II.

Chemical Analyses and Softening Points of Grogs.

Grog Number	1	2	3	4	4-a	4-b	4-c	5	6	7	8	9	10
Per cent SiO_2	51.87	56.11	55.93	58.13	53.99	58.67	61.95	53.95	56.58	56.23	59.17	38.77	60.13
Per cent Al_2O_3	35.36	33.63	36.15	36.33	39.01	36.57	31.49	39.48	28.60	32.93	33.96	52.82	32.22
Per cent Ignition loss	0.45	1.76	0.67	0.63	0.09	1.49	0.52	0.72	0.89	0.73	0.16	0.19	0.11
Per cent Fe_2O_3	5.34	3.75	3.31	3.15	4.42	1.91	3.46	1.42	3.00	5.28	2.25	2.03	3.35
Per cent TiO_2	1.87	1.87	1.93	1.75	2.02	1.05	1.39	1.23	1.75	1.61	1.46	2.46	1.93
Per cent MgO	1.05	0.95	0.73	0.74	1.01	0.60	0.65	1.00	0.74	1.25	1.20	0.96	1.10
Per cent CaO	0.54	0.33	0.34	0.12	0.27	0.16	0.07	0.97	0.14	1.13	0.48	0.58	0.98
Per cent Na_2O	0.07	0.46	0.09	0.06	0.03	--	0.10	0.02	0.10	0.08	0.05	0.87	0.07
Per cent K_2O	0.33	0.69	0.50	0.39	0.42	--	0.50	0.07	1.19	0.41	0.74	0.89	0.33
* Per cent zinc	2.72	0.52	0.10	0.20	0.20	--	--	--	4.59	0.51	--	--	--
Softening Point	27	28-29	31	30-31	30	32-33	30-31	32-33	20-23	26-27	30-31	35 +	28-29

* Zinc not plotted.



TiO2
MgO
CaO
K2O
Na2O
SiO2
Fusion Points
Al2O3
Fe2O3
Ignition Loss
Per Cent
Softening Point, Orton Cone Number
6 7 1 2 10 4a 4c 4 8 3 4b 5 9
Grog Number

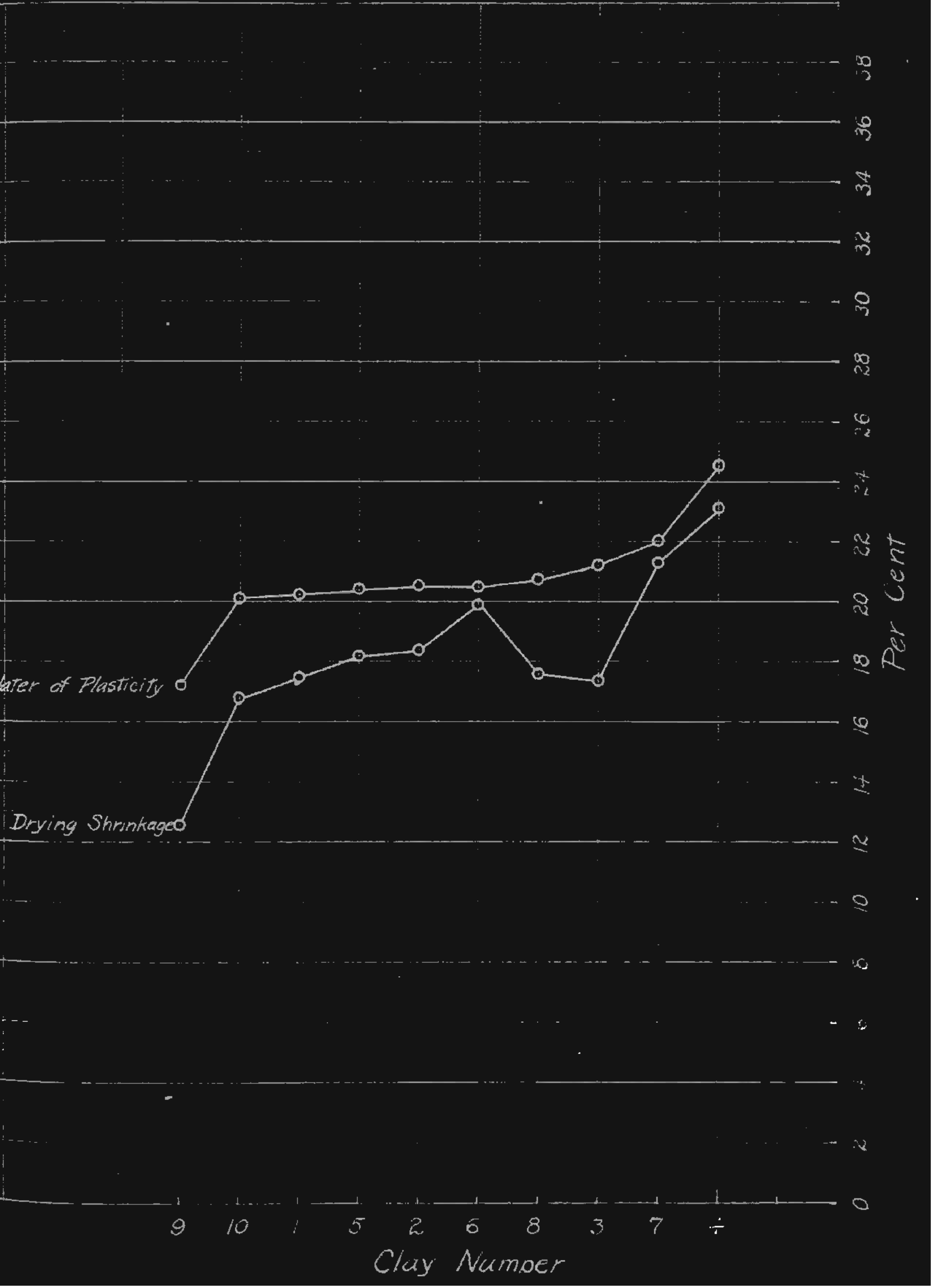
Figure 6.

Chemical Analyses and Softening Points of Grogs.

Table III.

Water of Plasticity and Drying Shrinkage of Clays.

Clay Number	Per cent Water of Plasticity	Per cent Drying Shrinkage
1	20.2	17.5
2	20.5	18.4
3	21.2	17.4
4	24.5	23.1
5	20.4	18.2
6	20.5	19.9
7	22.0	21.3
8	20.7	17.6
9	17.2	12.6
10	20.1	16.8



ater of Plasticity
Drying Shrinkage
Per Cent
Clay Number
9
10
1
5
2
6
8
3
7
0
2
10
12
14
16
18
20
22
26
28
30
32
34
36

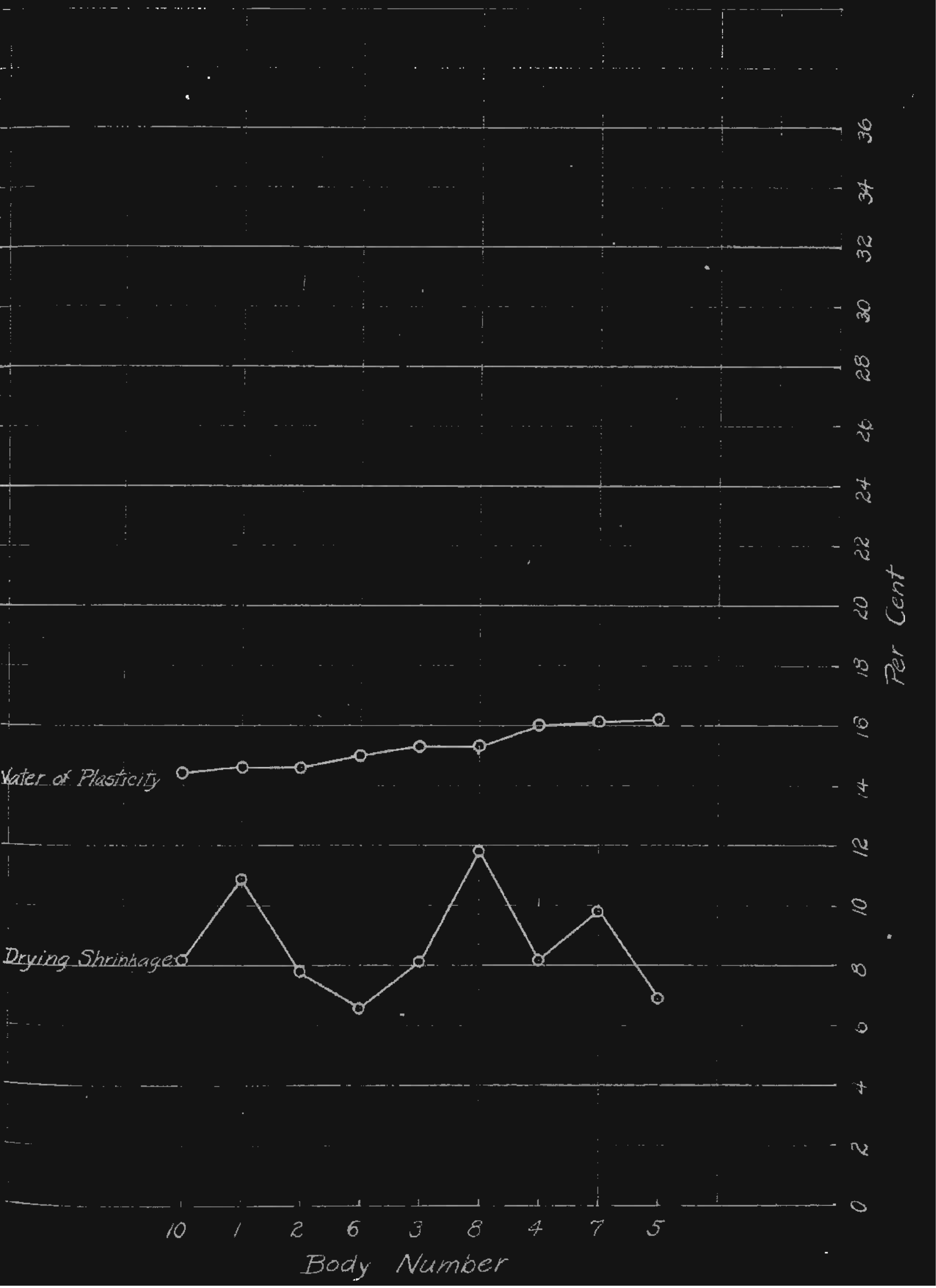
Figure 7.

Water of Plasticity and Drying Shrinkage of Clays.

Table IV.

Water of Plasticity and Drying Shrinkage of Body Mixtures.

Body Mixture Number	Per cent Water of Plasticity	Per cent Drying Shrinkage
1	14.6	10.9
2	14.6	7.8
3	15.3	8.1
4	16.0	8.2
5	16.2	6.9
6	15.0	6.6
7	16.1	9.8
8	15.3	11.8
10	14.4	8.2



Water of Plasticity
Drying Shrinkage
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
Per Cent
10
1
2
6
3
8
4
7
5
Body Number

