5-1-1930

The Ignition Temperature of North Dakota Lignite

George Anthony Brady

Recommended Citation
Brady, George Anthony, "The Ignition Temperature of North Dakota Lignite" (1930). *Theses and Dissertations*. 450.
https://commons.und.edu/theses/450

THE IGNITION TEMPERATURE OF NORTH DAKOTA LIGNITE

BY

George Anthony Brady.

A Thesis submitted to the faculty of the College of Engineering at the University of North Dakota in partial fulfillment of the requirements for the degree of Master of Science in Chemical Engineering.

University of North Dakota.
May 28, 1930.

This Thesis, presented by George Anthony Brady as a partial fulfillment of the requirements for the degree of Master of Science in the University of North Dakota, is hereby approved by the Committee in charge of his work.

Introduction.

It is very difficult, if not impossible, to accurately define the ignition temperature of a coal. This may be verified by a study of the many attempts appearing in literature to formulate such a definition. If one should apply the generally accepted concept of ignition point to coal it would refer to the temperature to which coal must be heated in order that it shall burst into flame. The flame from burning coal is due to combustion of volatile products of distillation from the coal and the nature of these volatile combustibles depends largely on surrounding conditions of heating[1]. Hence for a given coal these varying conditions cause such large fluctuations in the flaming temperature that its determination is valueless. Similarly, to define ignition point of a coal as the temperature at which self-heating begins would be equally unsatisfactory. The accompanying study supports other more extensive experimental evidence[2] that even at atmospheric temperatures some coals will combine with oxygen in a reaction accompanied by the emission of heat. The reaction is not rapid, to be sure, but nevertheless it is very much in evidence. Hence if one defines the ignition point of coal as the temperature at which self-heating begins, the ignition point of lignite may be placed at a point below atmospheric temperature.

In 1918 Wheeler[3] investigated the ignition temperatures of a number of English coals from a standpoint of the oxidizing tendency of the various coals under given conditions. His method consisted of heating a sample of the coal at a constant rate in an electrically heated sand bath. Air was dried by passing through a tube of calcium chloride and then was admitted to the combustion tube containing the sample. Simultaneous readings of the coal and sand bath temperatures were recorded. The results were plotted as two time temperature curves, one of which defined the heating rate of the sand bath, the other defined the heating rate of the coal. Wheeler designated the point where these two curves intersected as the relative ignition temperature. Since information gained by use of this method seemed to be of both interest and value in connection with problems involved in a study of the oxidizing tendency of bituminous coals, the method was extended to lignite in the present investigation. It was not, however, found to be generally applicable to lignite because of its relatively high moisture content.

Arms[4] made a thorough study of the heating curves of bituminous coals and adopted as the ignition point the temperature at which the coal assumed a uniform glow when heated by an external source. His method of heating the coal differed from other methods of the same nature, in that the oven temperature was not increased at a constant rate, but rather the flow of current in the heating elements of the furnace was kept constant. Arms found the glow point to be rather definite in the heating curve and that it could be checked by use of various types of apparatus. On the strength of these facts he assumed the glow point to be the most logical point to select as ignition temperature. It appears in the zone of 400-600° C., depending on the nature of the coal. When coal is heated in air a number of important reactions are known to take place before the temperature of glow point is reached. The reactions are not concerned in the method of Arms but nevertheless are of importance and can not be neglected.

In 1925 Parr[5] referred to the temperature at which carbon dioxide is evolved as the critical oxidation temperature for coal in storage and at that time designed an apparatus to indicate the initial appearance of carbon dioxide when coal in the presence of oxygen is heated by an external source. The apparatus used was essentially similar to that designed by Wheeler with the exception of the additional carbon dioxide indicator mentioned above. This unit used a solution of barium hydroxide as the indicating medium. Gas from the combustion tube was directed against a nozzle from which dripped the barium hydroxide solution. Any CO_2 present in the gas expelled from the combustion tube precipitated barium carbonate from the indicating medium.

