

AN INVESTIGATION OF THE RELATIONSHIP BETWEEN THE
SHADE OF COAL ASH AND THE FUSION POINT

A THESIS

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By

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Approved By:

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DISCUSSION OF THE PROBLEM

The determination of the fusion point of coal ash has long been an important part of coal analysis. In some cases the knowledge of the fusion point of the ash far overshadows the ultimate analysis of the coal in view of the fact that some equipment, although it will handle coal high in ash or low in heating value, absolutely cannot operate on a coal that has an ash with a low fusion temperature.

The use of a coal with a low fusion point in our modern steam generating units has many disadvantageous and even dangerous results, and with the introduction of larger and higher temperature units the importance of this phase of coal testing is increasing. It has become essential that the knowledge of the fusion point of the ash of any coal that the operating engineer is contemplating putting through his furnace is known if the evil effects of slagging and its consequent delays and costs are to be avoided.

With the increasing use of small stokers in private homes and small buildings another large group of hitherto uninterested people are becoming interested in the fusion point of the coal they buy due to the

fact that if the coal burned in these units does not have the proper clinkering characteristics it is a difficult job to remove the refuse from the fire box of the furnace.

The present methods of determining the fusion point of coal ash are slow and expensive, and in this work it has been attempted to develop a means of determining the fusion point that will be both speedy and inexpensive as compared to the present method, provided that it is possible to establish a relationship between the fusion point and the color or shade of the ash sample.

THE PRESENT METHOD OF DETERMINING
FUSION POINTS

A sample of coal, properly prepared for coal analysis*, is burned down to ash in an electric furnace at a temperature ranging from 1400 to 1700 degrees Fahrenheit, the period of burning being approximately eight hours. The sample of ash so obtained is then finely pulverized with a mortar and pestle until it will pass through a 200 mesh sieve.

This finely pulverized sample is placed on a glass plate and moistened and mixed with a 10% solution of sucrose until a thick paste is produced. The paste is then forced into heated brass molds and allowed to dry and harden. The dry product, when removed from the mold, resembles the ordinary segar cone.

* Coal is sampled from the car as provided by the A.S.M.E. Code and is brought to the laboratory where it is air dried and then crushed to a point where it will all pass through a sixty mesh sieve. This sixty mesh sample is used for determining the proximate analysis of the coal and the fusion sample is taken from this same crushed coal.

Two ash cones are then mounted with a series of six segar cones on a refractory base with a special refractory cement, and the whole mount is dried in an oven for several hours, the temperature of the oven being between 100 and 200 degrees Fahrenheit. If an optical pyrometer is used it is not necessary to use the segar cones, although it is considered good practice to mount a segar cone with a known fusion in order to furnish a check on the pyrometer.

The base with the ash cones and the segar cones is then placed in a muffle furnace and heated very slowly to prevent damage to the cones and the furnace. During the heating the cones are observed through an inspection port in the furnace and as soon as a noticeable softening of the cones occurs (usually taken as the time the cone is half down), heating is discontinued and the furnace is allowed to cool.

Slow cooling of the furnace is absolutely essential to prevent breaking of the furnace and its contents, and five or six hours are usually allowed before the tested samples can be removed.

After cooling, the base is removed and by inspection of the segar cones it is possible to determine a temperature interval within which the fusion point of the ash is located. Of course, with the optical

pyrometer the temperature is observed at the time the cone reaches the fusion point and the fusion temperature is known within the accuracy of the instrument.

It can readily be seen that this is a slow, laborious process and would be quite expensive. It is to be noted that with this present method a time interval of approximately fifteen hours elapses between the time the sample is started and the time the results are available.

In obtaining the fusion point, the ash cone in melting passes through three stages, the initial point is where the cone of ash begins to soften and the tip rounds off; the softening point which is commonly taken as the fusion point is reached when the ash of the cone has softened to such an extent that it assumes almost the shape of a sphere; the final point is known as the fluid point and occurs when the ash has become fluid and flows across the base of the mount.

RELATIONSHIP OF ASH COMPOSITION TO FUSION
POINT

In the past many attempts have been made to set up a relationship between various component elements of the coal ash and the fusion point.

Although some of the elements gave indication of influencing the fusion point in proportion to the amount of the element present in the ash, the relationship was only vague at the best, and repeated tests have shown this method to be entirely unreliable.

In order to illustrate the futility of attempting to determine the fusion point by referring to the chemical analysis of the ash, Figure 1 has been drawn up listing fourteen different coals, their proximate analysis, the chemical analysis of the ash, and the fusion point of the ash.

From the data of Figure 1 a series of plots have been made with the purpose of showing the relationship, if any, between the various components and the fusion point.

ANALYSES OF COALS AND ASHES

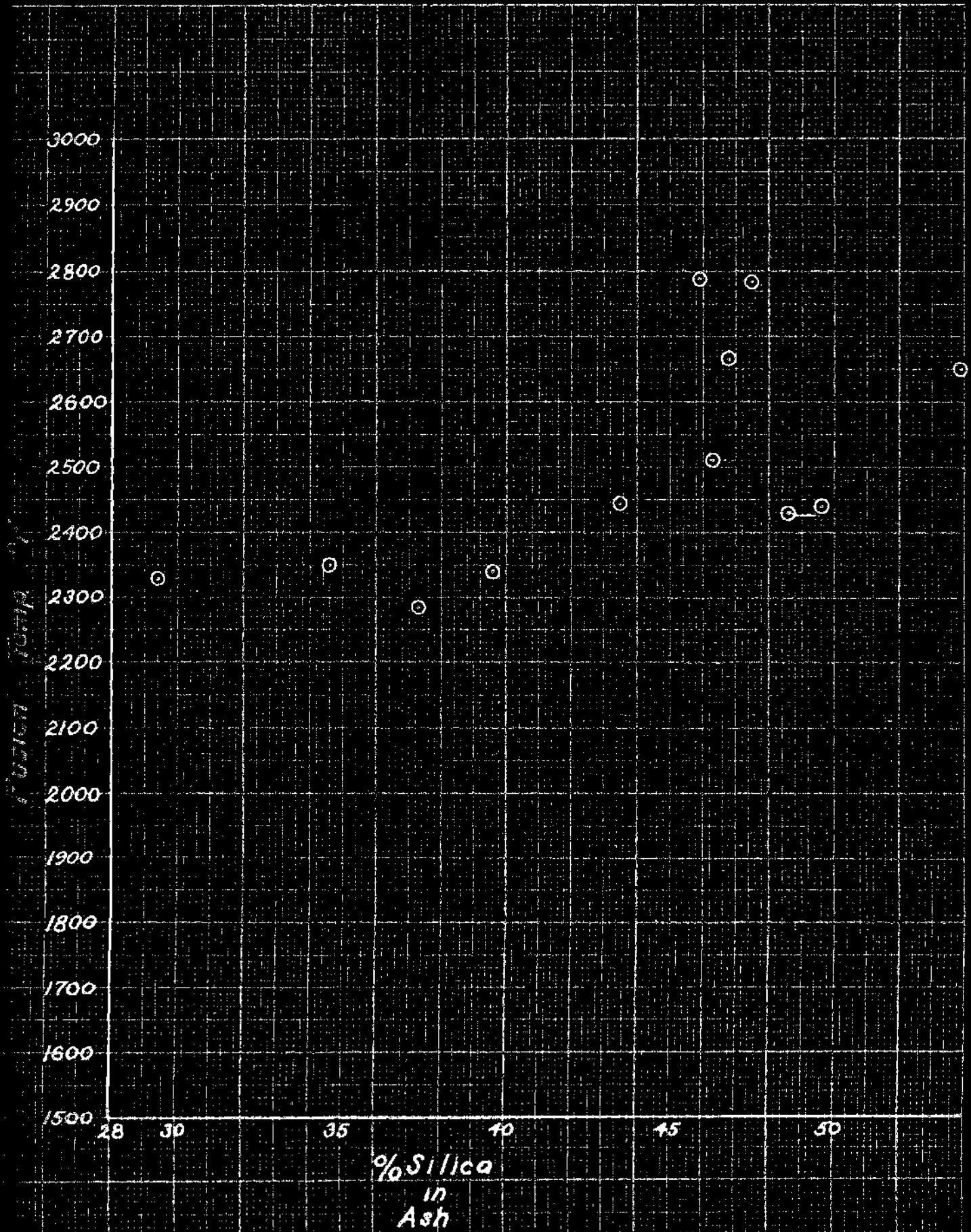
C o o l	Analyses of Dry Coal			Ash Analyses										°F. Softening Temp.
	State	V.M.	Ash	Sulphur	Silica	Alumina	Titan. Dio.	Lime	Magnesia	Su. Trioxide	Fe. Oxide	Alkalies		
A	Pa.	17.3	7.7	0.8	45.9	36.3	2.6	3.4	0.7	2.2	7.4	1.6	2790	A
B	Pa.	39.2	5.9	1.5	43.6	27.7	2.1	3.0	0.3	2.0	19.4	2.0	2445	B
C	Pa.	37.0	10.3	3.2	37.3	26.9	1.7	2.8	0.9	2.3	27.7	0.4	2285	C
D	Pa.	18.1	7.5	1.1	46.8	31.7	2.4	1.7	0.3	1.0	15.2	0.9	2665	D
E	Pa.	38.2	6.3	1.4	48.6	25.5	2.6	3.6	0.9	2.6	14.6	1.7	2430	E
F	Pa.	36.1	7.2	2.8	29.4	21.5	2.1	2.1	0.7	1.0	42.9	0.3	2330	F
G	Pa.	34.1	8.0	1.1	49.6	26.9	1.4	5.1	1.2	3.8	10.5	1.5	2440	G
H	WVa.	36.9	6.0	1.0	39.6	23.0	1.2	10.7	1.8	9.0	11.2	3.5	2340	H
I	Pa.	33.1	8.0	0.9	54.9	28.4	1.5	1.8	0.9	0.5	9.0	3.1	2650	I
J	Pa.	30.5	5.6	1.6	34.6	28.1	1.4	6.6	0.6	6.0	21.6	1.0	2350	J
K	Pa.	33.4	6.6	0.8	53.9	29.3	1.5	2.3	0.9	1.0	8.7	2.5	2650	K
L	Pa.	26.9	8.8	2.0	43.5	27.6	1.2	1.6	0.9	0.7	22.4	2.2	2445	L
M	Pa.	33.5	8.6	1.3	46.3	29.7	1.2	4.2	0.9	3.2	13.1	1.5	2510	M
N	Pa.	21.7	6.2	1.1	47.5	36.5	2.1	2.1	0.6	0.4	10.5	0.2	2785	N