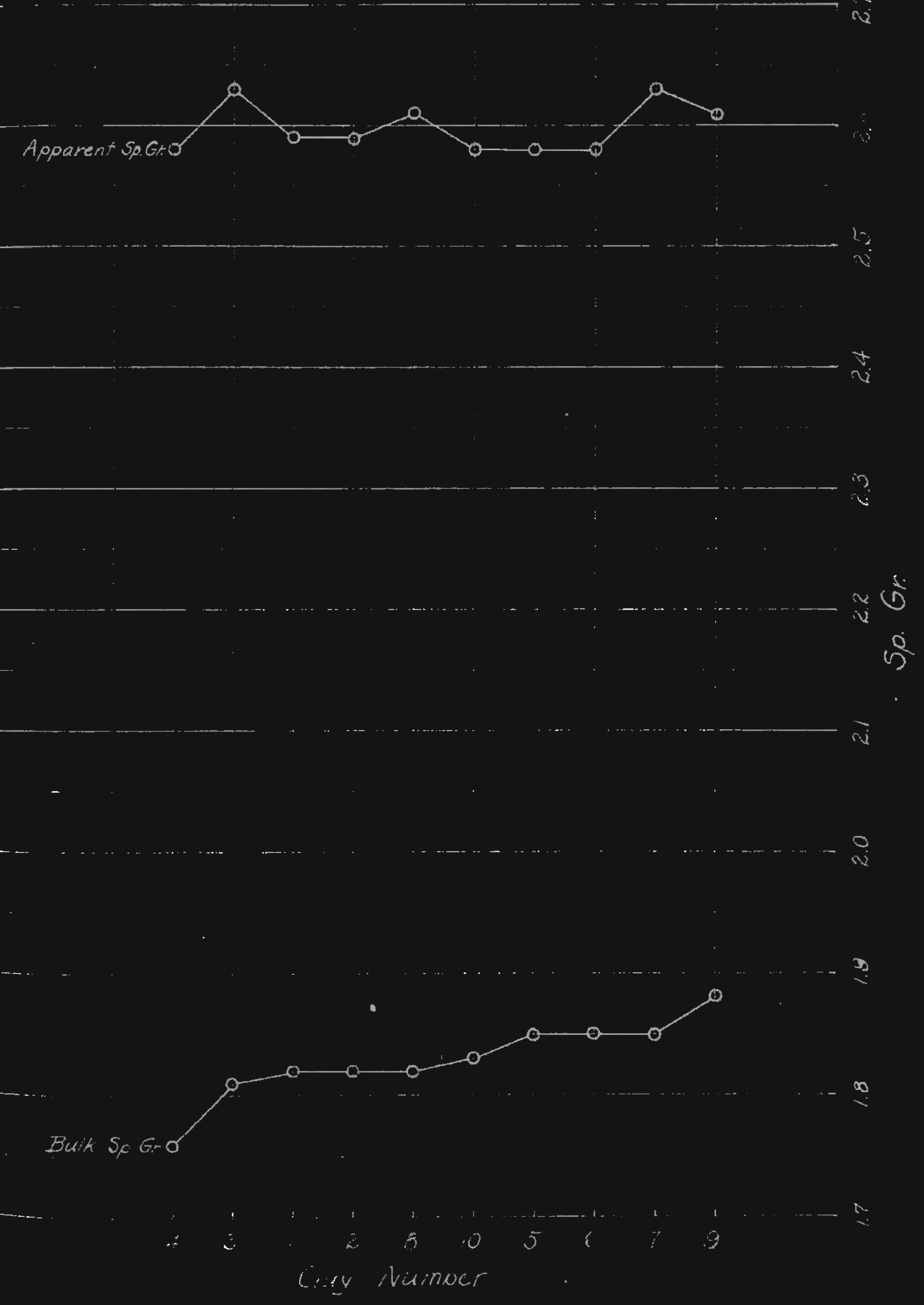
Figure 8.

Water of Plasticity and Drying Shrinkage of Body Mixtures.

Table V.

Apparent and Bulk Specific Gravity on Clays Fired at 800° C.

Clay Number	Apparent Specific Gravity	Bulk Specific Gravity
1	2.59	1.82
2	2.59	1.82
3	2.63	1.81
4	2.58	1.76
5	2.58	1.85
6	2.58	1.85
7	2.63	1.85
8	2.61	1.82
9	2.61	1.88
10	2.58	1.83



Apparent Sp.Gr.
Bulk Sp.Gr.
2.5
2.4
2.3
2.2
2.1
2.0
1.9
1.8
1.7
Sp. Gr.
4
3
2
8
5
7
9
Number

Apparent and Bulk Specific Gravity on Clays Fired at 800° C.

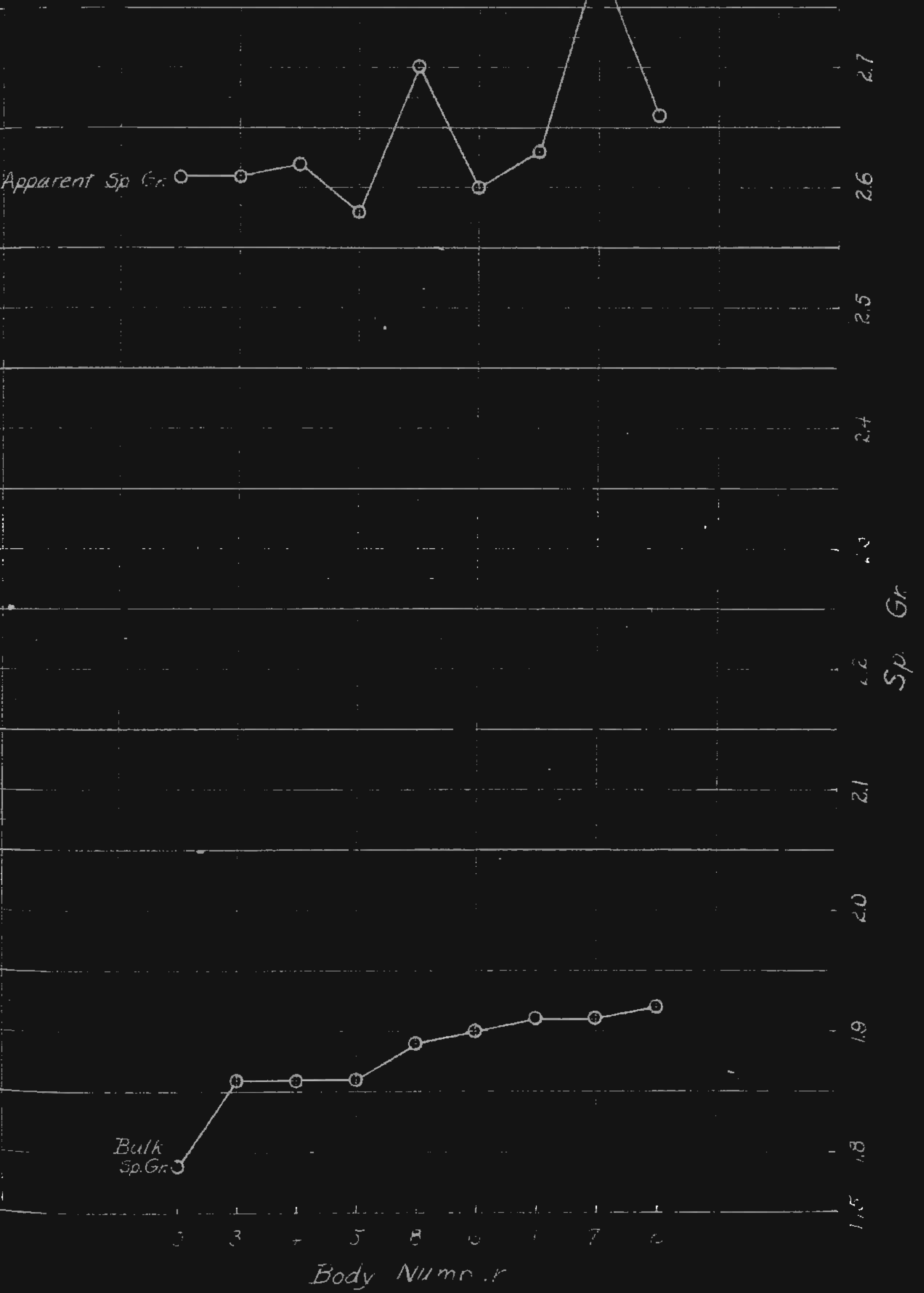
Figure 9.

Apparent and Bulk Specific Gravity on Clays Fired at 800° C.

Table VI.

Apparent and Bulk Specific Gravity on Body Mixtures Fired at 800° C.

Body Mixture Number	Apparent Specific Gravity	Bulk Specific Gravity
1	2.63	1.91
2	2.66	1.92
3	2.61	1.86
4	2.62	1.86
5	2.58	1.86
6	2.60	1.90
7	2.79	1.91
8	2.70	1.89
10	2.61	1.79



Apparent Sp. Gr.
Bulk Sp. Gr.
Sp. Gr.
Body Number
2.7
2.6
2.5
2.4
2.1
2.0
1.9
1.8

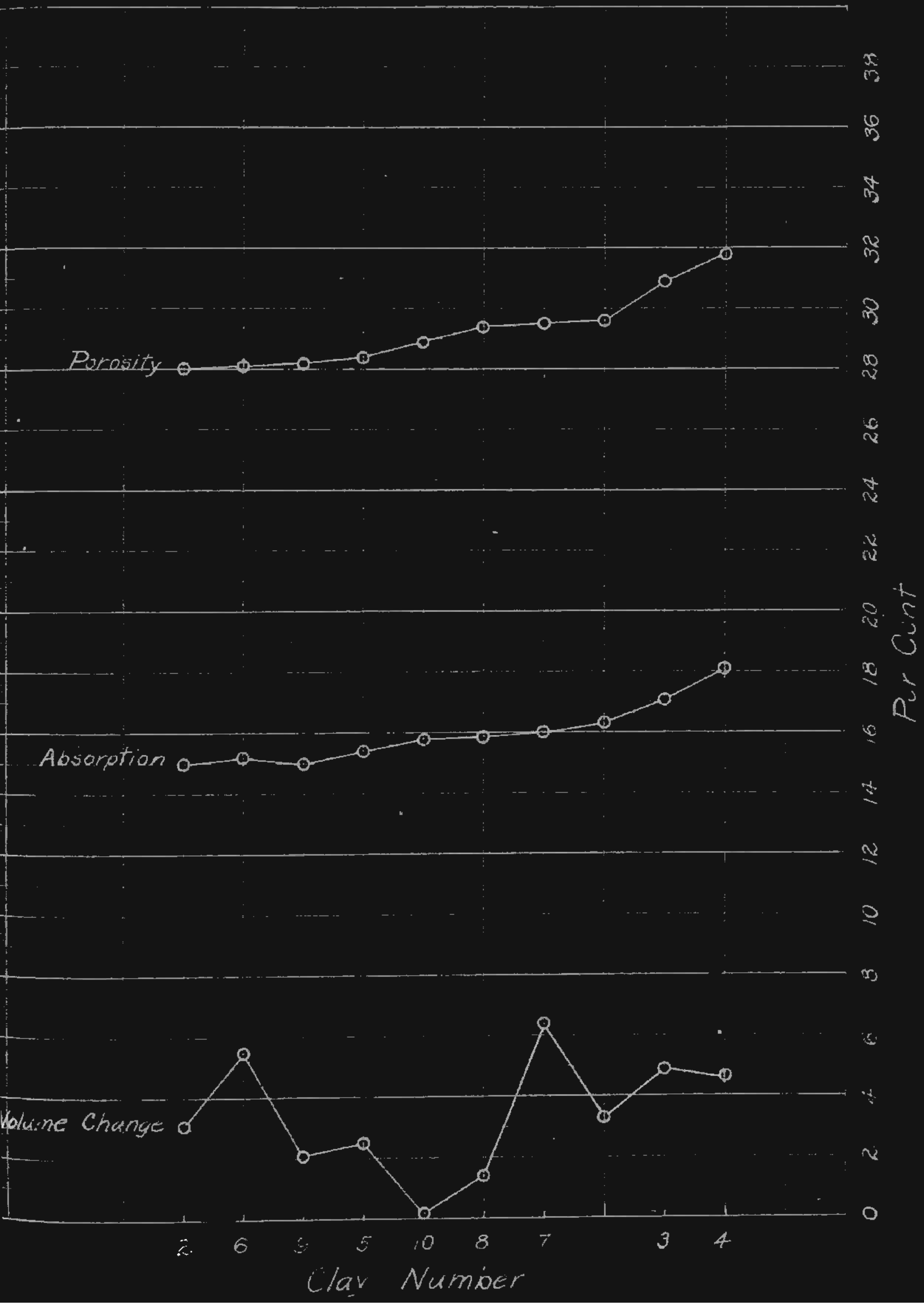
Figure 10.

Apparent and Bulk Specific Gravity on Body Mixtures Fired at 800° C.

Table VII.

Porosity, Absorption and Volume Change on Clays Fired at 800° C.

Clay Number	Per cent Porosity	Per cent Absorption	Per cent Volume Change
1	29. 6	16.3	3.3
2	27.95	14.95	3.1
3	30.85	17.05	4.9
4	31.75	18.1	4.6
5	28.4	15.35	2.5
6	28.1	15.2	5.45
7	29.5	16.0	6.4
8	29.35	15.9	1.35
9	28.15	15.0	2.05
10	28.9	15.8	0.15


Porosity
Absorption
Volume Change
Per Cent
Clay Number
2 6 9 5 10 8 7 3 4
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38

Porosity, Absorption and Volume Change on Clays Fired at 800° C.

Figure 11.

Porosity, Absorption and Volume Change on Clays Fired at 800° C.

Table VIII.

Porosity, Absorption and Volume Change on Body Mixtures Fired at 800° C.