The temperature of evolution of carbon dioxide suggested by Parr as an index to the critical oxidation temperature was the point adapted as ignition temperature in the present investigation of Dakota lignite. This point marks the beginning of the second stage of oxidation of coal as it is explained by the "Carbon-complex" Theory.[6] It may also be regarded as the beginning of the first stage of oxidation that occurs above atmospheric temperature because carbon dioxide is one of the initial products of combustion most in evidence. It is not contended that this point on the heating curves of lignite designates the stage of rapid heating irrespective of all other conditions. Neither could it be assumed that the ultimate attainment of the kindling temperature is inevitable when lignite is once heated to the point of evolution of

CO_2 either by an external source or by the heat liberated spontaneously from its own oxidation. It seems there has been a general tendency to confuse the terms ignition temperature of a coal and its oxidizing tendency. Recently Rosin[7] pointed out that there is a fundamental difference in the two terms. He defines ignition temperature as "the statistical coordination of a temperature which is dependent upon experimental conditions" and tendency to spontaneous combustion as "the property possessed by a substance of heating spontaneously at a rate rapid enough for the ignition temperature to be attained." It is obvious that in the case of spontaneous combustion the ignition temperature is not nearly so important as the amount of heat necessary to raise the temperature of the coal to the ignition point. For example, the flame of a match reaches a temperature of approximately 700° C, far above the ignition point of the coal and yet it is generally known that a match alone will produce only enough heat to ignite very small quantities of coal.

It is possible that ignition temperature assumes its greatest significance in connection with problems involved in the combustion of powdered coal. This practical incentive was one of the factors which prompted the present investigation on lignite. It is generally contended[8] that one of the chief objections to powdered coal in the past has been the large combustion space required to permit complete combustion of the coal without excessive deterioration of the furnace lining due to the impingement of flame on the brick work. High-volatile coals, therefore, on account of their greater ease of ignition may have an advantage over the low volatile coals. Aside from the above mentioned possible advantage, lignite has properties which render it well suited for use in the powdered form. For example, specially designed grates are necessary for economical combustion of lignite owing to its tendency to slack, followed by subsequent loss due to sifting through the grates. Since it seemed that the ease of ignition is an important factor in the combustion of powdered fuel and the inherent properties of lignite suggest that it might be used advantageously in this form, it was desired to investigate its ignition temperature. The information was also desired for the purpose of comparing the ignition temperature of raw lignite with that of lignite dried by the Fleissner method.

The following is a report of the results obtained from a study of the effect produced on ignition temperature by such physical properties as particle size, moisture content, and previous history of the coal.