Fig. 1

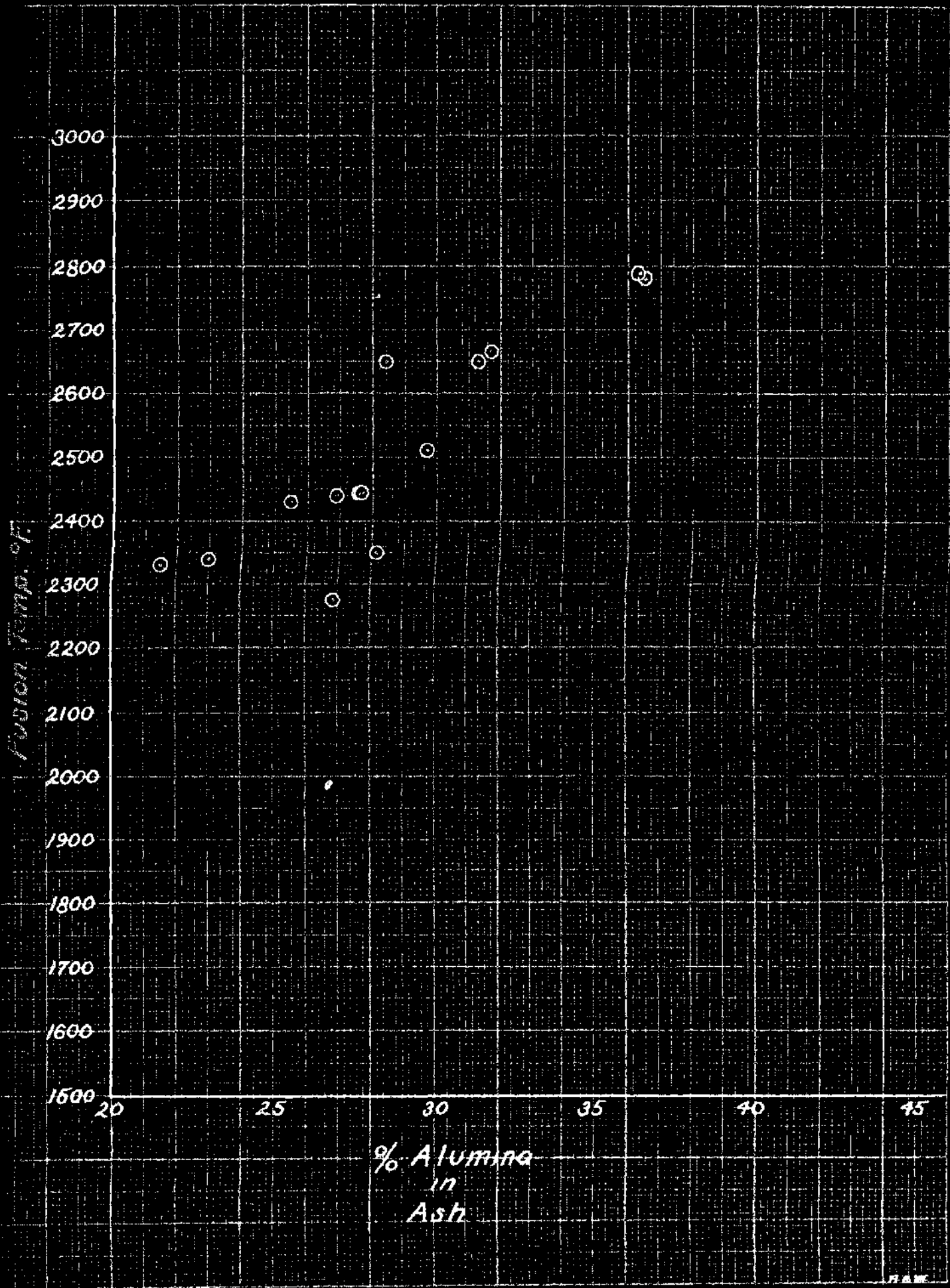
From the fusion temperature-silica plot on page 9 it is noted that for the medium fusion point of 2300 to 2500 degrees Fahrenheit the percentage of silica can range from 29% to 54%. However, it is shown that with these particular samples, the ashes with the higher fusion points showed a silica content of over 44%. It can readily be seen that it would be impossible to forecast the fusion point from a curve of this type.

On the plot of alumina against fusion temperature, page 10, a marked tendency is exhibited for the fusion temperature to rise with the increase in percentage of alumina. However, if a line were drawn through the mean of these plotted points it would still be impossible to predict the fusion temperature with the accuracy of 100 degrees Fahrenheit.

Nevertheless, it is to be noted that this curve comes closer to giving a rational relationship than any of the others plotted.