Body Mixture Number	Per cent Porosity	Per cent Absorption	Per cent Volume Change
1	27.65	14.45	0.7
2	28.05	14.7	1.2
3	28.85	15.55	0.0
4	29.1	15.7	0.0
5	27.95	15.0	0.0
6	27.3	14.45	0.0
7	31.7	16.6	2.99
8	29.75	15.7	2.42
10	31.55	17.65	0.45

Porosity
Absorption
Volume Change
Body Number
Per Cent
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38
5 3 4 10

Figure 12.

Porosity, Absorption and Volume Change on Body Mixtures Fired at 800° C.

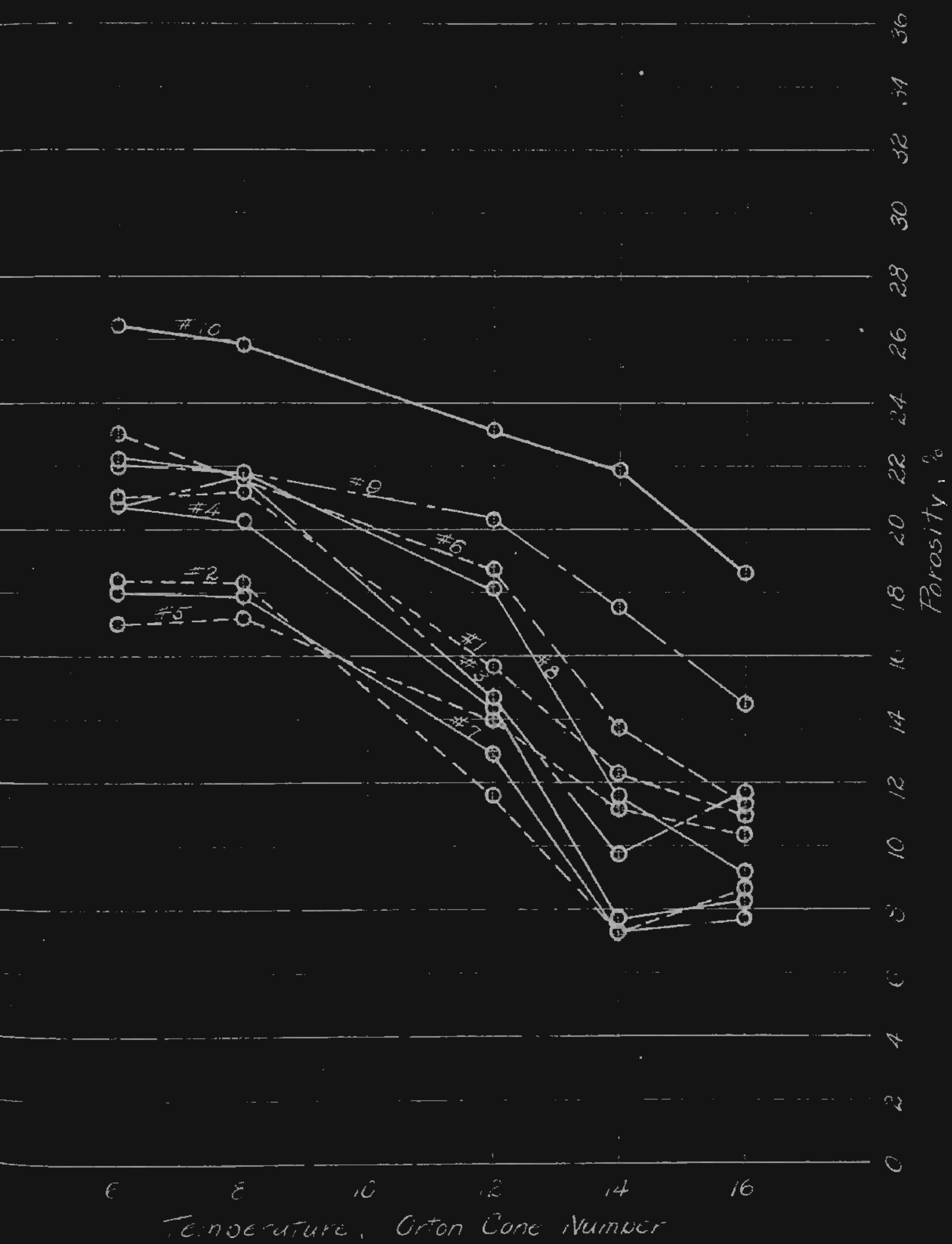
Figure 12.

Porosity, Absorption and Volume Change on Body Mixtures Fired at 800° C.

Table IX.

Porosity of Clays Fired at Cones 6, 8, 12, 14 and 16.

Clay Number	Per cent Porosity at Cones				
	6	8	12	14	16
1	21.0	21.2	15.65	12.3	11.0
2	18.4	18.35	11.55	7.24	8.64
3	20.75	21.7	14.65	9.73	11.65
4	20.75	20.3	14.35	7.73	8.23
5	17.0	17.2	13.95	11.15	10.36
6	23.05	21.6	18.7	13.75	11.35
7	18.0	17.9	12.9	7.23	7.65
8	22.25	21.75	18.1	11.6	9.17
9	22.05	21.8	20.3	17.5	14.5
10	26.45	25.85	23.1	21.85	18.6



Porosity, %
Temperature, Orton Cone Number
#10
#8
#4
#6
#2
#5
#1
#3
#7
#9

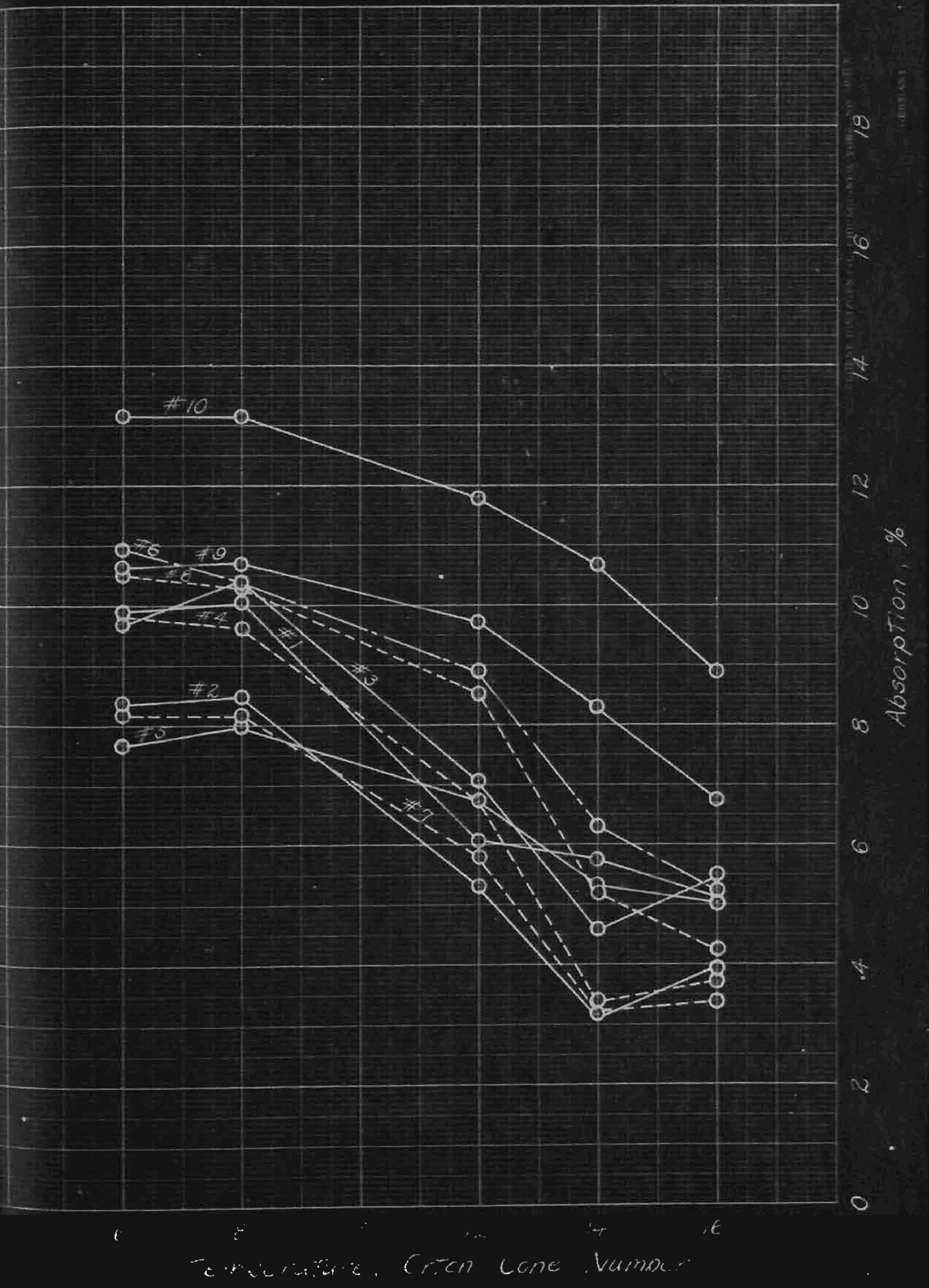
Figure 13.

Porosity of Clays Fired at Cones 6, 8, 12, 14 and 16.

Table X.

Absorption of Clays Fired at Cones 6, 8, 12, 14 and 16.

Clay Number	Per cent Absorption at Cones				
	6	8	12	14	16
1	9.88	10.03	6.06	5.75	5.11
2	8.36	8.47	5.30	3.11	3.95
3	9.68	10.4	7.06	4.56	5.46
4	9.83	9.63	6.74	3.37	3.73
5	7.68	7.97	6.71	5.30	5.04
6	10.95	10.35	8.88	6.30	5.21
7	8.19	8.18	5.81	3.16	3.4
8	10.5	10.3	8.52	5.22	4.24
9	10.65	10.70	9.72	8.28	6.75
10	13.15	13.15	11.77	10.65	8.83



#10
#6
#9
#8
#4
#1
#3
#2
#5
#7
0
2
4
6
8
10
12
14
16
18
Absorption, %
Temperature, Orton Cone Number

Figure 14.

Absorption of Clays Fired at Cones 6, 8, 12, 14 and 16.

Table XI.

Volume Change of Clays Fired at Cones 6, 8, 12, 14 and 16.

Clay Number	Per cent Volume Change at Cones				
	6	8	12	14	16
1	18.55	17.85	14.95	18.9	19.4
2	19.1	18.0	18.75	22.7	18.9
3	20.65	20.4	18.1	20.85	21.4
4	19.55	20.4	21.45	27.15	23.5
5	20.65	18.95	16.25	18.1	13.95
6	15.75	14.75	14.85	18.55	18.35
7	21.55	22.15	22.55	22.95	23.75
8	16.55	16.1	17.3	20.4	18.75
9	11.45	8.89	12.05	12.65	14.9
10	9.65	8.46	7.68	11.45	13.95