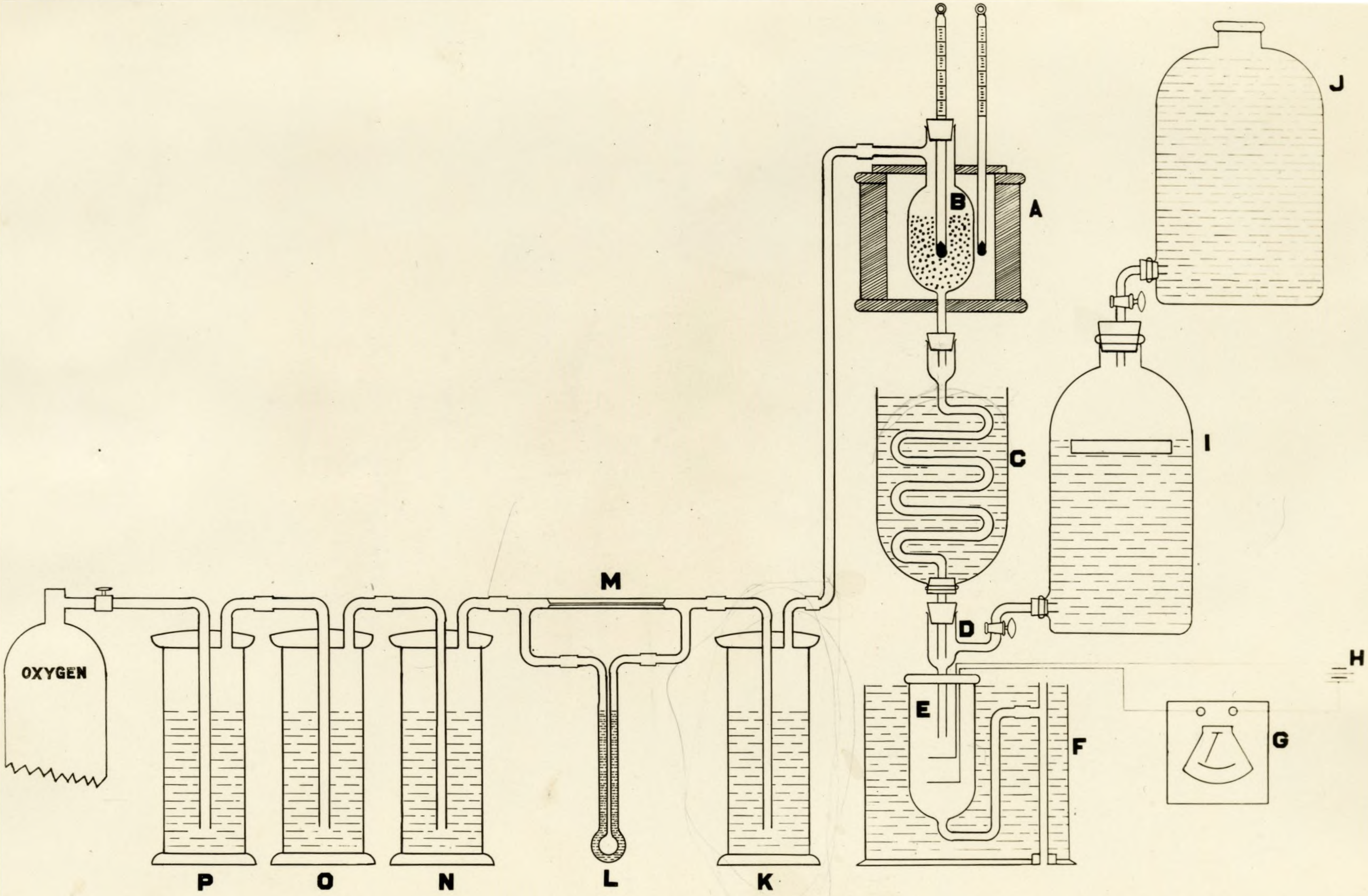


FIG 1

APPARATUS FOR DETERMINING THE IGNITION TEMPERATURE OF LIGNITE

Experimental

Apparatus:

The apparatus used in this investigation is shown diagrammatically in figure 1. The furnace A was constructed purposely for these experiments with the aim in view of having one in which the temperature could be accurately controlled. It consists of a heating chamber 5 inches in length by 2 inches in diameter, surrounded by a 2-inch layer of asbestos fiber held in place by a sheet metal sleeve and slate asbestos end pieces. The heating element was made from 24 feet of No. 21 B. & S. gauge chromel "A" wire wrapped on the refractory which was furnished with grooves built in the form of a spiral on its surface. Temperature was controlled by means of a sliding contact rheostat in series with the furnace circuit. Two 500-degree nitrogen-filled thermometers were used to indicate the temperatures of furnace and coal, with the exception of two series of runs in which the thermometers were replaced by platinum-rhodium thermocouples. The accuracy of both thermometers and thermocouples was checked at five different points by comparison with the boiling points of the following liquids:

Liquid	Boiling Point °C.
Benzene	80.4
Water	100
Chlorobenzene	132
Aniline	184.4
Diphenyl methane	262

The combustion tube (B) was made of pyrex glass with a capacity of 25 grams of lignite. The outlet of this tube protrudes through an opening in the bottom of the furnace and leads to the cooling coil (C) which is 60 inches in length and surrounded by a water jacket through which tap-water was circulated to cool the gas expelled from the combustion tube.

The mixing chamber (D) affords a compartment in which gas from the furnace is mixed with the electrolyte.

The system used to indicate the initial appearance of carbon dioxide embodies a number of the features suggested by Taylor and Taylor[9] in their description of an automatic carbon monoxide recorder. The conductivity cell (E) made from a 1 1/4 inch glass tube is fitted with two gold platinized electrodes 1.5 cm. in diameter and placed 1.5 cm. apart. These electrodes are connected in series with a milliameter (G) and ten dry cells (H). A double-pole knife switch was placed in the circuit in such a way that the current could be passed either through the cell or through a standard 500 ohm resistance (not shown in diagram). With the resistance coil in series, ten new dry cells produced a current of 32 milliamperes in the circuit. By this method the strength of the cells could be tested regularly and replacement made when necessary. The voltage adjusted in this manner produced a current of approximately 10 milliamperes through the cell filled with .1 N ammonium hydroxide at 26° C. Temperature of the cell was controlled by means of the constant temperature bath (F). The elaborately designed pump used by Taylor to maintain a constant ratio between gas and reagent flow was replaced in these experiments by the capillary (M) and manometer (L) used to indicate gas flow and the constant pressure head (I) to deliver the ammonium hydroxide at a constant rate. The bottle (J) served as a reservoir from which solution was drawn to maintain a constant level in (I).