PLATE

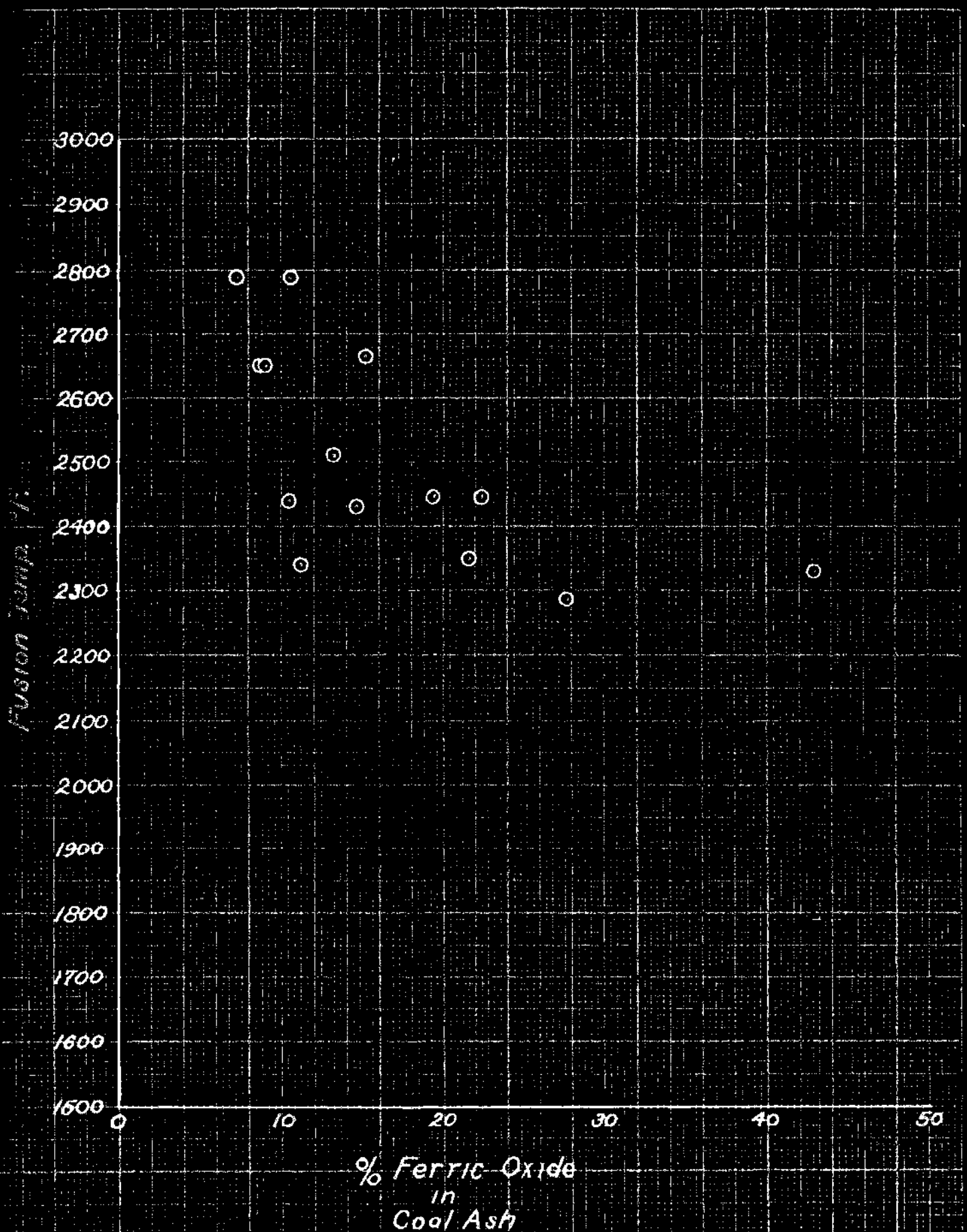


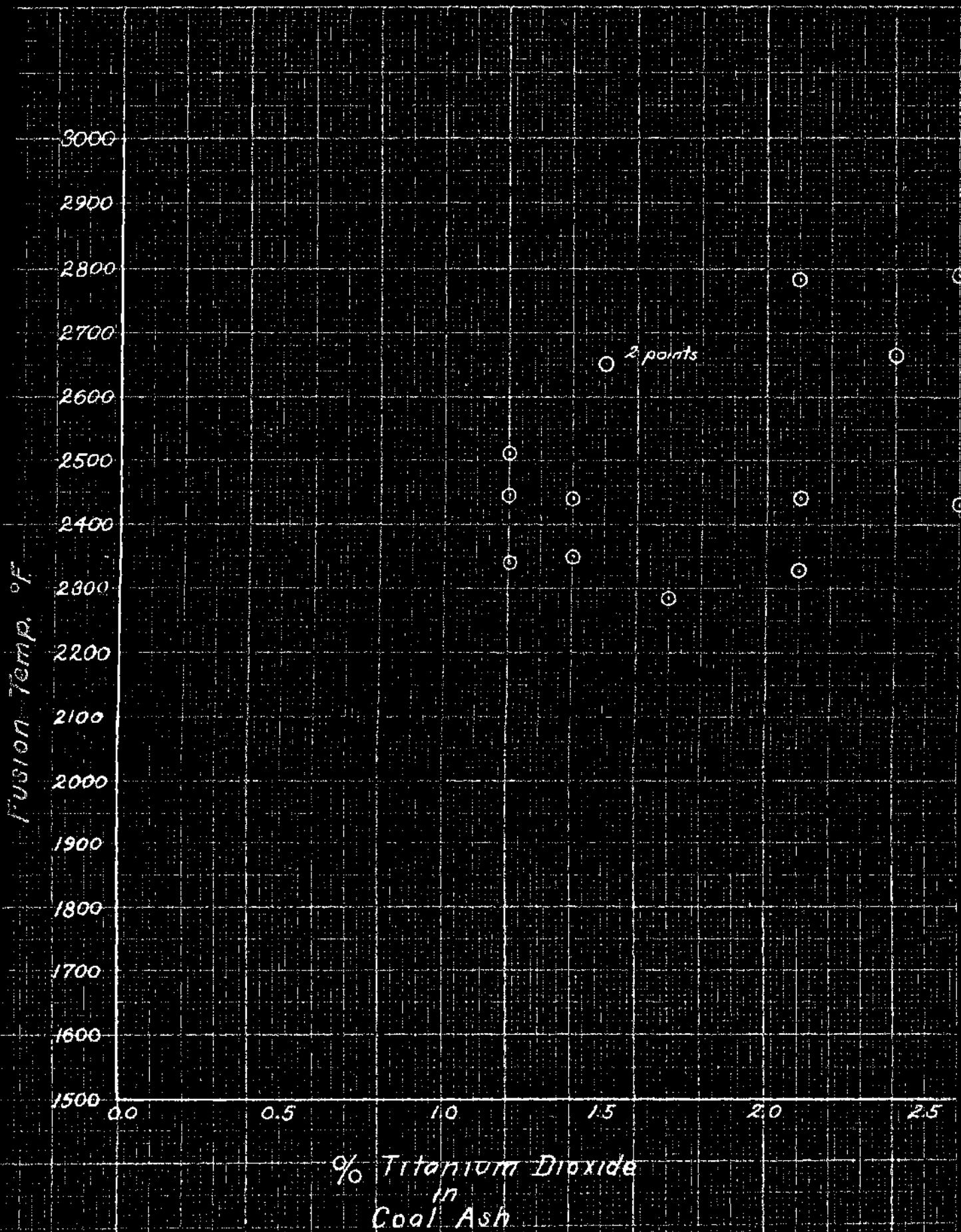
The plot of percentage ferric oxide against fusion temperature, page 12, shows the higher fusion points to occur with the lower percentages of the ferric oxide, and the average of the points would show the fusion points to decrease as the percentage of ferric oxide increases. Here again, however, there is very little basis for predicting fusion temperature from the percentage of ferric oxide.

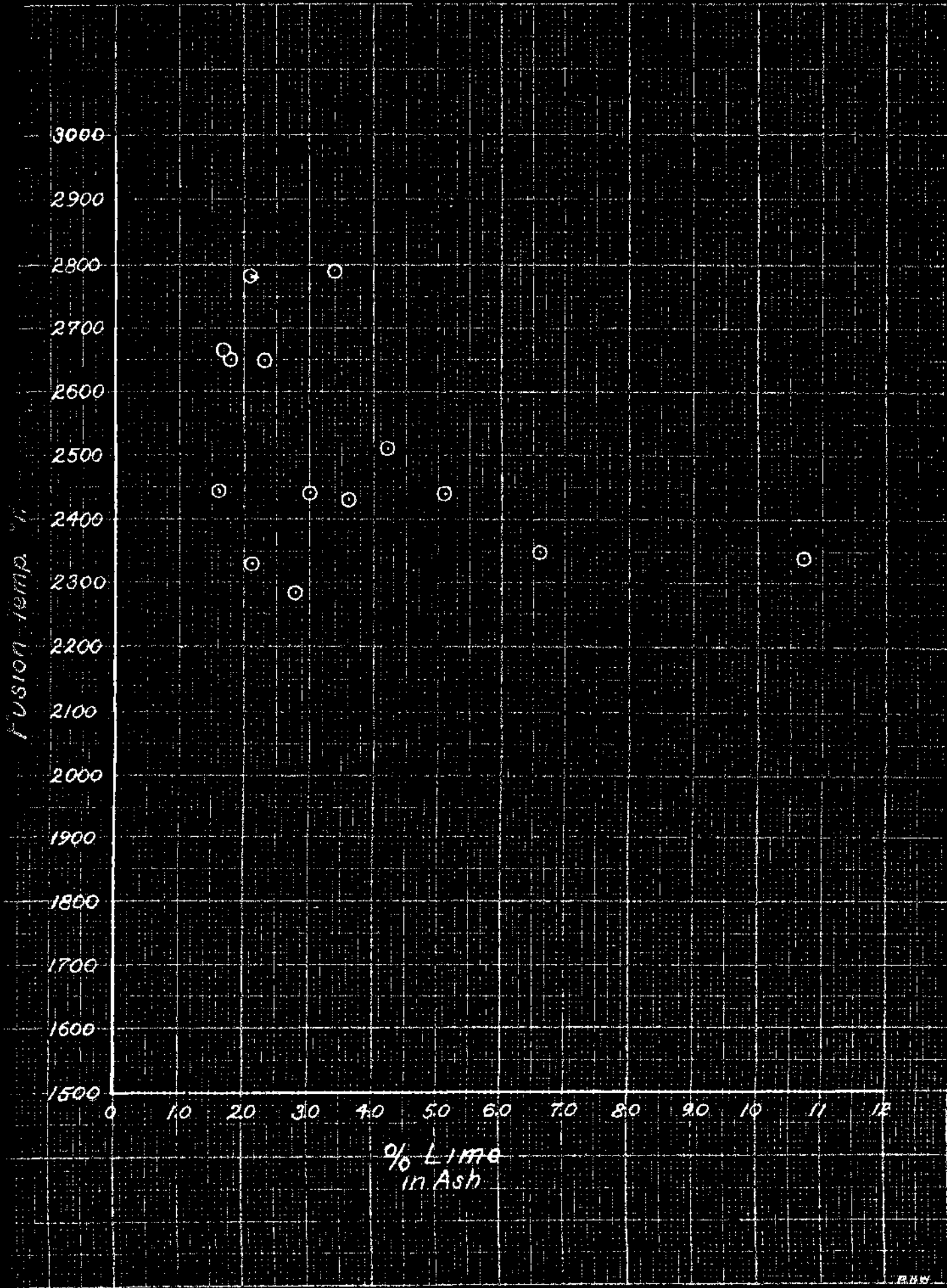
The titanium dioxide plot on page 13 shows very little that would indicate that it effects the fusion point materially. It should be noted that the percentages of titanium dioxide are rather small.

Likewise, the percentage of lime, as shown on page 14, have very little effect on the fusion temperature.

The percentages of magnesia, although small, show quite a spread for the fusion temperatures, but there is apparently no relationship existing directly between the magnesia percentage and the fusion temperature.







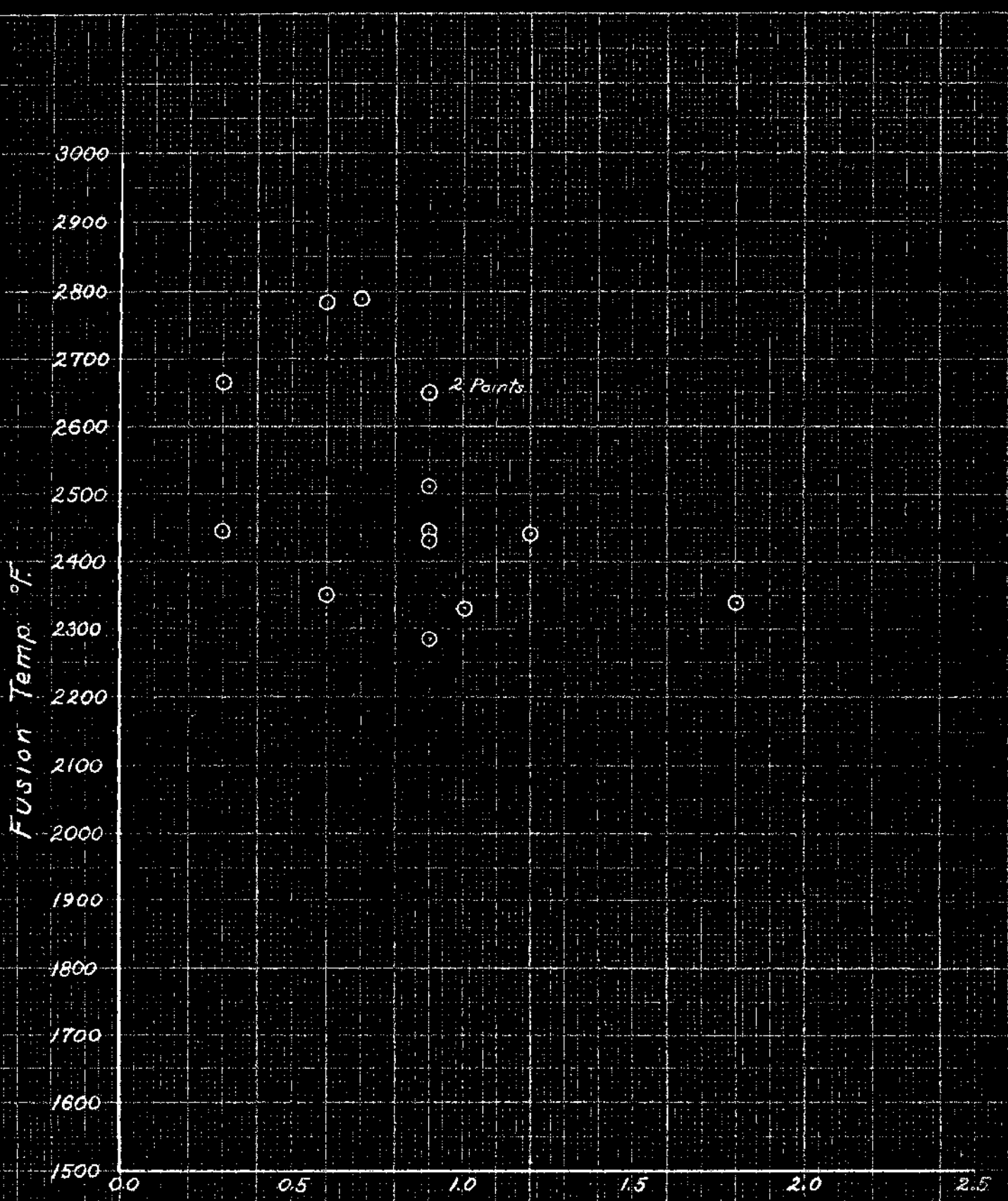
% Lime
in Ash

From the plot of percent magnesia against fusion point, page 17, a general tendency is shown for the ashes with small percentages of magnesia to have higher fusion points than those with the higher percentages of the magnesia present. However the tendency is not definite enough to warrant any belief in the theory that magnesia has the effect of a catalyst on the ash, causing it to fuse at lower temperatures.