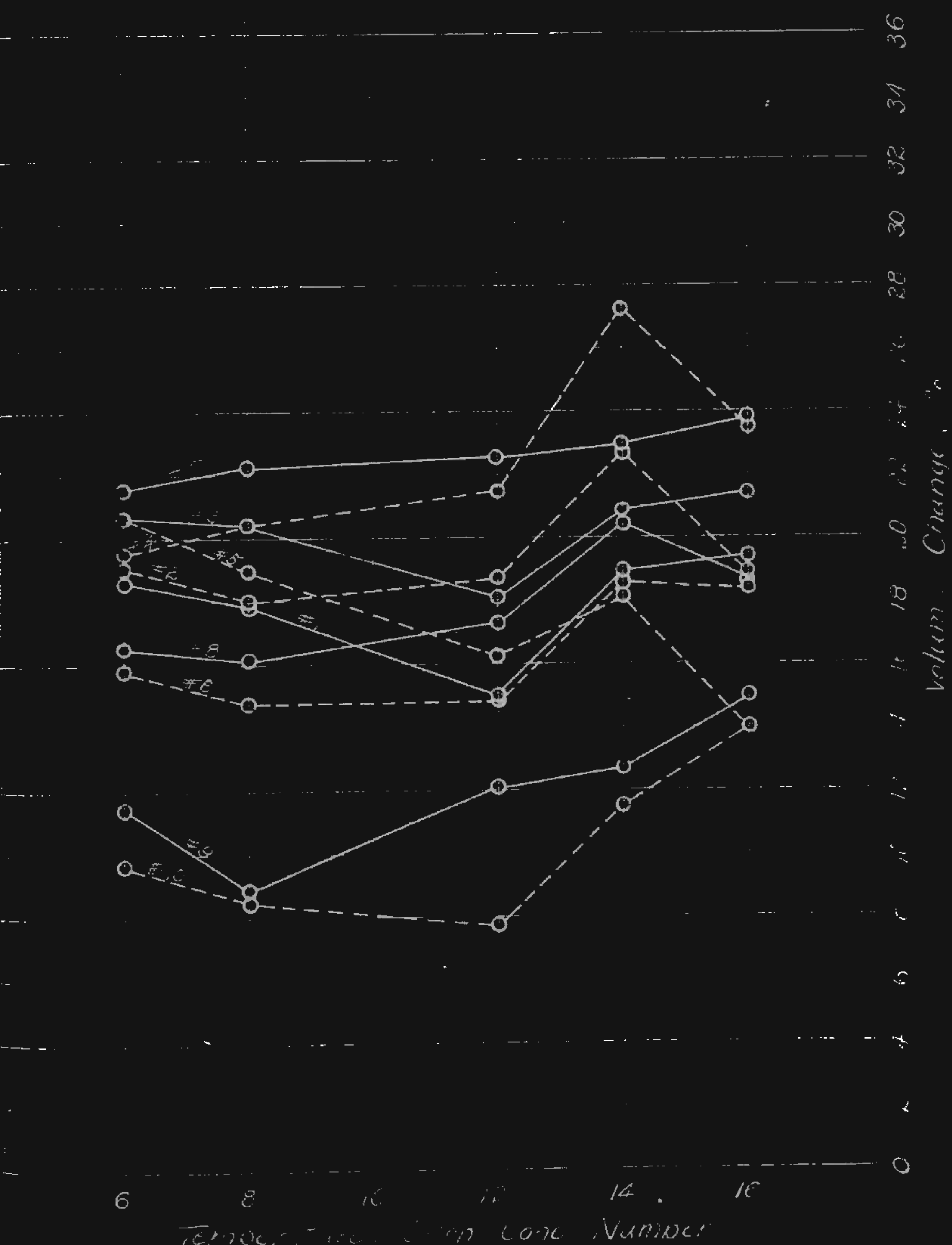

36
34
32
30
28
18
0
6
8
14
#5
#8
#6
#9

Figure 15.

Volume Change of Clays Fired at Cones 6, 8, 12, 14 and 16.

Table XII.

Porosity of Body Mixtures Fired at Cones 6, 8, 12, 14 and 16.

Body Mixture Number	Per cent Porosity at Cones				
	6	8	12	14	16
1	26.4	25.63	23.5	21.54	16.95
2	25.45	25.05	21.8	18.6	15.9
3	27.4	25.8	24.05	22.2	20.05
4	28.75	27.45	25.65	23.3	22.3
5	22.95	21.8	18.55	16.8	16.4
6	24.95	23.75	20.75	17.8	14.4
7	28.5	26.85	24.8	19.5	17.7
8	28.0	28.9	27.1	24.0	19.6
10	32.3	33.0	31.7	29.8	29.0

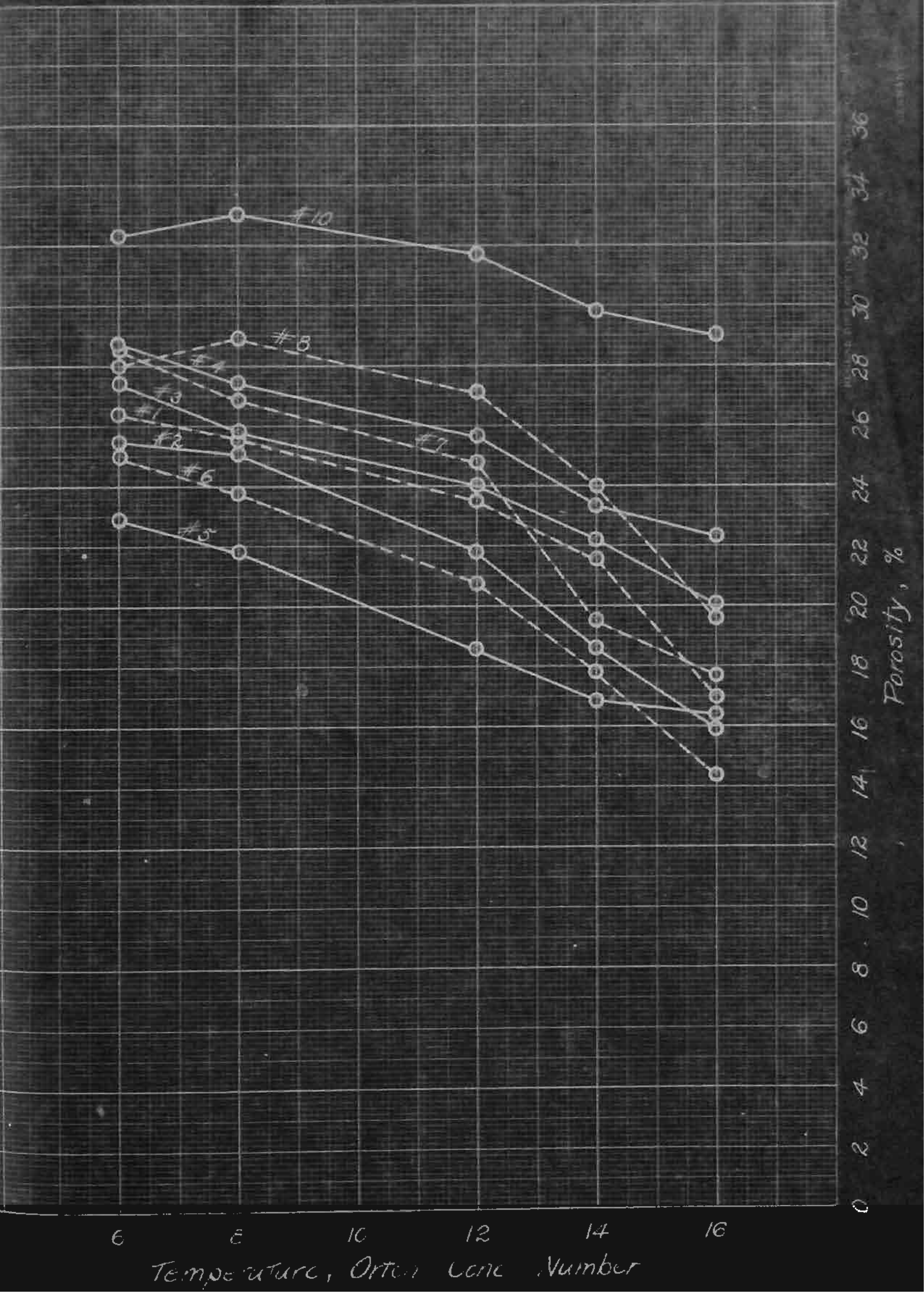

#10
#8
#4
#3
#1
#2
#7
#6
#5
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36
Porosity, %
6 8 10 12 14 16
Temperature, Orton Cone Number

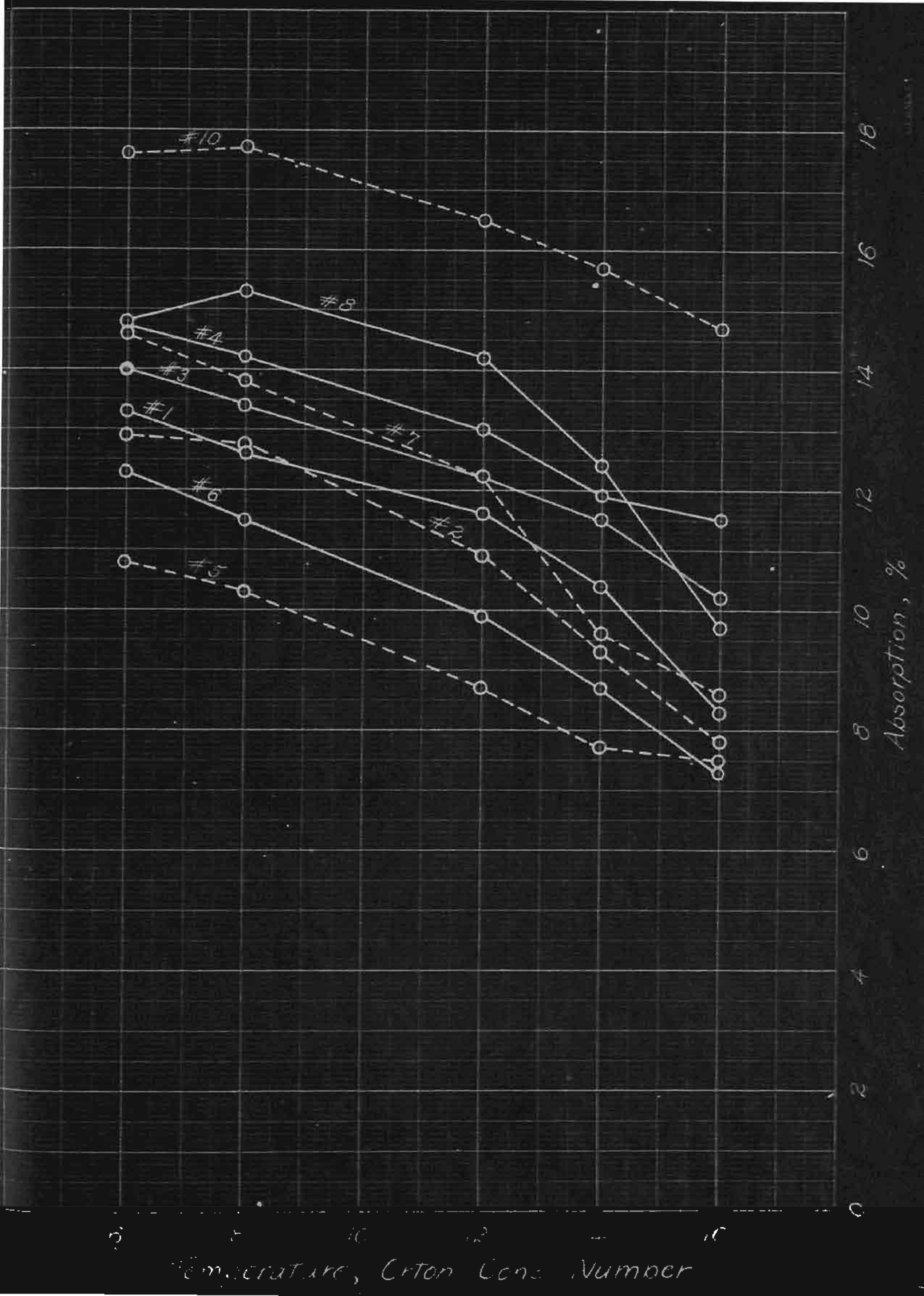
Figure 16.

Porosity of Body Mixtures Fired at Cones 6, 8, 12, 14 and 16.

Table XIII.

Absorption of Body Mixtures Fired at Cones 6, 8, 12, 14 and 16.