Gas to be passed through the coal was circulated through the train of wash bottles (K, N, O, P) filled with the proper solutions to either dehydrate or wet the gas to the desired moisture content. These bottles are of the standard "Milligan" type, each one of which has the absorbing capacity of a bottle 43 inches high.

General Procedure:

In order to meet desired conditions for different series of experiments a number of modifications (to be described later) were made in both apparatus and method of procedure. The general method adopted, however, was as follows: Coal ground to the desired size was placed in the combustion tube within the furnace which was heated at the rate of 2.5° C. per minute. The desired gas (either oxygen or nitrogen) was passed through the wash bottle (P) which contained a 40% solution of potassium hydroxide to remove all traces of carbon dioxide, and then through the remaining absorbing bottles to either dehydrate or wet the gas to the desired moisture content. After leaving the wash bottles the gas was metered and passed through the coal. From the combustion tube the gas flowed through the cooling coil and then was mixed with a .1 N solution of ammonium hydroxide continually flowing through the cell at a constant rate. Temperature of the furnace was recorded at 4-minute intervals while temperature of the coal and milliamperes of current through the cell were recorded simultaneously at 2- minute intervals. The results were plotted as two time-temperature curves and the initial change in conductivity recorded as the CO_2 point on the curve representing the heating rate of the coal. The mechanism of the CO_2 indicating system may be stated as follows: Pure oxygen or nitrogen has no effect on the conductivity of ammonium hydroxide but any CO_2 present will be absorbed and the conductivity of the solution increased in a direct proportion to the amount of CO_2 absorbed. The sensitivity of the CO_2 indicator, therefore, is dependent on the relative amounts of gas and solution flowing through the system. After some experimentation it was decided that 70 cc. of gas and 20 cc. of ammonium hydroxide constituted the most desirable ratio. With gas flowing at this rate it was calculated that approximately one minute intervened between the time it left the combustion tube and the time it entered the cell so accordingly the first change in conductivity was marked on the time-temperature curve one minute back of the point at which it was first observed.

Results and Discussion.

Comparison of the ignition point of lignites from different mines in North Dakota.

This series of experiments consisted of an investigation of ten samples of lignite taken from different mines throughout the State of North Dakota. The purpose was to ascertain if there is any material difference in the ignition temperature of lignites from different localities. The samples were all received in sealed containers from the following corporations:

Knife River Coal Mining Company,	Bismarck, North Dakota
Hebron Brick Company,	Hebron, North Dakota
Lehigh Briquetting Company,	Dickinson, North Dakota
Truax-Traer Coal Company,	Columbus, North Dakota
New Salem Mine,	New Salem, North Dakota
Pittsburgh Coal Mining Company,	Dickinson, North Dakota
Stevens Bros. Coal Company,	Garrison, North Dakota
Washburn Lignite Company,	Wilton, North Dakota
Scranton Collieries Company,	Scranton, North Dakota
Light Bros. Coal Company,	Noonan, North Dakota.

Each sample was air dried twenty-four hours. The coal was then ground to the proper size so that it passed through a 40-mesh sieve and was retained on a 60-mesh and then sealed in an air-tight container until it was to be tested. Temperature measurements were made with thermometers. For this series of runs oxygen was used that was first passed through a solution of potassium hydroxide to remove CO_2 and then through the remaining wash bottles filled with recently boiled distilled water to saturate the gas.

Results are tabulated in the following table.