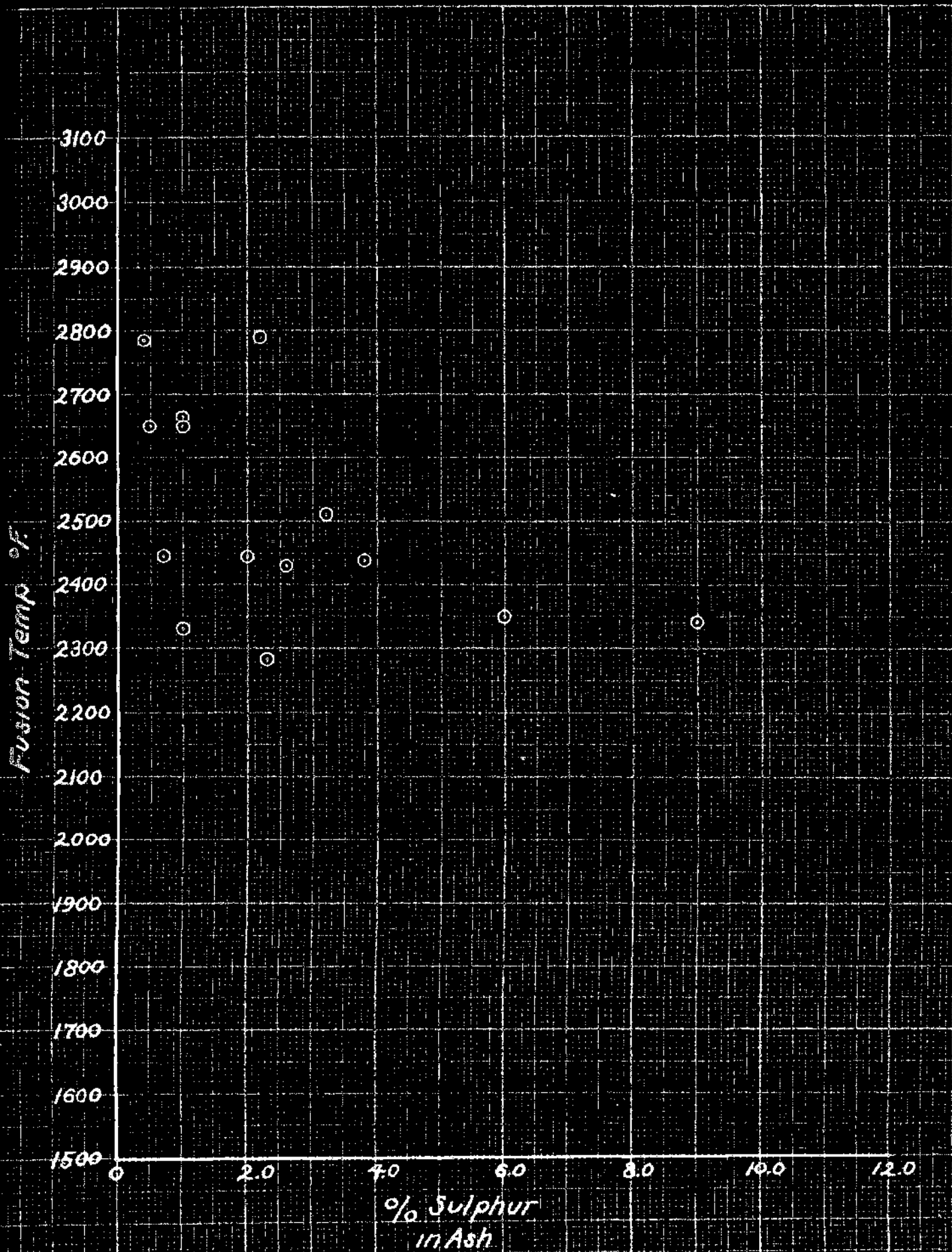
The sulphur plot on page 18 shows definitely that in these particular coals, the ashes with the higher fusion points are definitely low in sulphur, but at the same time there are enough coals with low sulphur content and also low fusion points to prevent one from drawing the conclusion that sulphur alone affects the fusion point.

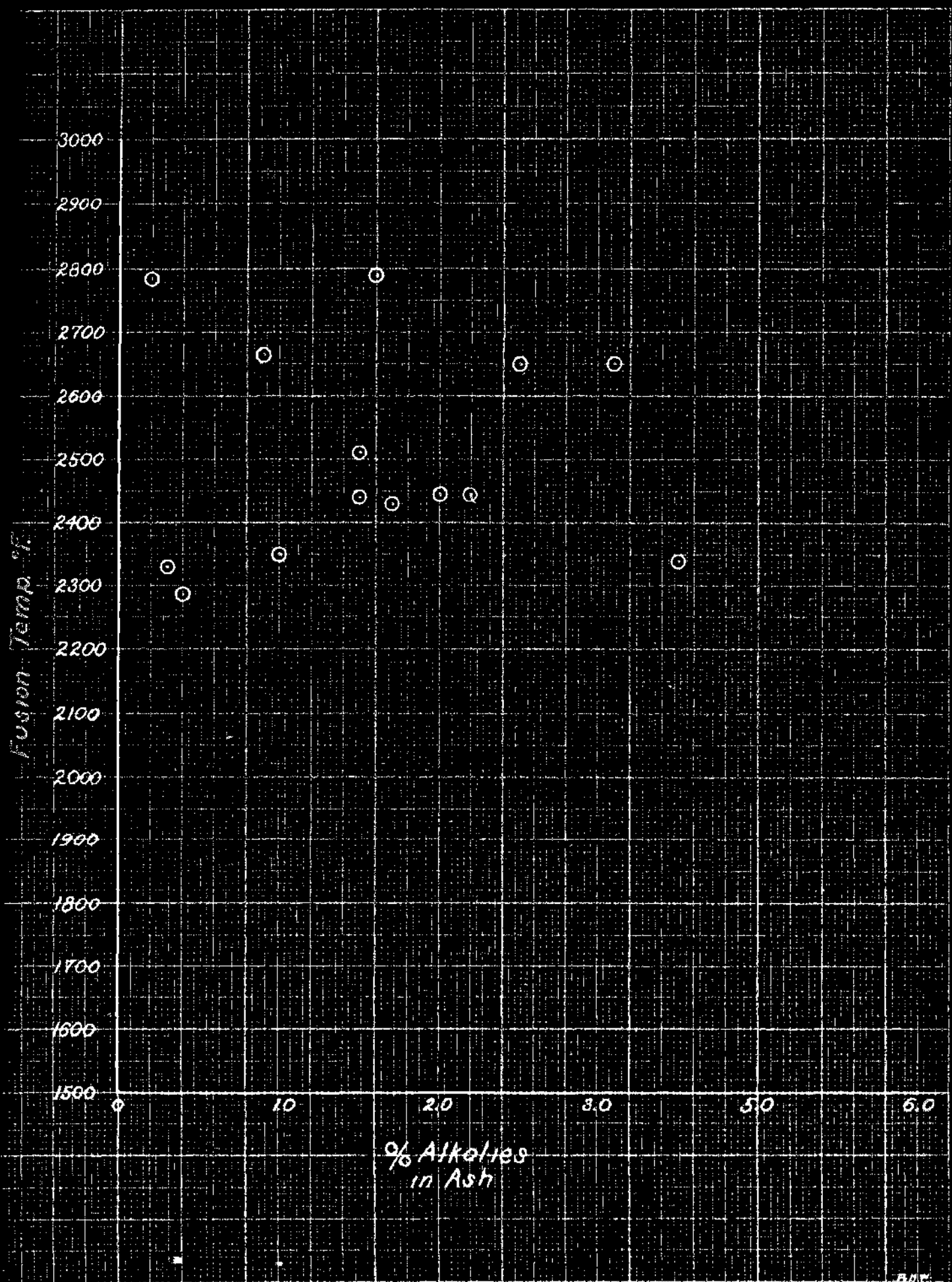
Earlier investigations of the fusion point led some observers to believe that the sulphur alone was the controlling factor in determining ash fusion temperature, but subsequent investigations by the U. S. Bureau of Mines have shown this to be erroneous.

The plot of the percent alkalies present in the ash as appears on page 19 shows little of interest, except that the alkalies in themselves have little or no governing effect on the fusion temperature.



% Magnesia
in Ash





The preceding plots of the fusion point against percentages of the various elements in the ash samples show that there is little or no relation directly connecting the fusion point with certain elements. It is to be understood that such a conclusion should not be drawn from just a few samples. As it can readily be seen from the ashes plotted here, sometimes four or more samples will fall in a straight line which would lead the casual observer to believe a relationship existed between the element in question and the fusion point.

The coal samples used from Figure 1 have been selected from a great many samples as giving representative results, and the plots with these ashes bring out the same results as are shown by larger plots covering hundreds of samples.

Recent work has shown that it is possible to establish relationships between the combined elements of silica, alumina, iron, and lime and the fusion point of the ash. These relationships are based on complex ratios of the various elements and the products of their combination chemically.

For example:

A curve plotted with fusion temperature against

$$\frac{\text{Al}_2\text{O}_3}{\text{Si O}_2} \cdot \frac{\text{Si}_2\text{O}_2 + \text{Al}_2\text{O}_3}{\text{FeO} + 0.6(\text{CaO} + \text{MgO} + \text{K}_2\text{O} + \text{Na}_2\text{O})} \quad *$$

gives fairly good results when used to forecast fusion temperatures. The percentages of elements are by weight as occurring in the coal ash.

It can readily be seen that such relations as the above are too complicated to be of any use in speeding up the process of determining the fusion points because of the fact that they would entail a great deal of rather complicated chemical procedure.