Body Mixture Number	Per cent Absorption at Cones				
	6	8	12	14	16
1	13.3	12.6	11.62	10.40	8.27
2	12.9	12.7	10.93	9.31	7.84
3	14.0	13.4	12.16	11.52	10.24
4	14.7	14.2	12.98	11.87	11.43
5	10.8	10.3	8.71	7.73	7.46
6	12.3	11.45	9.88	8.77	7.30
7	14.6	13.75	12.21	9.58	8.59
8	14.75	15.3	14.15	12.35	9.74
10	17.6	17.7	16.5	15.65	14.69



#10
#8
#4
#3
#1
#7
#6
#2
#5
18
16
14
12
10
8
6
4
2
0
Absorption, %
Temperature, Orton Cone Number

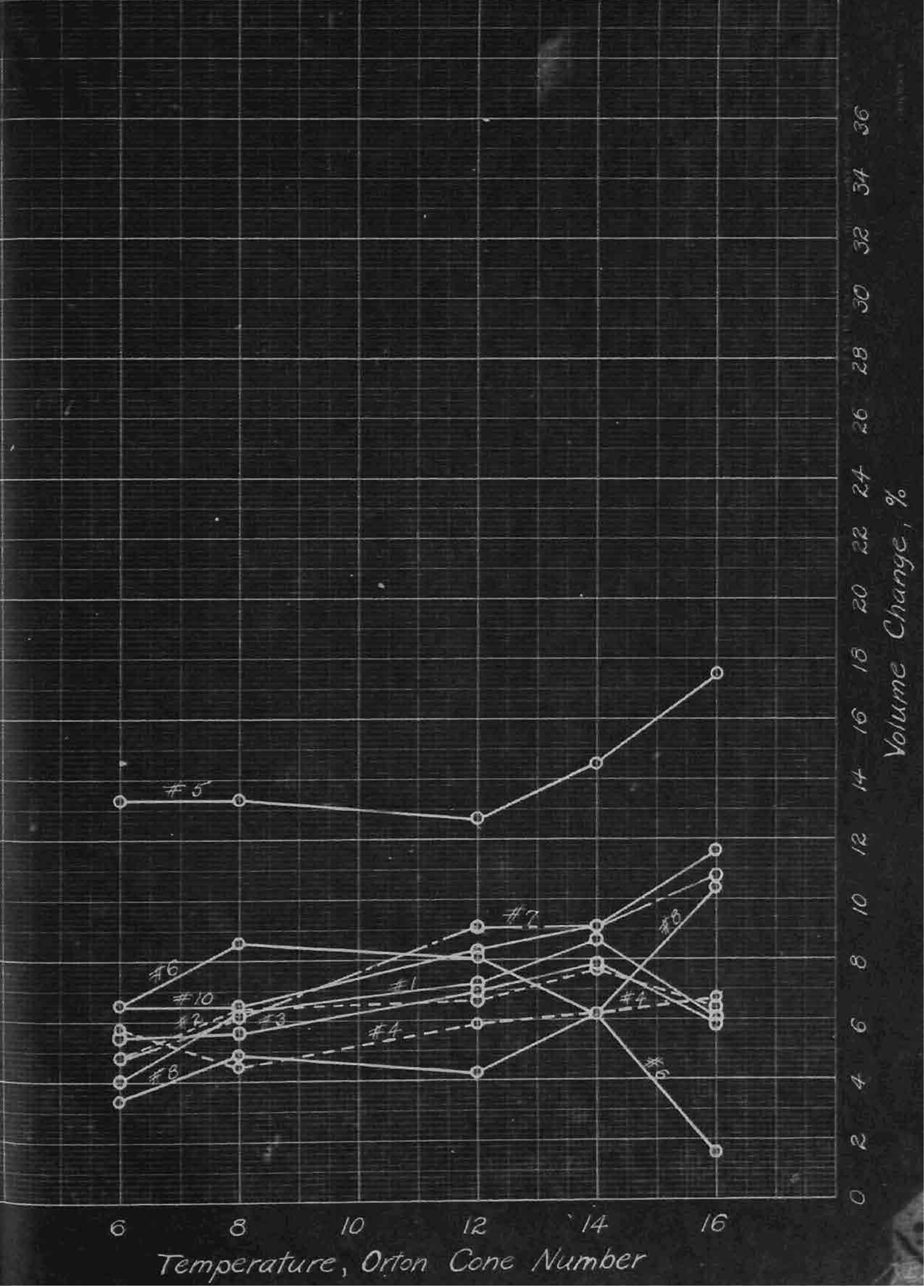
Figure 17.

Absorption of Body Mixtures Fired at Cones 6, 8, 12, 14 and 16.

Table XIV.

Volume Change of Body Mixtures Fired at Cones 6, 8, 12, 14 and 16.

Body Mixture Number	Per cent Volume Change at Cones				
	6	8	12	14	16
1	4.06	6.30	7.18	8.63	6.04
2	4.79	6.37	6.65	7.68	6.37
3	5.55	5.61	7.03	7.85	5.88
4	5.73	4.46	5.86	6.25	6.70
5	13.35	13.34	12.65	14.5	17.45
6	6.53	8.59	8.03	6.20	1.57
7	4.74	6.19	9.10	9.02	10.8
8	3.45	4.89	4.27	6.13	10.4
10	6.58	6.49	8.27	9.15	11.6



Volume Change, %
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
Temperature, Orton Cone Number
6
8
10
12
14
16
#5
#6
#10
#2
#3
#8
#1
#4
#7
#8
#4
#6

-45-

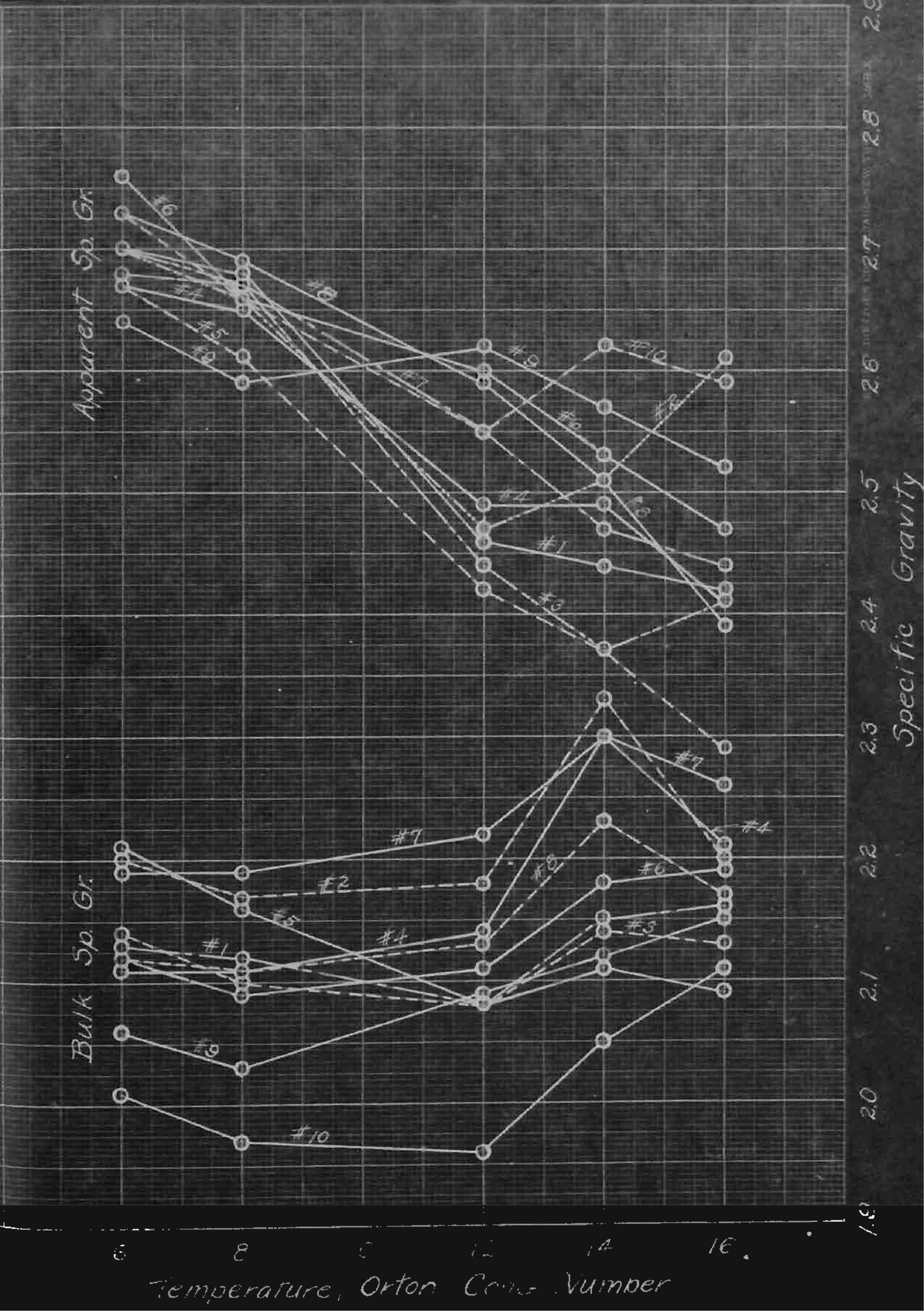
Figure 18.

Volume Change of Body Mixtures Fired at Cones 6, 8, 12, 14 and 16.

Table XV.

Apparent and Bulk Specific Gravity on Clays at Cones 6, 8, 12, 14 and 16.

Clay Number	Per cent Apparent Specific Gravity at Cones					Per cent Bulk Specific Gravity at Cones				
	6	8	12	14	16	6	8	12	14	16
1	2.70	2.68	2.46	2.44	2.42	2.13	2.12	2.08	2.15	2.16
2	2.70	2.66	2.47	2.51	2.61	2.20	2.17	2.18	2.33	2.20
3	2.70	2.67	2.44	2.37	2.41	2.14	2.10	2.08	2.14	2.13
4	2.67	2.65	2.49	2.49	2.41	2.11	2.11	2.14	2.30	2.21
5	2.67	2.61	2.42	2.37	2.29	2.21	2.16	2.08	2.11	2.09
6	2.76	2.66	2.60	2.53	2.47	2.12	2.09	2.11	2.18	2.19
7	2.68	2.67	2.55	2.47	2.44	2.19	2.19	2.22	2.30	2.26
8	2.73	2.69	2.59	2.51	2.39	2.12	2.11	2.13	2.23	2.17
9	2.64	2.59	2.62	2.57	2.52	2.06	2.03	2.09	2.12	2.15
10	2.73	2.66	2.55	2.62	2.59	2.01	1.97	1.96	2.05	2.11



Apparent Sp. Gr.
Bulk Sp. Gr.
#1
#2
#3
#4
#5
#6
#7
#8
#9
#10
2.0
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
Specific Gravity
6
8
12
14
16
Temperature, Orton Cone Number

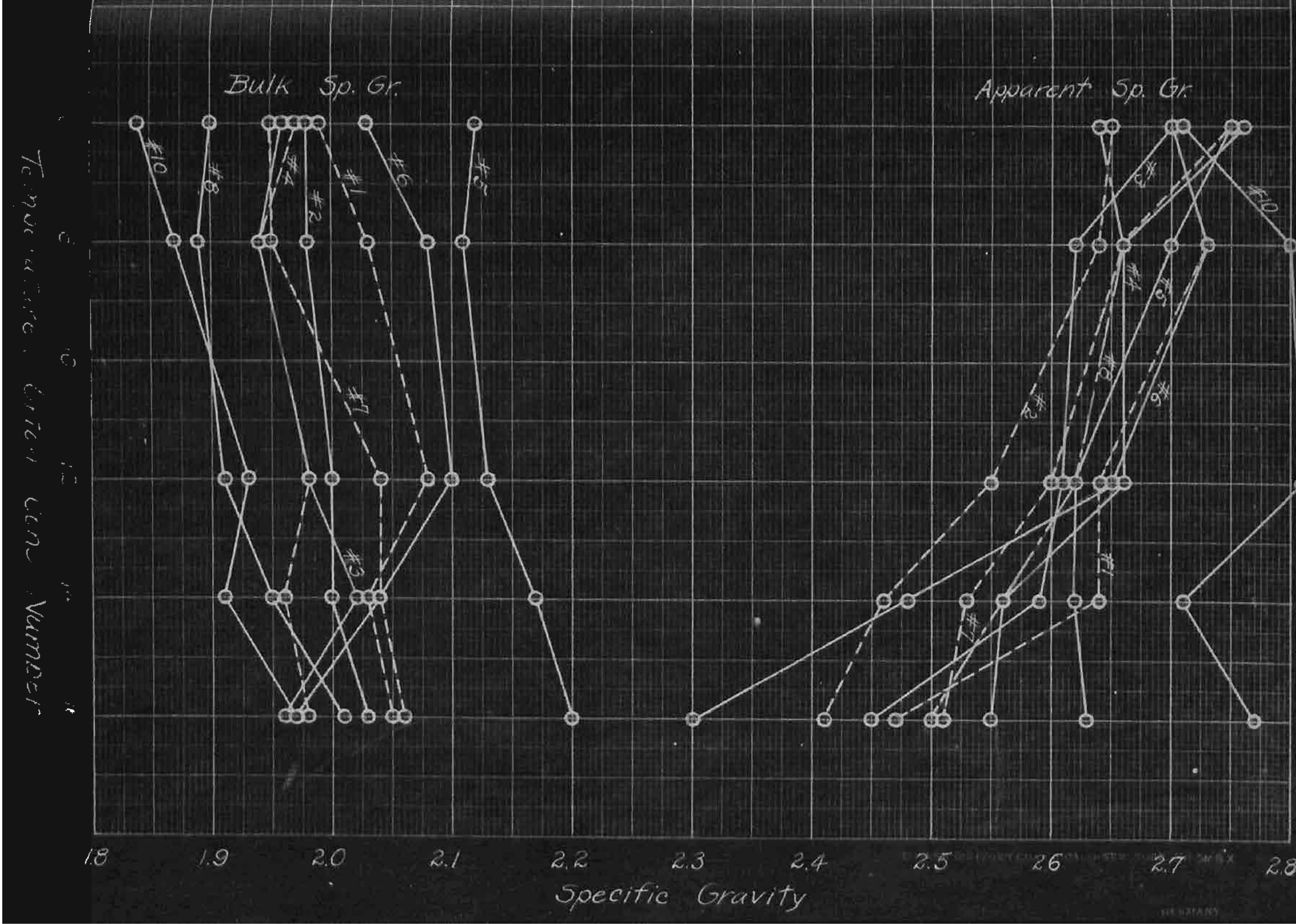
Figure 19.