Table 1

Location of Mine	CO_2 temperature Individual	CO_2 temperature Average	Crossing Temperature Individual	Crossing Temperature Average
Bismarck, No. Dak.	(70 (72	71	(221 (223	222
✓ Hebron, No. Dak.	(72 (74	73	(226 (218	222
Dickinson, No. Dak.	(75 (75	75	(211 (220	215.5
Columbus, No. Dak.	(78 (78	78	(213 (217	215
New Salem, No. Dak.	(77 (76	76.5	(230 (233	231.5
Dickinson, No. Dak.	(77 (81	79	(229 (230	229.5
Garrison, No. Dak.	(78 (82	80	(232 (232	232
Wilton, No. Dak.	(81 (79	80	(226 (227	226.5
Scranton, No. Dak.	(79 (76	77.5	(236 (226	231
Noonan, No. Dak.	(77 (75	76	(231 (229	230

An inspection of table 1 reveals no material difference in the ignition temperatures of different lignites. A striking similarity may be observed also in the nature of the heating curves, an example of which is shown in figure 2. The broken line in this, as in all other graphs in this report, defines the heating rate of the furnace. Other curves in this series are not shown since they would furnish no additional information because of their general similarit

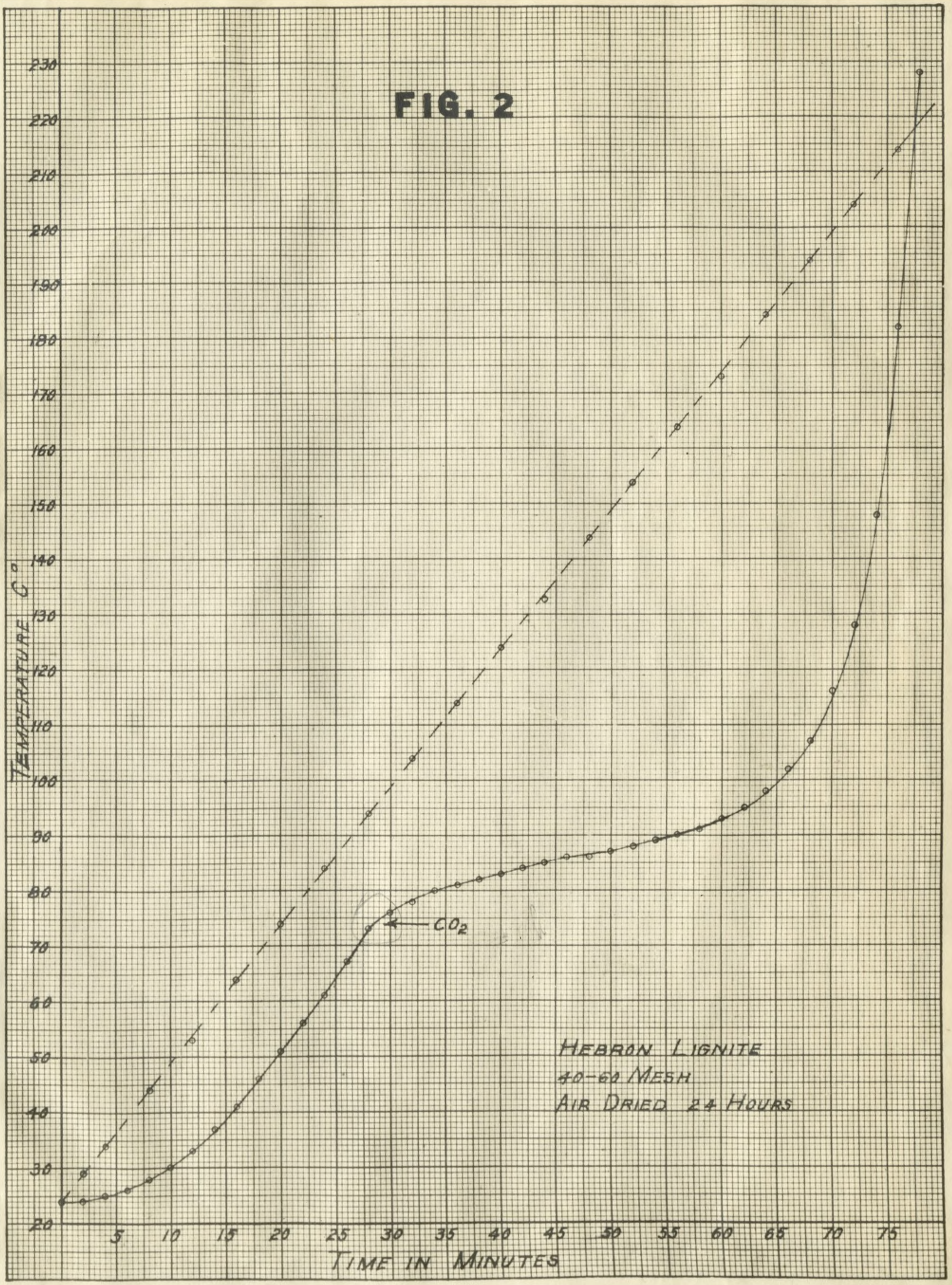


FIG. 2

230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
TEMPERATURE C°
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
TIME IN MINUTES
CO_2
HEBRON LIGNITE
40-60 MESH
AIR DRIED 24 HOURS

Comparison of ignition temperature of lignite with those of higher rank coals.