From the foregoing data and discussion it is rather obvious that it is impractical, at least, to attempt to determine the fusion point of coal by chemical analysis. Therefore the problem must be attacked from a different angle.

* "Fusibility of Coal Ash and Its Relation to the Chemical Composition of the Ash" by D. J. Demorest, Ohio State University - 1934.

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DETERMINATION OF THE FUSION POINT
BY THE COLOR METHOD

Since the fusion point must depend upon the composition of the ash, and the relation has been proven to be a complex combination of all the elements rather than a simple direct variation of fusion point under control of one single element of the ash, a physical property of the ash that embodies all the elements combined as a whole would be most likely to furnish an index and a simple relation for determining the fusion point.

Of all the physical characteristics of the coal ash, color is the most prominent. In the course of performing several hundred fusion tests on coal ash by the conventional method it has been noted by some observers that coals with very nearly the same color ash have very nearly the same fusion temperature.

It is the purpose of this thesis to determine whether the color of the coal ash can be used as a reliable general determinant of the fusion temperature of the ash, and if it is, to produce a device based on this fact that will indicate the fusion point of the ash directly.

As preliminary work for this thesis a series of coal ashes with known fusion points was prepared.

By comparison of unknown samples with the series, making a forecast of the fusion point, and then fusing the sample by the approved method, it has been possible in many cases to predict the fusion temperature. This was accomplished by comparing the colors of the ashes with the unaided eye, with an accuracy of within 100 to 200 degrees Fahrenheit with this particular series of coal ashes.

In approaching the problem the first step was to determine whether the method of burning the coal to ash had any effect on the color. This problem was solved by burning samples of the same coal in laboratory furnaces with the door open, giving an excess of oxygen; with the door closed and vents open, giving a normal supply of oxygen; and with the door and vents closed, giving an insufficient supply of oxygen.

The above tests resulted in samples with slightly different colors on the surface, but when the samples were pulverized to such an extent that they would pass through a 200 mesh sieve, the colors of all the samples were uniform and as far as the eye could detect, the ash of one coal had the same color regardless of the manner in which burned.

The conclusion drawn from this part of the experiment is that the way the samples are burned has a

negligible effect on the color of the ash as long as the coal is completely burned and the temperature is not high enough to partially fuse the sample.

In order to determine a relationship between the fusion point and the color or shade of the coal ash it was first necessary to develop some type of instrument capable of comparing colors with a great degree of accuracy. The vacuum type photo-electric cell used in conjunction with a supersensitive amplifier, exposure box for ash sample and a microammeter seemed to lend itself most readily to this type of work. Extensive experimenting finally resulted in the unique instrument described in appendix I.

Before making any observations on the ash samples it is first necessary to calibrate the fusion meter for the range of light over which it is operating by the procedure described in appendix II.

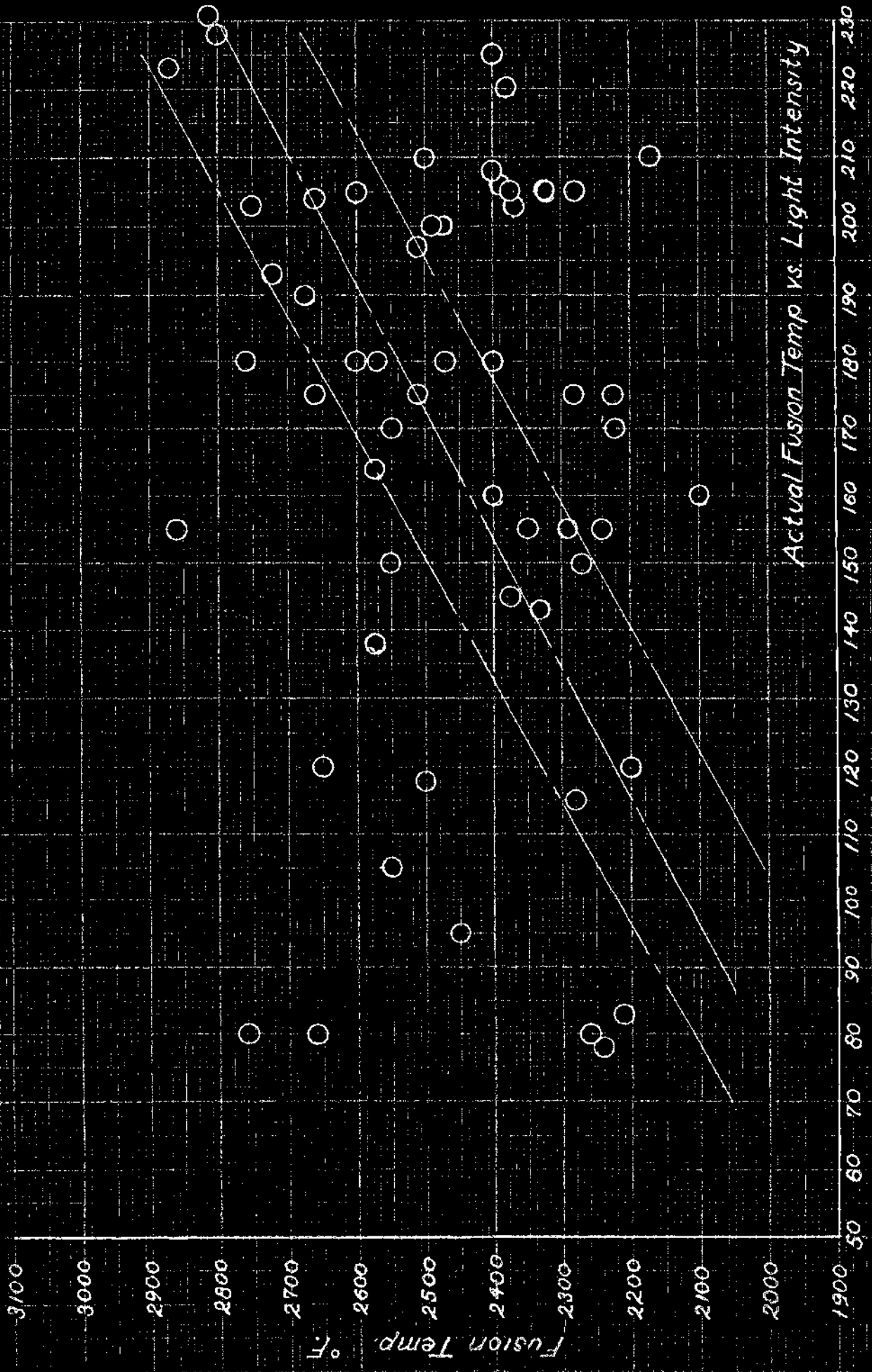
With the meter calibrated, a sample of the finely ground ash is placed in the exposure tube and packed down with a two pound ram to insure a uniform surface being exposed to the light source and photo-electric cell. The meter button is pressed and the meter indicates in microamperes the increase or decrease of current corresponding to the difference in the amount of light reflected from the calibration card. To insure the ac-

curacy of all readings the fusion meter was checked for calibration between each sample run.

The meter readings along with the fusion temperature of the sample and the name or number of the sample are recorded on the Data Sheet of Observations.

DATA SHEET OF OBSERVATIONS
MADE ON FUSION METER

Sample Number	Fusion Temp. F.	Meter Read-Ing	Sample Number	Fusion Temp. F.	Meter Read-Ing
1	2100	160	29	2450	95
2	2170	210	30	2490	200
3	2210	83	31	2475	200
4	2220	170	32	2500	118
5	2270	150	33	2500	210
6	2280	115	34	2510	197
7	2290	155	35	2510	175
8	2280	175	36	2550	105
9	2240	155	37	2550	150
10	2240	78	38	2550	170
11	2280	205	39	2570	180
12	2200	120	40	2575	165
13	2225	175	41	2575	138
14	2260	80	42	2600	1805
15	2330	143	43	2600	180
16	2320	205	44	2650	120
17	2380	220	45	2660	204
18	2375	205	46	2660	80
19	2370	203	47	2660	80
20	2375	145	48	2675	175
21	2350	155	49	2750	190
22	2390	206	50	2760	203
23	2400	180	51	2760	80
24	2400	160	52	2720	180
25	2400	225	53	2800	193
26	2400	208	54	2810	228
27	2420	245	55	2860	231
28	2470	180	56	2870	155
					223