Apparent and Bulk Specific Gravity of Clays Fired at Cones 6, 8, 12, 14 and 16.

Table XVI.

Apparent and Bulk Specific Gravity on Body Mixtures Fired at Cones 6, 8, 12, 14 and 16.

Body Mixture Number	Per cent Apparent Specific Gravity at Cones					Per cent Bulk Specific Gravity at Cones				
	6	8	12	14	16	6	8	12	14	16
1	2.70	2.73	2.64	2.64	2.47	1.99	2.03	2.08	2.03	2.05
2	2.65	2.64	2.55	2.46	2.41	1.98	1.98	2.00	2.00	2.03
3	2.70	2.62	2.61	2.59	2.45	1.96	1.94	1.98	2.02	1.96
4	2.76	2.66	2.66	2.56	2.55	1.97	1.94	1.98	1.96	1.98
5	2.75	2.70	2.62	2.62	2.63	2.12	2.11	2.13	2.17	2.20
6	2.70	2.73	2.65	2.48	2.30	2.03	2.08	2.10	2.04	1.97
7	2.75	2.66	2.60	2.53	2.51	1.95	1.95	2.04	2.04	2.06
8	2.64	2.66	2.62	2.56	2.50	1.90	1.89	1.91	1.95	2.01
10	2.71	2.80	2.81	2.71	2.77	1.84	1.87	1.93	1.91	1.97



Bulk Sp. Gr.
Apparent Sp. Gr.
#1
#2
#3
#4
#5
#6
#7
#8
#10
1.8
1.9
2.0
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
Specific Gravity

Figure 20.

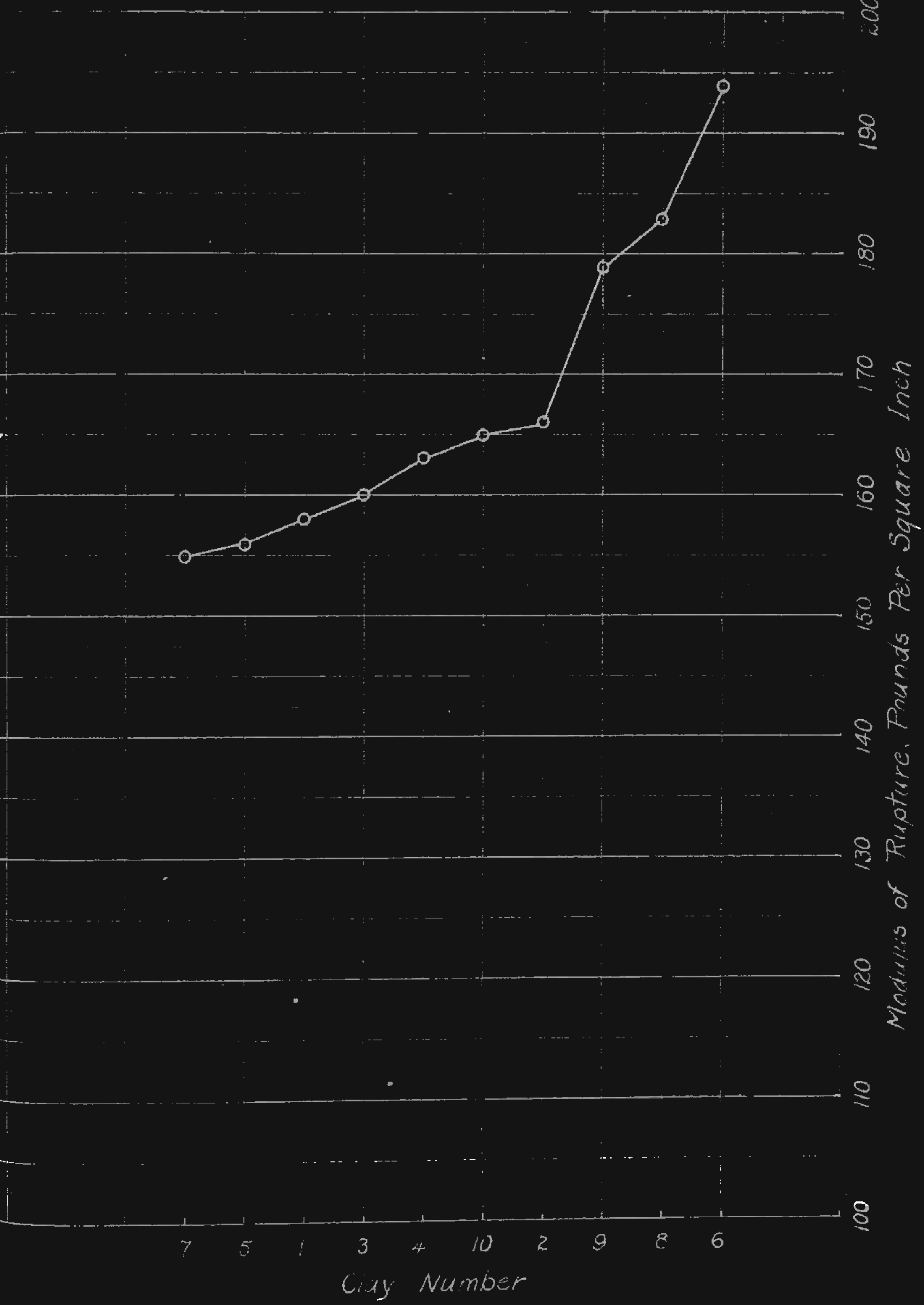
Apparent and Bulk Specific Gravity on Body

Mixtures Fired at Cones 6, 8, 12, 14 and 16.

Table XVII.

Modulus of Rupture of Clays.

Clay Number	Modulus of Rupture, Pounds per Square Inch
1	158
2	166
3	160
4	163
5	156
6	194
7	155
8	183
9	179
10	165



Modulus of Rupture, Pounds Per Square Inch
100
110
120
130
140
150
160
170
180
190
200
Clay Number
7
5
1
3
4
10
2
9
8
6

Figure 21.

Modulus of Rupture of Clays.

Table XVIII.

Slaking of Clays.

Clay Number	Slaking Time	
	Minutes	Seconds
1	43	53
2	12	10
3	13	48
4	19	34
5	12	4
6	17	25.5
7	11	00
8	9	53
9	29	9
10	14	00

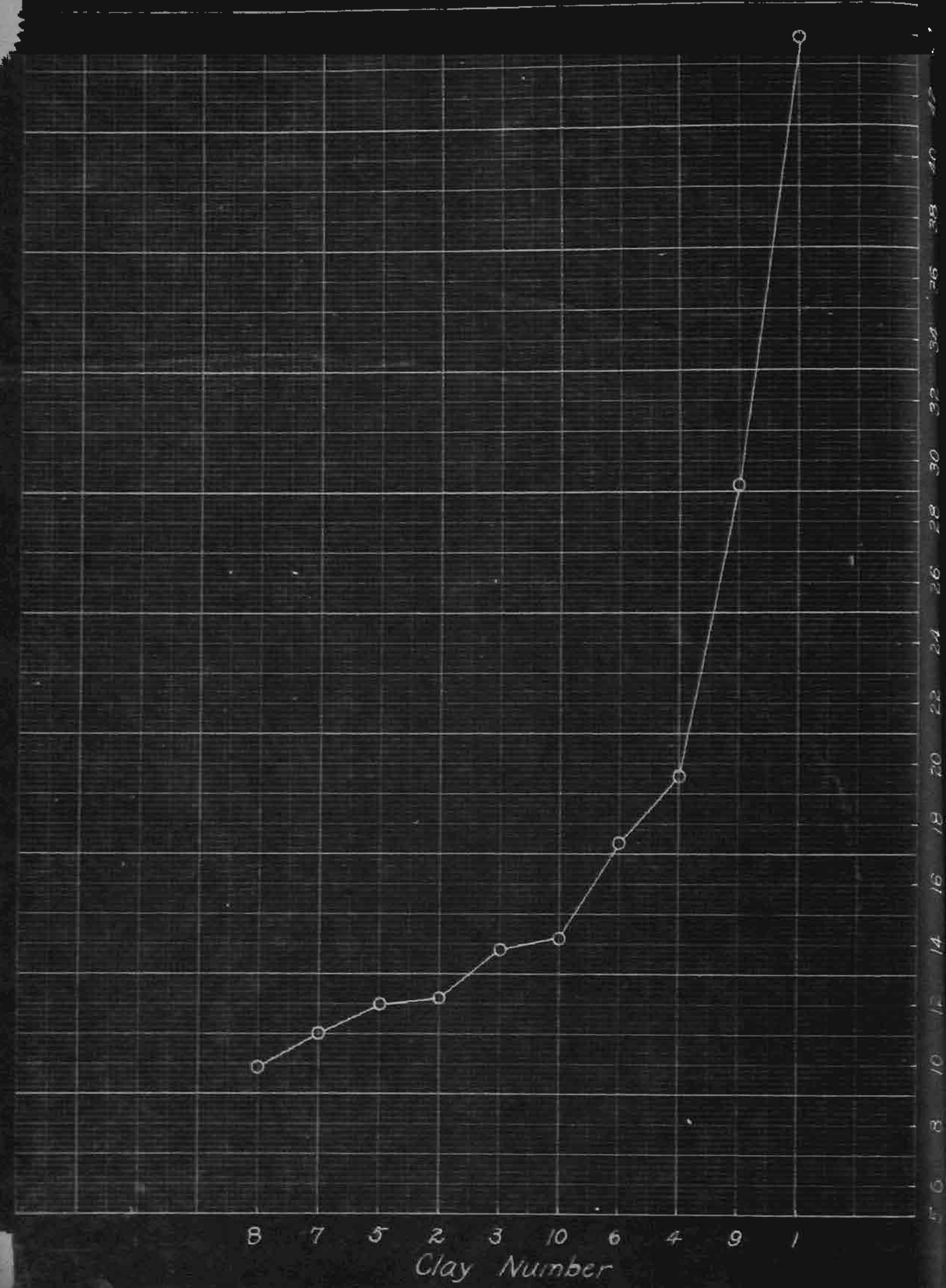

8 7 5 2 3 10 6 4 9 1
Clay Number
5 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42

Figure 22.

Slaking of Clays.

Table XIX.

Screen Analyses of Grogs.