In this series of tests a comparison was made of five different ranks of coals, including lignite, Wyoming bituminous, Illinois bituminous, Pocahontas, and anthracite. The coals were air dried one day then ground to 40-60 mesh and run in the manner described before using saturated oxygen. Pyrometers were used to indicate the temperatures. Each sample was subjected to two heat treatments; that is, it was treated as described above then allowed to cool to room temperature without removing from the furnace and was reheated under exactly the same conditions as in the first treatment. Duplicate runs were also made on each sample. Results of these tests arelisted in table 2, showing results of first heat treatment and table 3 showing results of second treatment.

Sorp curves
3 - H_2O content

Table 2.

Coal	Ignition temperature		Crossing temperature	
	Individual	Average	Individual	Average
Lignite	(66 (66	66	(183 (183	183
Wyoming Bituminous	(88 (96	92	(180 (170	175
Illinois Bituminous	(124 (122	123	(164 (168	166
Pocahontas	(176 (152 (164	164	(215 (204 (209	209
Anthracite	(248 (228	238	(248 (266	257

Table 3

Coal	Ignition temperature		Crossing temperature	
	Individual	Average	Individual	Average
Lignite	? (114 (98	106	(160 (150	Should be (less H_2O) 155
Wyoming Bituminous	(120 (128	124	(110 (148	129
Illinois Bituminous	(96 (136 ?	111	(163 (151	157.
Pocahontas	(184 (162	173	(204 (208	206
Anthracite	(248 (234	241	(268 (300	284

It will be noted that both the CO_2 points and the crossing points of the heating curves of lignite are somewhat lower than those of other lignites, listed in table 1. A possible explanation of this might lie in the fact that the lignite used in this series was taken from the cars and hence had not been subjected to the same conditions as those which were sealed in containers at the mines. It is interesting to observe the decided increase in temperature at which CO_2 was evolved when the coals were heated the second time under the same conditions. This phenomenon is more marked in the younger coals than in those of the higher rank. The crossing temperature of the curves, however, are lowered in case of the younger coals.

Table 4 shows the increase in the two indicated points when the sample was heated the second time.

Table 4

Coal	Carbon dioxide	Crossing point
Lignite	+ 40 ° C.	- 28 ° C.
Wyoming Bituminous	+ 32 ° C.	- 46 ° C.
Illinois Bituminous	- 12 ° C.	- 9 ° C.
Pocahontas	+ 5 ° C.	- 5 ° C.
Anthracite	+	+ 27 ° C.

Apparently the first heat treatment tends to affect materially the reactivity of carbon in the coals of lower rank. No attempt was made to study the mechanism of this action but it is possible that a number of factors might be evolved such as a physical change in structure of the pores and the action of oxygen on the coal at higher temperatures. A marked difference can also be observed in the shape of the heating curves representing the first and second treatments of the same sample of lignite as is shown in figure 3. It can be observed from tables 2 and 3 that this difference is less pronounced in the higher rank coals; anthracite being the least affected by the first heat treatment. As was expected, there is a marked increase in ignition temperatures of coals ranging in rank from lignite to anthracite.