Actual Fusion Temp vs. Light Intensity

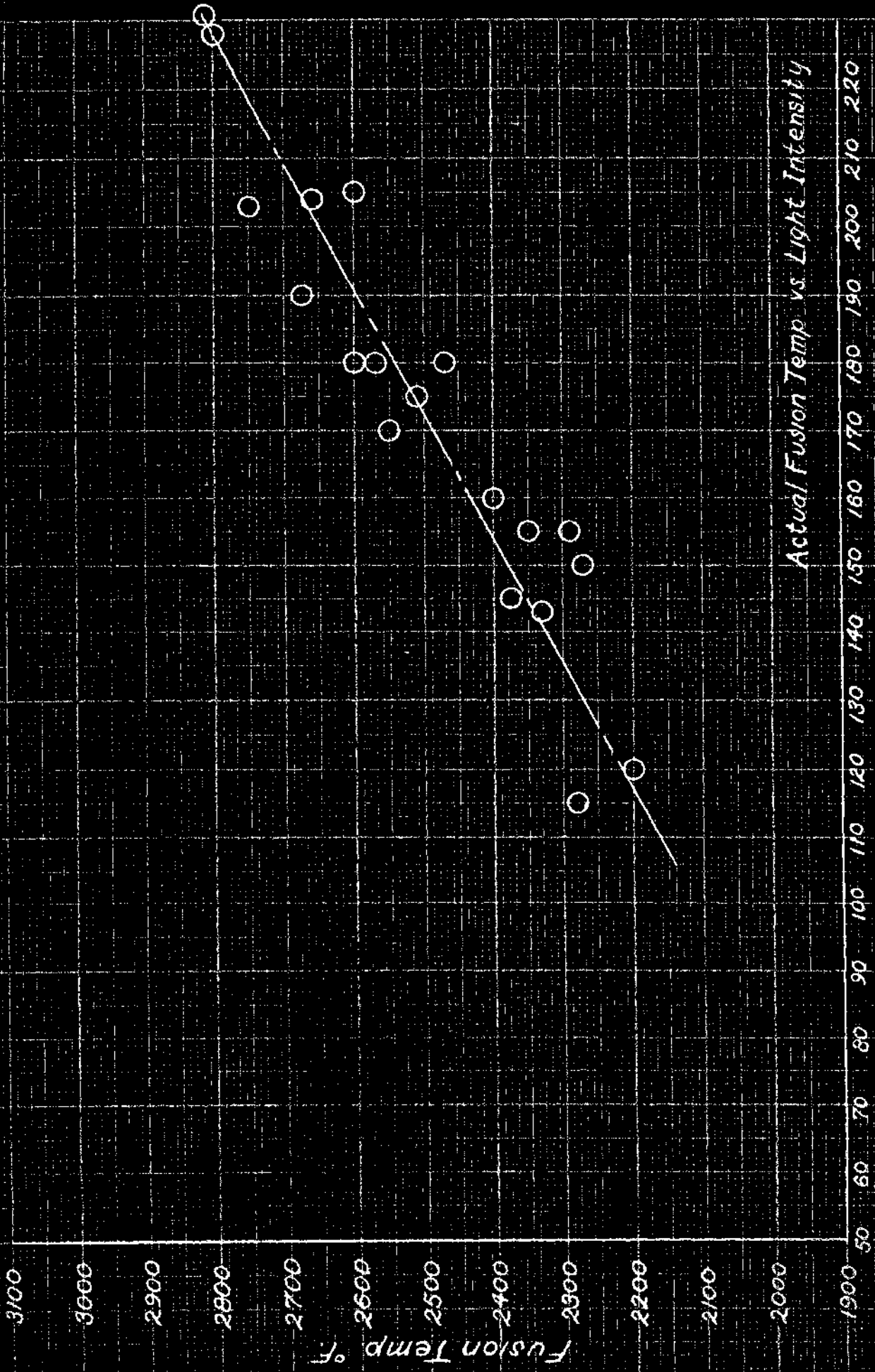
Meter Readings
Microamperes
Figure 2

SELECTED DATA

Figure 3

Sample Number	Fusion Temp. F.	Meter Read- ing
6	2280	115
12	2200	120
15	2330	143
20	2375	145
5	2250	150
7	2290	155
21	2350	155
24	2400	160
38	2550	170
35	2510	175
28	2470	180
39	2570	180
43	2600	180
48	2675	190
42	2600	205
45	2660	204
49	2750	203
53	2800	228
54	2810	231

The above data were selected from the general data for the purpose of illustrating the manner in which a number of samples will fall in some semblance of a smooth curve. It was in this manner that it was hoped that all points would fall in order to definitely prove that there is a relationship between the color of the coal ash and the fusion point of the ash.



Actual Fusion Temp vs Light Intensity

Meter Readings

Microamperes

Figure 3

DISCUSSION OF DATA AND RESULTS

From the Data Sheet of Observations the plot designated as Figure 2 was made to illustrate the results of the tests on all the samples. From figure 2 certain points were selected as listed on the sheet Selected Data; from this data Figure 3 was constructed.

From Figure 2 it is at once apparent that there is no sound basis for the assumption that the color of the coal ash is an indication of the fusion point. However, a general trend for rising meter readings to correspond with rising fusion temperatures is apparent on the right hand side of the plot.

When certain points are selected as the data for Figure 3, for example, it is apparent that there are a number of samples that will exhibit a striking tendency to follow what seems to be practically a straight line variation between temperature of fusion and meter reading, or in other words, light reflected from the sample to the photo-electric cell.

From Figures 2 and 3 the following results have been established:

- 33.9 % of samples will fall within 100 degrees of a mean line drawn across the figure.
- 25.0 % of the samples will fall between 100 and 200 degrees of the mean line.
- 41.0 % of the samples fall farther than 200 degrees from a mean line.

COAL ASH SAMPLES

On page 32 are groups of actual ash samples to illustrate the various colors encountered in coal ash. The two top rows are samples selected in order of rising fusion points. It is to be noted that the samples vary in color from dark to light as the fusion temperatures rise. The purpose of this illustration is to show how the idea arose that color might be an indication of the fusion point.

The third row of samples, it will be noted, have very nearly the same fusion temperature yet their colors very greatly. This is to show how impossible it would be to set up an instrument to measure color with an idea of indicating fusion temperatures from the color readings.

The dark sample at the bottom of the page was inserted because it is a rather unusual sample and the only one of its kind encountered in the course of these experiments. It will be noted that there is a much greater jump between the color of the bottom samples which fused at a temperature of 2150 degrees Fahrenheit and the upper left hand sample which fused at 2170 degrees Fahrenheit, a difference of 20 degrees, than there is between any other two samples on the page.

The figures under each sample represent the fusion point, as found by actual test, in degrees Fahrenheit.

COAL ASH SAMPLES

2
210
2170



6
115
2280



15
143
2330



27
245
2420



Sample No.
Meter Reading
Fusion Temp.



2470
180
28



2600
180
22



2720
193
52



2800
228
53

Fusion Temp.
Meter Reading
Sample No.



2400
208
26



2380
220
17



2375
205
18



2350
155
21

Fusion Temp.
Meter Reading
Sample No.



2150 Fusion Temp.

DISCUSSION

From the results of tests run in connection with this problem it is apparent that with 41.0% of the samples being so far from any curve or line that could be drawn on the plots of fusion against light intensity that there is obviously no connection between the coordinates. The conclusion is only obvious that it would give reliable results.

From the fact that on these tests 33.9% of the samples fell within a range of 100 degrees it is possible to see where the belief arose that color is an indication of the fusion point.

The plots showing fusion points of coal ash against the various elements in the ash likewise give no indication of a relation between the fusion temperature and the composition.

It is therefore an obvious conclusion that the only reliable and accurate method of determining the fusion point of coal ash is by actually fusing a sample of the ash in a furnace and observing the temperature at the fusion point.

RECOMMENDATIONS

This thesis has demonstrated the futility of attempting to set up a relationship between the fusion point of coal ash and the color or shade or amount of light reflected from the various samples of ash.

However, there are several other approaches to the problem that might be attempted although there is no rational reason for believing that they might prove more successful than this attempt. Nevertheless, determination of fusion points of coal ashes is so important that any attempt to create a new, simpler, and quicker method of determining the fusion point should not be overlooked.

It is the author's belief that an attempt to analyze the color of the ash after the light reflected from the ash has been passed through a prism and broken up into its spectrum might give interesting results.

Another suggestion, abandoning the color idea altogether, might be to make spectrographic analyses of the ash.

To the author's knowledge, these two methods have not been tried as yet and are about the only remaining possibilities to be exploited.

APPENDIX

APPENDIX I

DESCRIPTION OF APPARATUS

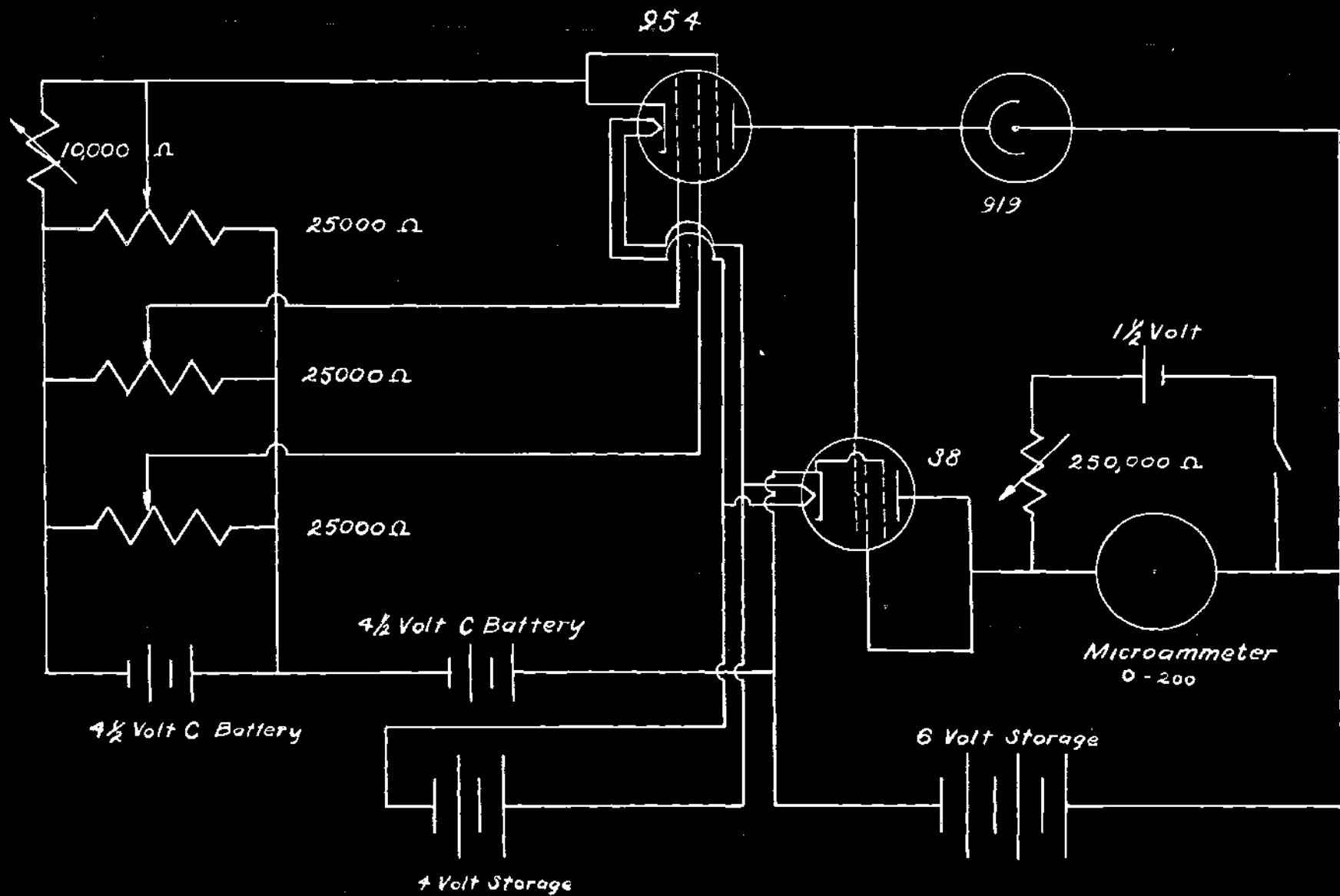
The Amplifier and
Photo-Electric Cell
Unit*

Due to the fact that it was impossible to secure any commercial equipment capable of making measurements of light changes of the small magnitude necessary in this work, it was necessary to construct, after extensive experimentation, the unit described on the following pages. This sensitive photo-amplifier is capable of indicating light differences or changes which may amount to small parts of one percent.