Mesh Number	Grog Number 1		Grog Number 2		Grog Number 3		Grog Number 4		Grog Number 5		Grog Number 6		Grog Number 7		Grog Number 8		Grog Number 9		Grog Number 10	
	Per cent	Cumulative per cent	Per cent	Cumulative per cent	Per cent	Cumulative per cent	Per cent	Cumulative per cent	Per cent	Cumulative per cent	Per cent	Cumulative per cent	Per cent	Cumulative per cent	Per cent	Cumulative per cent	Per cent	Cumulative per cent	Per cent	Cumulative per cent
On 6	0.21	0.21	6.53	6.53	0.2	0.20	0.46	0.46	0.25	0.25	1.30	1.30	0.14	0.14	2.36	2.36	0.54	0.54	0.39	0.39
On 8	13.72	13.93	14.07	20.60	14.3	14.50	8.35	8.81	12.18	12.43	8.42	9.72	8.28	8.42	13.13	15.49	19.25	19.79	13.67	14.06
On 10	21.03	34.96	16.00	36.60	19.88	34.38	15.08	23.88	23.31	35.74	22.67	32.39	38.70	47.12	24.08	39.57	23.33	43.12	17.73	31.79
On 14	13.48	48.44	10.64	47.24	13.23	47.61	12.13	36.01	16.10	51.83	14.25	46.64	20.66	67.78	15.28	54.85	13.68	56.80	11.12	42.91
On 20	11.96	60.40	10.02	57.26	11.92	59.53	12.08	48.09	13.52	65.36	12.22	58.86	12.43	80.21	12.09	66.94	11.82	68.62	9.93	52.84
On 28	9.62	70.02	8.65	65.91	9.61	69.14	10.77	58.85	10.07	75.43	9.54	68.40	6.32	86.53	9.11	76.06	9.21	77.83	8.48	61.32
On 35	8.77	78.79	8.16	74.07	8.40	77.53	10.06	68.92	7.79	83.21	8.38	76.78	3.79	90.31	7.38	83.44	7.35	85.18	8.21	69.53
On 48	5.59	84.38	5.46	79.53	5.44	82.97	6.82	75.74	4.52	87.74	5.41	82.19	1.91	92.22	4.54	87.98	4.52	89.70	5.81	75.33
On 65	4.24	88.62	4.66	84.19	4.39	87.36	5.63	81.37	3.24	90.97	4.30	86.49	1.38	93.60	3.33	91.31	3.11	92.81	5.04	80.37
On 100	3.25	91.87	3.89	88.08	3.51	90.86	4.86	86.23	2.62	93.60	3.34	89.83	1.17	94.77	2.57	93.87	2.60	95.41	4.59	84.96
On 150	2.27	94.14	3.14	91.22	2.59	93.46	3.75	89.98	1.92	95.51	2.50	92.33	1.04	95.81	1.87	95.74	1.71	97.11	4.14	89.10
On 200	1.32	95.46	2.12	93.34	1.64	95.10	2.46	92.44	1.16	96.68	1.62	93.95	0.78	96.59	1.08	96.81	0.89	98.01	3.06	92.16
Thru 200	4.44	99.90	6.65	99.99	4.9	99.99	7.56	99.99	3.32	99.99	6.05	100.00	3.41	100.00	3.19	100.00	1.99	99.99	7.83	99.99

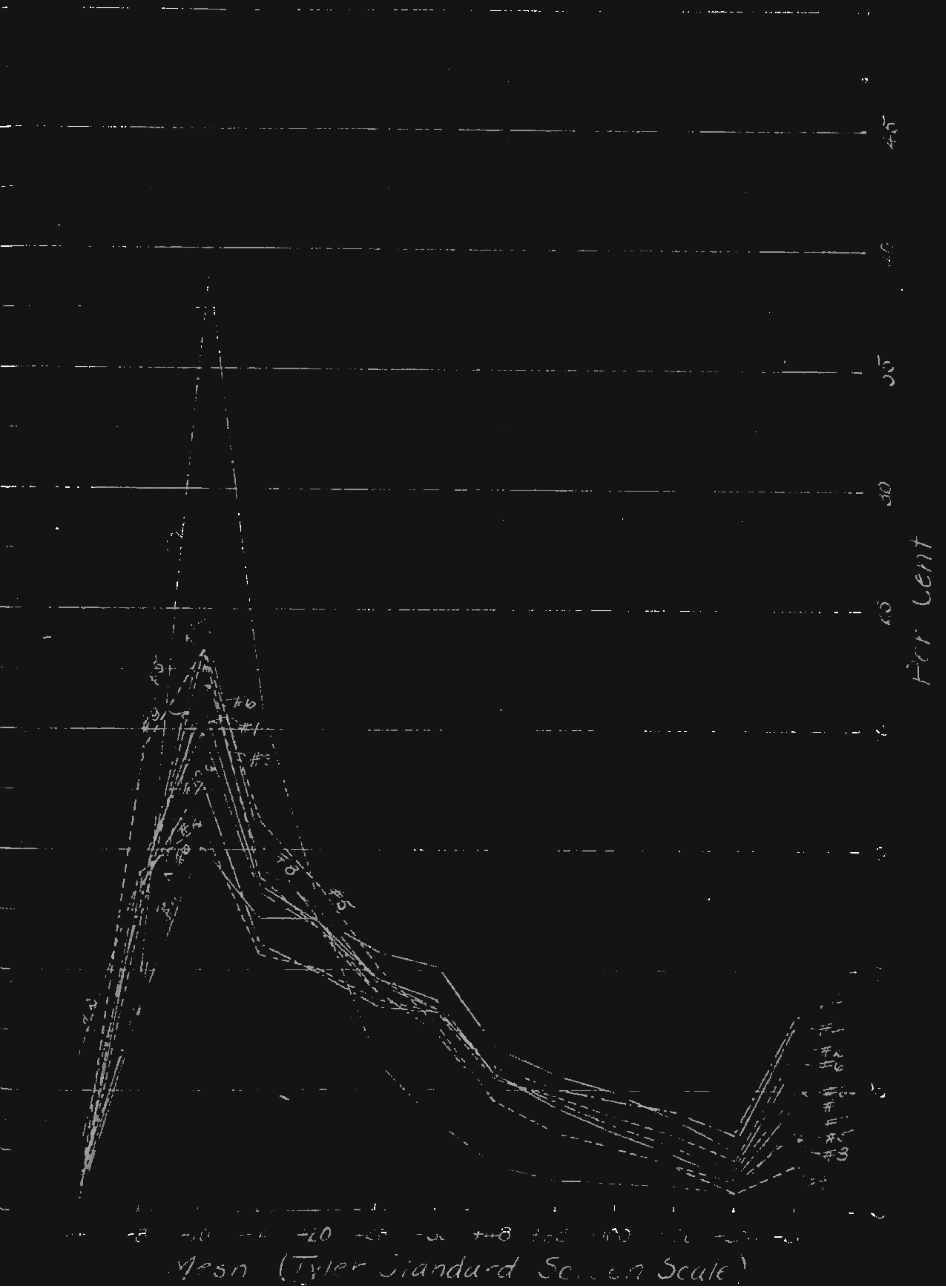

Per Cent
30
+8
+20
+48
Mesh (Tyler Standard Screen Scale)

Figure 23.

Screen Analysis of Grogs.

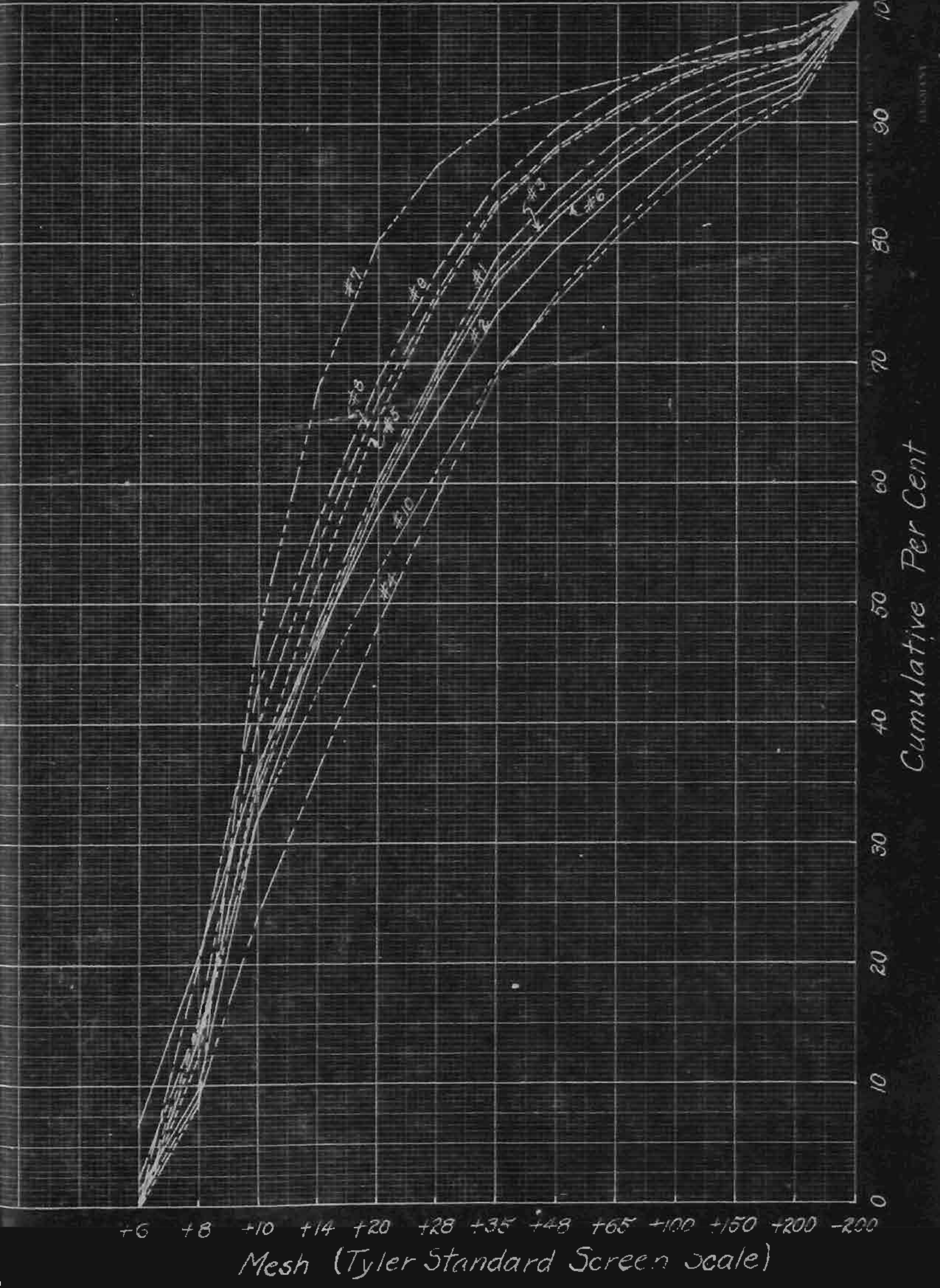

Cumulative Per Cent
0
10
20
30
40
50
60
70
80
90
100
+6
+8
+10
+14
+20
+28
+35
+48
+65
+100
+150
+200
-200
Mesh (Tyler Standard Screen scale)
#7
#9
#8
#5
#1
#2
#3
#6
#10
#4

Figure 24.

Cumulative Screen Analysis of Grogs.

S U M M A R Y.

The results of the tests that have been described may best be summarized under three headings: Clays, Grogs, and Bodies.

Clays: The clays used at all the zinc smelters from which samples were obtained are St. Louis (Cheltenham) plastic fire clays. There is little variation in the chemical analyses, except that the alumina-silica ratio differs considerably in the different samples. This may have some bearing upon the resistance of the clays to the corrosive action of slags, but seems to have little relation to their softening points. The softening points of all the bond clays tested lay between Cones 27-1/2 and 30.

All but two of the bond clays required between 20 and 22 per cent of water to form a soft plastic mixture; Clay No. 9 required only about 17 per cent and Clay No. 4 required about 24.5 per cent. The drying shrinkage, with the exception of the same two clays, was from slightly less than 17 per cent to slightly over 21 per cent; Clay No. 9 had a drying shrinkage of only about 12.5 per cent and Clay No. 4 about 24.5 per cent.

The behavior of the clays in firing to 800° C., the temperature at which retorts are usually tempered, did not vary greatly, volume shrinkage varying from almost nothing to slightly over six per cent, porosity from 28 to 32 per cent, absorption from 15 to 18 per cent, bulk specific gravity from 1.76 to 1.88, and apparent specific gravity from 2.58 to 2.63. The behavior on firing to higher temperatures varied considerably, the highly siliceous clays showing less shrinkage and a greater porosity after burning than the aluminous ones; there was a gradual gradation between the maximum and minimum.

The modulus of rupture varied from 155 to 194 pounds per square inch. The time required for slaking varied greatly, from 10 to 44 minutes for one-inch cubes.

Grogs: There is a great deal greater variation in the properties of the grogs used at various zinc smelters than in those of the clays. The softening points of the samples tested varied from Cone 21-1/2, in the case of a grog made up partly of recovered retort material, to Cone 35-1/2 in the case of a calcined flint clay sold by one of the clay producing companies to be used as grog. As might be judged from the variation in softening points, the alumina-silica ratio and the amount of impurities present in the different grogs also varied greatly. The uniformity in the size of the grog used at different plants is remarkable, as shown in Figures 23 and 24; only one sample, No. 7, showed any great variation from the average.

Bodies: In water of plasticity the body mixtures showed even less variation than the bond clays, all of them requiring between 14.5 and 16 per cent of water to give a soft plastic mixture. The drying shrinkage varied more and showed no relation to the drying shrinkage of the bond clays used in them. The shrinkage of all body mixtures in firing to 800° C. was very low (less than three per cent); the porosity varied from slightly over 27 to slightly less than 32 per cent. The shrinkage of the body mixtures was, of course, less, and the porosity greater than those of the bond clays used in them. The shrinkage did not vary greatly, with the exception of Body No. 5, which had an especially high shrinkage. The high porosity of Body No. 10 was due to the burning out of the coke contained in it.