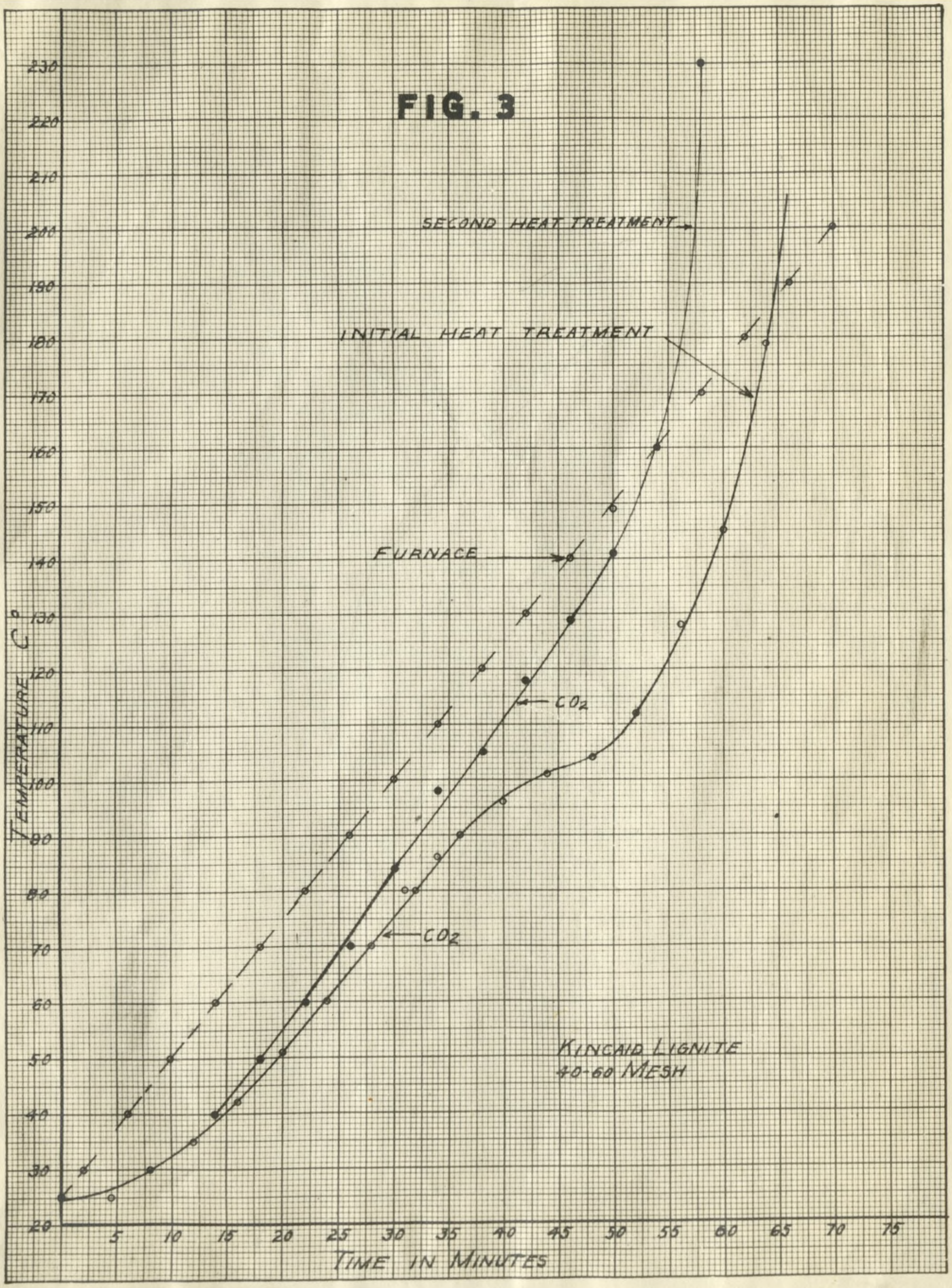


FIG. 3

SECOND HEAT TREATMENT
INITIAL HEAT TREATMENT
FURNACE
CO2
CO2
KINCAID LIGNITE
40-60 MESH
TEMPERATURE C°
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
TIME IN MINUTES

Study of the effect of particle size on ignition temperature.

Since combustion is a surface phenomenon, and for a given mass of coal the surface exposed is a function of the particle size it was deemed desirable to investigate the relation between ignition temperature and size of the coal particles. The Kincaid lignite used in these tests was air-dried two days and after grinding was graded according to size as follows:

20 - 40 mesh
60 - 80 mesh
80 - 100 mesh
100 - 150 mesh
150 - 200 mesh
Through 200 mesh

Samples from each cut were subjected to the treatment described in the general procedure. Oxygen was saturated for use in this series and pyrometers used to indicate temperatures. Results are shown in table 5.