The photo-electric cell chosen for this work was an RCA 919 vacuum type constructed with a top-cap cathode connection so as to have high resistance to leakage current between electrodes. This tube offers stability of operation and permanence of calibration.

For constant calibration of high precision instruments such as this, the photo-electric tube should be operated at an anode voltage of about 20 volts. Higher anode voltages cause ionization of any traces of

* This information was furnished by Mr. W. L. Jones, Jr. who constructed the amplifier used in this work.



*Circuit Diagram of the Photo-Electric Cell
Light Measuring Instrument*

*Circuit Design By
William L. Jones, Jr.*

Figure A

R.H.W.

residual gas that may be present in the tube. The gas current resulting from this ionization may produce slow changes in the tube's characteristics which would change calibration of the instrument. In this unit the tube is operated at an anode potential of twenty volts.

A further consideration for the maintenance of constant calibration is that the light incident on the phototube should be spread over as large a portion of the cathode surface as possible. This will minimize any variations in sensitivity that might be caused by a shift in the position of the light spot on the cathode.

Another factor in favor of the 919 was its spectral response. This phototube is sensitive over the entire visible spectrum with a large response in the infrared region which makes the tube particularly useful where tungsten filament lamps are employed as a light sources.

For maximum sensitivity of phototube circuits it is desirable to use a high resistance connected in series with the phototube and coupled to the grid circuit of an amplifier tube. In this circuit arrangement the high impedance 954 pentode acts as a load impedance for the 919.

The potential of the common connection between the

919 and the 954 is determined by the intersection of their characteristics. This output voltage is applied to the grid of a type 38 power amplifier pentode, connected as a triode, whose plate current is measured on a microammeter whose scale is 0-200 microamperes.

As the phototube with the 954 load has an extremely high output impedance it is necessary to operate the 38 tube so that its grid input impedance is extremely high. To reduce the grid emission to a minimum, the voltage to the heaters of the 38 tube and the 954 tube is reduced from the rated 6.3 volts to 4.0 volts.

The possibility of emission from the heaters to the grid is eliminated by operating the heaters at a potential positive with respect to the plate of the 954 and the grid of the 38. Gas current to the grid of the 38 is kept to a minimum by keeping the potential within the 38 low in order to minimize the ionization of any gas that may be in the tube.

If it is desirable to reduce the sensitivity to small percentage changes of light, the plate characteristics of the 954 can be varied between that of a pentode and that of a triode. This may be accomplished by adjusting the potentiometers to control the relative potentials on the control and screen grids. When the number two grid of the 954 is positive with respect to the cathode, the 954 has high impedance pentode

characteristics, and changing the number one grid bias changes the height of the characteristic curve and thus the point of intersection with the curve of the 919 tube.

It is apparent, therefore, that the 954 load can be adjusted to give practically any desired positive impedance load at any desired current and desired voltage across the tube by proper manipulation of the controls, and thus the output meter can be made to show a full scale deflection covering only a fraction of a percent of light variation.

When maximum sensitivity of phototube circuits is desired, the leakage resistance of circuit parts and of wiring insulation should be high. Leakage currents from anode to cathode over the external surface of the bulbs were reduced by cleaning the glass with carbon tetrachloride to remove all traces of dust and grease. By proper layout of the tubes the high impedance external connections were protected from leakage by proper spacing. The entire amplifier was built up on a bakelite panel, supported by a wooden base, using isolanite sockets and spacers. All connections were made with tinned copper bus bar and the leads were properly spaced so that no insulation on the bus bar was necessary.

THE EXPOSURE BOX

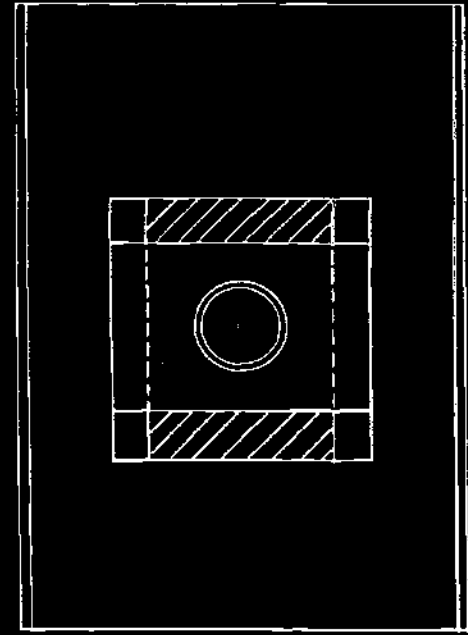
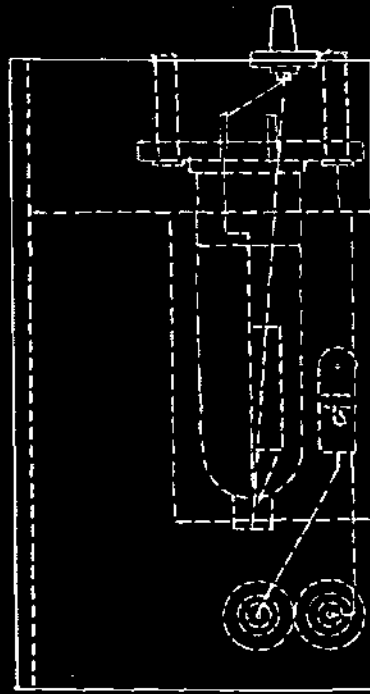
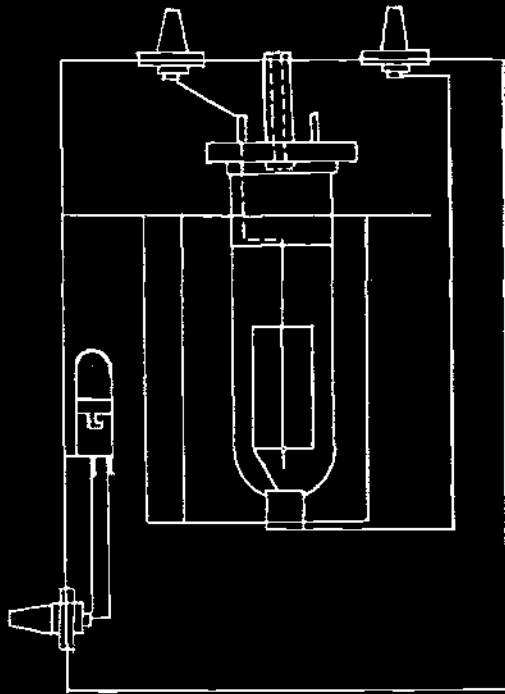
In order to expose the samples of coal ash in a uniform manner and in such a way that readings could be duplicated again it was necessary to construct a device known as the exposure box. To avoid any chance of stray light leaking into the photo-electric cell it was necessary that the box be absolutely light proof. To accomplish this the box was constructed of tongue and groove joints with the cover sliding in grooves at the top of the box. The whole unit was painted on the outside with heavy black enamel.

In the cover of the box a three-quarter inch hole was cut which determined the area of the sample that would be exposed to the tube. The three-quarter inch hole was covered by a thin glass slide held in place by a groove. Over the glass plate was a fixed cover that contained a one inch hole whose center was in line with the three-quarter inch hole. The one inch hole served to locate and hold in position the sample tube which stands on top of the exposure box.

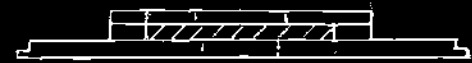
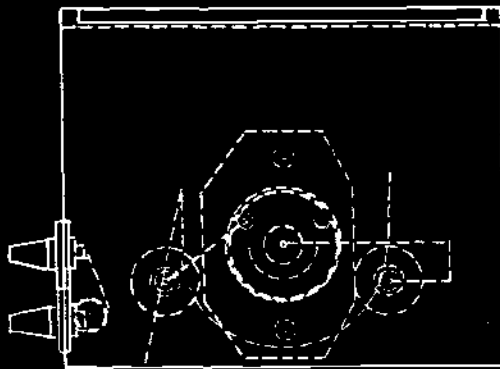
The inside of the exposure box was painted dead black to reduce internal reflection to a minimum and the light source and the photo-electric cell and its mounts were surrounded with a series of baffles to further reduce stray reflection and direct the light on to the

Exposure Box

Box Cover



Approximately $\frac{1}{2}$ Full Size



EXPOSURE BOX FOR COAL ASH SAMPLES

Figure B

Design by R.H. White, Jr.

ash sample being tested.

The light source was a six volt bulb operated by a storage battery and so placed that its direct rays fell on the ash sample and were reflected back to the photo-cell. The baffle arrangement in the box prevented any stray light from this bulb reaching the photo-electric cell without first being reflected from the sample. The voltage on the bulb was carefully checked and held constant during the tests.

To reduce the chances of interference and leakage in the circuit of the amplifier, the exposure box was mounted directly to the amplifier chassis and became an integral part of the unit. Figure B represents the layout of the exposure box and cover, and Figure C shows the unit as a whole in various positions.