C O N C L U S I O N S.

As some of the most important tests of this series have not yet been completed the author does not feel warranted in drawing too many conclusions from the portion of the work described in this thesis. He ventures the following, however:

1. The use of reclaimed retort material in the grog for new retorts is a very doubtful economy.
2. If old fire brick bats are used as grog, care should be taken that they were originally made of good quality clay.

3. The use of at least some good quality, well calcined flint clay in the grog is advisable.

In choosing a bond clay some refractoriness must be sacrificed for the sake of obtaining the requisite plasticity, binding power, and low shrinkage. The St. Louis plastic fire clays combine these latter qualities with fairly high refractoriness, but they are not as refractory as flint clays. The grog, in turn, which is always calcined and therefore possesses no plasticity, even though made from a plastic clay, should be chosen for its refractory qualities; if clays such as flint clays are used they add to the refractoriness of the body mixture, whereas if reclaimed old retort material is used as grog the body mixture may be less refractory than the bond clay itself.

B I B L I O G R A P H Y.

Books.

Austin, Leonard S., The metallurgy of the common metals. San Francisco and London, 1911. Manufacture of retorts and condensers, pp. 469-470.

Havard, F. T., Refractories and furnaces. New York, 1912. Zinc distilling vessels, pp. 239-246.

Hofman, H. O., Metallurgy of zinc and cadmium, New York. McGraw-Hill Book Co., 1922. Retorts and condensers, pp. 131-63.

Ingalls, Walter Renton, The metallurgy of zinc and cadmium, New York. McGraw-Hill Book Co., 1906. Examples from practice, pp. 632-56.

Liebig, R. G. Max, Zink und Cadmium, Leipzig, 1913. pp. 325-373.

Lodin, A., Metallurgie du Zinc. Paris, 1905. pp. 262-68; 313-25; 571-75; 594-648.

Schnabel, Carl, Handbook of metallurgy, translated by Henry Louis. Vol. 2, second edition, Mac Millan & Co., 1907.

Smith, Ernest A., The zinc industry, London. Longmans, Green & Co., pp. 96-7. 1918.

Papers.

Leslie, E. H., Zinc smelting in the middle west. San Francisco. Min. Sci. Press, 1915. 40 pages.

U. S. Geological Survey, Mineral Resources, 1889-90. Use of fluorspar for zinc retorts. p. 472.

Periodicals.

Audley, J. A., Refractories in the zinc industry. Trans. Ceram. Soc. (Eng.), Vol. 18, 1918-19, pp. 43-66.

Audley, J. A., Further notes on zinc furnace refractories. Trans. Ceram. Soc. (Engl), Vol. 18, 1918-19; pp. 468-477.

Babcock, M. G., Refractories for the zinc industry. Jour. Amer. Ceram. Soc., Vol. 2, 1919, pp. 81-95.

Breger, Carpel L., The American zinc smelter at Hillsboro, Illinois. Min. & Eng. Wld., Vol. 37, Nov. 9, 1912; pp. 847-50.

Degenhardt, F. C., On the blue color of refuse zinc retorts, Amer. Chemist, Vol. 5, April, 1875; p. 355.

Engineering, The British spelter industry, Vol. 105, Feb. 1918; pp. 167-169; 200-202; 204.

Engineering & Mining Journal, Fire clay in zinc smelting, Vol. 84, Aug. 10, 1907, p. 249.

Engineering & Mining Journal, Recent improvements in the metallurgy of zinc, Vol. 99, May 22, 1915, p. 896.

Engineering & Mining Journal, Zinc condenser machine, Vol. 107, April 26, 1919; p. 760.

Fiske, C. P., Palmerton zinc refractories. Trans. Am. Inst. Min. Eng., Vol. 57, 1918, pp. 868-90.

Garrison, Russell, Garrison-Whipple condenser and ball machine. Eng. & Min. Jour., Vol. 90, Oct. 8, 1910; pp. 722-23.

Gilbert, J., Costs and profits of an up-to-date spelter works. Min. Jour., Vol. 114, July 1916, pp. 480-81; 496-98.

Higgins, Edward, Jr., Zinc mining and smelting in Southwestern Virginia, Eng. & Min. Jour., Vol. 79, April 6, 1905; pp. 658-9.

Ingalls, Walter Renton, The present conditions of the zinc industry in Europe; Mineral Industry, Vol. 2, 1893; pp. 635-69. Retort and muffle fabrication; pp. 649-654.

Ingalls, Walter Renton, Zinc and cadmium. Mineral Industry, Vol. 5, 1896; pp. 589-610. Retort fabrication; pp. 597-600.

Ingalls, Walter Renton, Progress in the metallurgy of zinc in 1899; Mineral Industry, Vol. 8, 1899; pp. 647-657. Retorts, pp. 655-658.

Ingalls, Walter Renton, A review of progress in the metallurgy of zinc in 1900. Mineral Industry, Vol. 9, 1900; pp. 671-693. Non-corrosive retort lining; pp. 682-683.

Ingalls, Walter Renton, A review of progress in the metallurgy of zinc in 1901; Mineral Industry, Vol. 10, 1901; pp. 661-684. Non-corrosive retort lining; pp. 670-671.

Ingalls, Walter Renton, A review of progress in the metallurgy of zinc in 1902; Mineral Industry, Vol. 11, 1902; pp. 609-623. Retorts, p. 612.

Ingalls, Walter Renton, Progress in the metallurgy of zinc, Mineral Industry, Vol. 13, 1904; pp. 418-31. Carborundum (siloxicon or silicon carbide) for retorts, p. 431.

Ingalls, Walter Renton, Progress in the metallurgy of zinc, Mineral Industry, Vol. 14, 1905; pp. 589-603. Retorts and condensers, pp. 599-600.

Ingalls, Walter Renton, Progress in the metallurgy of zinc, Mineral Industry, Vol. 15, 1906; pp. 776-80. Retorts and charging devices, p. 779.

Ingalls, Walter Renton, Progress in the metallurgy of zinc, Mineral Industry, Vol. 16, 1907; pp. 924-930.

Ingalls, Walter Renton, Metallurgy of zinc, Mineral Industry, Vol. 25, 1916; pp. 772-80. Hydraulic retort presses; p. 773.

Ingalls, Walter Renton, Metallurgy of zinc, Mineral Industry, Vol. 31, 1922; pp. 742-45. Distillation practice, pp. 743-44.

Ingalls, Walter Renton, The new zinc smeltery at Langeloth, Eng. & Min. Jour., Vol. 98, Dec. 5, 1914, pp; 985-89. Pottery, p. 988.

Ingalls, Walter Renton, Some points in the economics of zinc metallurgy, Eng. & Min. Jour., Vol. 100, Oct. 2, 1915; pp. 551-554.

Ingalls, Walter Renton, The Donora zinc works, Eng. & Min. Jour., Vol. 102, Oct. 7, 1916; pp. 648-54. Pottery, pp. 652-3.

Ingalls, Walter Renton, Comments and speculations on the metallurgy of zinc, Eng. & Min. Jour., Vol. 102, Oct. 7, 1916; pp. 621-24. Retorts, pp. 623-24.

Iron Age, Zinc manufacture in the Pittsburgh district, Vol. 95, May 13, 1915; pp. 1064-7.

Iron Age, The American Steel and Wire Company's zinc works, Vol. 97, Jan. 6, 1916; pp. 82-86. Pottery, p.86.

Johnson, Edward Mackay, The zinc works pottery. Met. & Chem. Eng., Vol. 16, May 1, 1917; pp. 475-78.

Johnson, Edward Mackay, Zinc furnace temperatures. Met. & Chem. Eng., Vol. 17, Sept. 15, 1917; pp. 300-302; Vol. 18, Jan. 1, 1918; pp. 14-17.

Laur, Francis, Notes sur la creation des usine a zinc, et l'industrie du zinc en general, Bull. de la Soc de l'ind. Minerale, Vol. 3, 1874; pp. 395-443.

Leslie, E. H., Zinc smelting at Bartlesville, Oklahoma. Min. Sci. Press, Vol. 109, July 11, 1914; pp. 44-9. Pottery, p. 48.

Leslie, E. H., The National Zinc Company, Bartlesville, Oklahoma, Min. Sci. Press, Vol. 109, July 25, 1914; pp. 136-41. Pottery p. 140.

Leslie, E. H., Collinsville smelter of the Bartlesville Company, Min. Sci. Press, Vol. 11, Aug. 8, 1914, pp. 204-8. Pottery, p. 208.

Leslie, E. H., Zinc smelting at Hillsboro, Illinois. Min. Sci. Press, Vol. 109, Aug. 22, 1914, pp. 280-286. Pottery, p. 286.

Leslie, E. H., The Rose Lake smelter of the Granby Company, Min. Sci. Press, Vol. 109, Sept. 12, 1914; pp. 395-402. Pottery, pp. 400-401.

Leslie, E. H., The Nassau zinc works at Depue, Illinois, Min. Sci. Press, Vol. 109, Sept. 26, 1914; pp. 475-80. Pottery, p. 479.

Leslie, E. H., Notes on the metallurgy of zinc, Min. Sci. Press. Vol. 111, July 31, 1915; pp. 162-66. Pottery, p. 165.

Libman, Some properties of zinc oxide bodies, Jour. Am. Ceram. Soc., Vol. 5, 1922, pp. 488-91.

Meister, H. C., The zinc smelting industry of the middle west, Trans. Am. Inst. Min. Eng., Vol. 35, 1905; pp. 734-45. Retorts, p. 743.

Metallurgie, Leistungen von zinkofen, Vol. 5, Sept. 8, 1908, pp. 522-28.

Met. & Chem. Eng., Improved form of zinc retort, Vol. 12, March, 1914, p. 196.

Meyer, Franz, Review of the zinc industry, Electrochem. & Met. Ind., Vol. 3, pp. 7-9. Retorts, pp. 7-8.

Mex. Min. Jour., Zinc retorts, Vol. 9, Oct. 1909, p. 28.

Moulder, J. C., Zinc, its production and industrial applications, Jour. Royal Soc. of Arts, Vol. 64, May 26, 1916; pp. 495-513. June 2, 1916; pp. 517-531.

Moxham, Edgar C., Zinc smelting at the Bertha Zinc Works, Virginia, Eng. & Min. Jour., Vol. 56, Nov. 25, 1893; p. 544.

Neuray, L., Le sechage des mouffles dans les usines a zinc, Rev. Un. Mines, Vol. 2, 6th series, June 1919, pp. 553-557.

Pierce, F. E., The zinc smelter of today, Eng. Soc. West. Pa., Vol. 32, Feb. 1916, pp. 20-60.

Primrose, J. S. G., Zinc and lead smelting in Silesia, Eng. & Min. Jour., Vol. 86, Aug. 8, 1908, pp. 265-69. Muffles, p. 267.

Queneau, A. L. J., Composite metallurgical vessels; a new system of making zinc retorts and refractory crucibles. Eng. & Min. Jour., Vol. 82, Oct. 13, 1906, pp. 677-79.

Scott, Alexander, Notes on the microstructure of zinc retorts, Trans. Ceram. Soc. (Eng.), Vol. 18, 1918-19; pp. 512-5.

Speier, Paul, The zinc industry in Silesia in 1905. Eng. & Min. Jour. Vol. 81, Jan. 27, 1906. p. 176.

Stone, G. C., Refractories for zinc smelting; Jour. Am. Ceram. Soc., Vol. 5, 1922; pp. 597-601.

Thum, F. A., Notes on zinc smelting, Eng. & Min. Jour., Vol. 27, Apr. 29, 1879; p. 275; May 3, 1879, pp. 311-2; May 17, 1879, pp.350-51; May 24, 1879, pp. 371-72.

Varian, J. P., An improvement in the manufacture of vessels used in retorting zinc ores, Eng. & Min. Jour., Vol. 113, Mar. 4, 1922, p. 363.

Walker, Edward, The zinc smelting works of Swansea, Wales, Eng. & Min. Jour., Vol. 85, July 27, 1907; pp. 161-3. Retorts, p. 163.

Watson, Thomas L., The mining, preparation and smelting of Virginia zinc ores, Trans. Am. Inst. Min. Eng., Vol. 37, 1906, pp. 304-18.

Wologdine, S., and Queneau, A. L., Conductivity, porosity and gas permeability of refractory materials, Electrochem. & Met. Ind., Vol. 7, pp. 383-89; 433-36.