THE FUSION METER

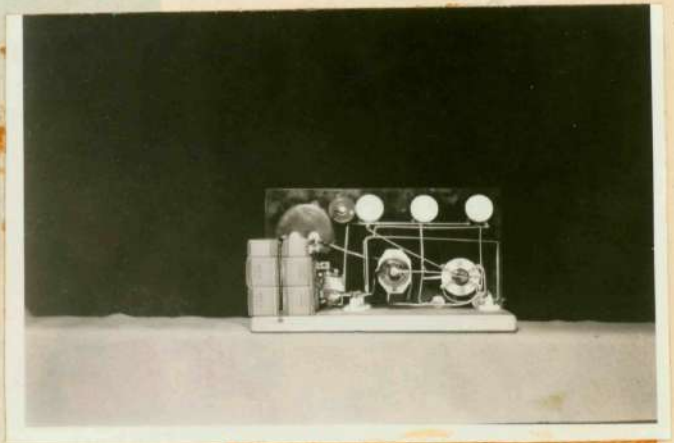
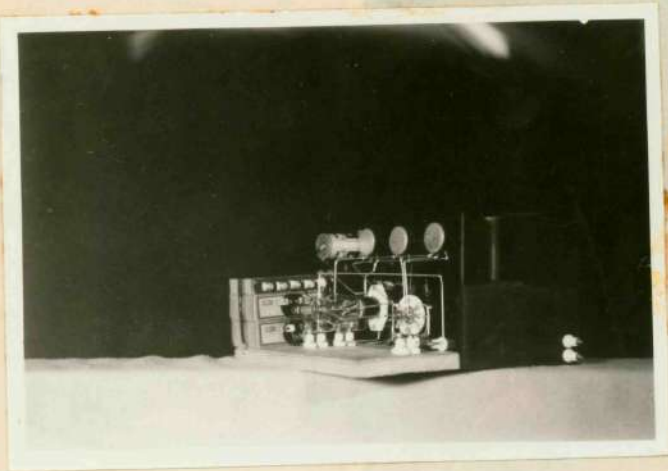
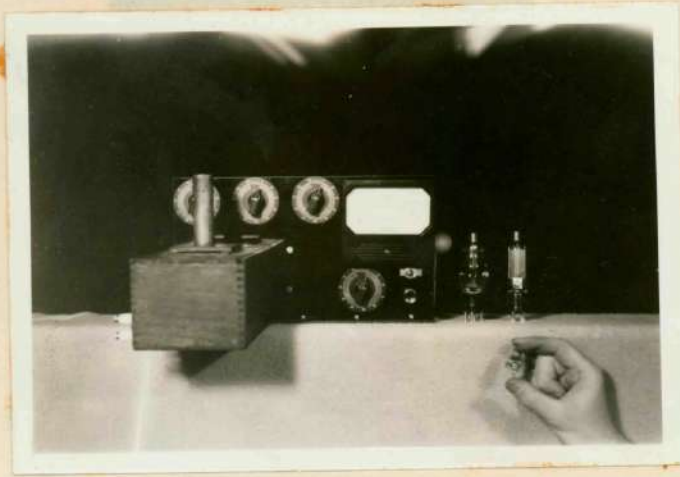


Figure C

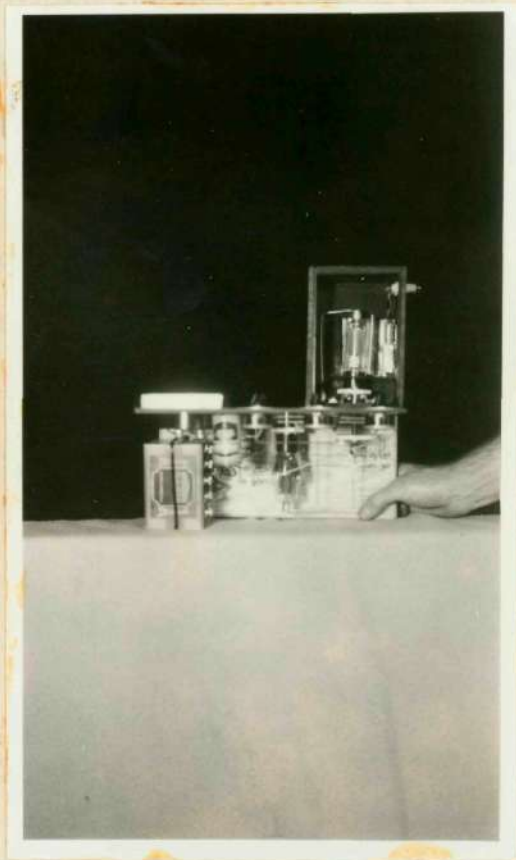


Figure C

APPENDIX II
METHOD OF PERFORMING TESTS

The instrument must first be set up and turned on and allowed a half hour warm up period before any adjustments are to be attempted. Following the warm-up period all voltages are carefully checked and adjusted; the instrument can then be calibrated as described below. By means of the calibration colors (pink and yellow) the sensitivity of the unit was so adjusted to give a change of thirty microamperes between these two colors. When this sensitivity was attained the meter was set by means of the voltage bucking circuit so that it read half scale deflection on the pink color.

The coal samples were arranged in order of ascending fusion points and the tests were run in this order. A portion of the sample to be tested was placed in the exposure tube and tamped down with a two pound weight so that a uniform surface was exposed to the light source through the glass cover plate. The meter button is then pressed and the meter indicates the amount of light reflected to the cell from the sample as compared with the amount reflected by the pink calibration color. In the process of performing the tests, if it was found that a sample was so light or dark as to run the meter off scale, the calibration slip was placed in the meter and a new

zero was established to accommodate the sample in question. Between each sample the calibration colors were exposed to the light source and photo-electric cell to make sure that the sensitivity of the unit and the zero setting had not changed.

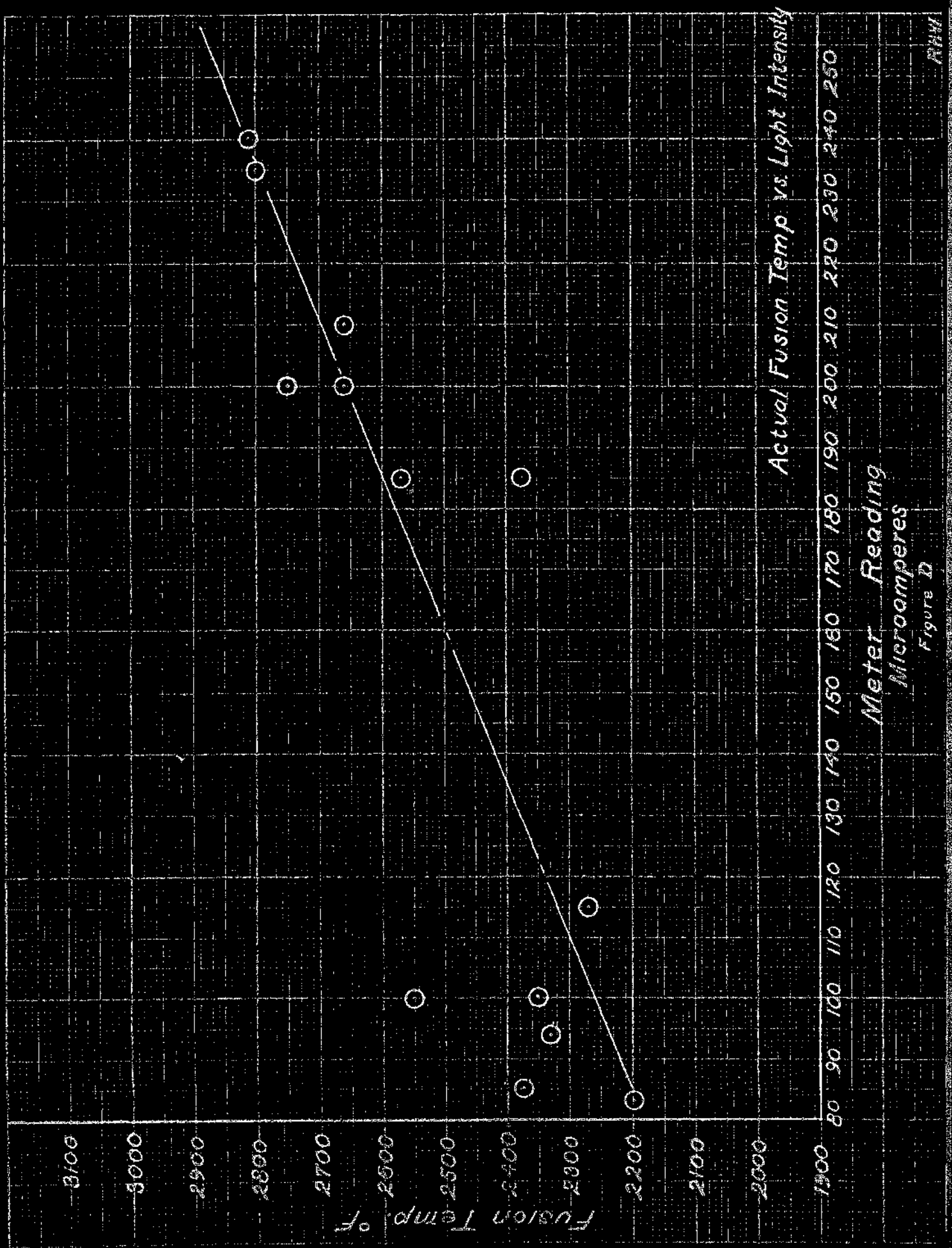
It can be seen that essentially, what this process did was to measure the difference in light reflected from pink color and the different coal samples. This method was chosen because it seemed to present the simplest way of determining whether or not there was a definite relationship between the color of the coal ash and the fusion point. If such a relationship had existed it should have become apparent when the meter readings were plotted against the known fusion points of the faribus samples.

The calibration colors of pink and yellow were chosen after it had been determined that the photo-electric cell (which exhibits color sensitive characteristics) was found to have fairly constant sensitivity between these two colors. By examination of the samples it was determined that the different coal samples seemed to exhibit the shades of pink and yellow or colors close to them more prominently than others.

As another test of the color sensitivity of the photo-electric cell, after the original tests were run, the samples that seemed to show the greatest

tendency of fusion point varying with the color were run using a blue light source and a red light source. The results of the run with the blue light source are plotted in Figure D. It is to be noted that these samples are the same as those plotted in Figure 3.

The blue light seems to have little effect upon the results as the slope of the line remains about the same as that from the curve of Figure 3. In running with blue light it was impossible to attain the same sensitivity between the pink and yellow that was accomplished with the white light and as a result the curve is more spread out than that of Figure 3.



Actual Fusion Temp vs. Light Intensity

Meter Reading
Microamperes

Figure D

Bibliography

1. "International Conference of Bituminous Coal"
November, 1926 - Carnegie Institute of Technology
2. "Proceedings of the Second Fuel Engineers' Meeting"
October 15, 1934 - Appalachian Coals, Inc.
3. "Standard Methods of Chemical Analysis"
- Wilford S. Scott
4. "Carnegie Institute of Technology Bulletin No. 62"
5. "Fusibility of Coal Ash and Its Relation to the
Chemical Composition of the Ash"
September, 1934 - D. J. Demorest, Ohio State Univ.