Table 5

Mesh	Ignition temperature Individual	Ignition temperature Average	Crossing temperature Individual	Crossing temperature Average
20 - 40	72 78	75	208 220	215
60 - 80	68 80	74	220 210	215
80 - 100	76 66	71	212 200	206
100 - 150	92 81	86.5	190 200	195
150 - 200	96 77	86	186 191	188.5
through 200	85 80	82.5	184 185	184.5

The results of this series of tests were somewhat disappointing. As indicated in table 5, the ignition temperature of duplicate runs did not check closely enough to warrant the formation of definite conclusions. This was attributed to the practical impossibility of obtaining a representative sample of each separate cut. For example, if the lignite was ground so that all would pass through a 60-mesh sieve, a relatively large percentage would pass through 200-mesh. The results, however, do seem to indicate a higher CO_2 point for the more finely ground portions. This was to be expected from the knowledge that the large amount of surface exposed by the small particles should increase the absorbing power. ? what gas In a group of samples such as those used in this series, where the moisture content may be assumed to be the same, it appears that the

210

I wonder

crossing points of the heating curves may give some indication as to the relative oxidizing tendency of the coals, since for the decrease in particle size there is an accompanying decrease in crossing temperature.

Determination of the effect of moisture content on ignition temperature of lignite.

The effect of moisture was studied by testing a number of samples ranging from 0 to 100% relative vapor pressure. Kincaid lignite "as received" from the car was used. The coal was in frozen condition, which lowered its vapor pressure sufficiently to maintain a moisture content of 33.7% as received at Grand Forks. The lignite was ground to 40-60 mesh in the wet condition; both operations of grinding and screening being carried out rapidly and with small quantities to prevent, as far as possible, moisture loss by evaporation. Portions of the sample were placed in desiccators over solutions of known relative vapor pressure; care being observed that each portion contained sufficient moisture to exert a higher relative vapor pressure than that of the solution over which it was placed in order to assure dehydration of the coal rather than hydration. This precaution was deemed necessary as a result of an investigation on the vapor pressure of lignite by Gauger and Lavine[10] who found that the dehydration of lignite is not reversible. The solutions used and their relative vapor pressure[11] are given in table 6.

Table 6.

Saturated Solutions Used to Maintain Constant Humidities at 20° C.

Solution	Relative Vapor Pressure %
H_2O	100
$ZnSO_4 \cdot 7H_2O$	90
K.Br.	84
NH_4Cl	79.2
$NaNO_2$	66
$NaH\ SO_4 \cdot H_2O$	52
H_2SO_4 (Sp. G. 1.42)	32
$KC_2H_3O_2$	20
H_2SO_4 (Sp. G. 1.56)	10 (25° C.)
H_2SO_4 (Sp. G. 1.84)	0

The lignite was desiccated over these solutions for a period of 21 days at which time it was assumed that the vapor pressure of the coal had reached equilibrium with that of the solutions. The grams of water per gram of dry lignite was determined from the known relative vapor pressure by use of data collected by Gauger and Lavine[12]. This set of tests was made in a manner similar to that described before but with a slight modification in the apparatus. Before entering the combustion tube oxygen was circulated through wash bottles containing the solution over which the sample to be tested had been desiccated. This modification was made to prevent moisture loss from the coal at lower temperature. All temperature measurements for this series were made by use of thermometers. The results as tabulated in table 7 show a slight tendency toward decrease in ignition temperature with decreasing moisture content although the rule is not followed rigidly. In this series very little significance can be applied to the crossing points of the heating curves, particularly those representing samples of high moisture content. It seems reasonable to assume there are few spots of local heating in the coal up to the time of evolution of carbon dioxide and hence a thermometer in any portion of the coal should indicate the approximate temperature of the mass, but it was established that this does not hold during the stages of more rapid heating. In the vicinity of 200° C. there was found to be a variation of approximately 30° C., ranging from top surface to bottom of the coal column. Hence the crossing temperature of the curves can not be used even as a means of comparison when the coals in question are at a different moisture content. There is a material shrinkage in volume with loss of moisture from the coal and since the decrease in volume is a function of the amount of moisture lost it can be seen that it would be impossible to arrange the thermometer at the proper depth so that it would in every case be the same distance from the top of the coal surface after contraction of the volume had occurred with loss of moisture in the vicinity of 100° C. With dry lignite, however, only a slight decrease in volume was observed as a result of heating to 200°. The effect of various moisture contents on the shape of the heating curves of lignite

Table 7

Relative Vapor Pressure %	Grams Water per grams dry lignite	Ignition temperature Individual	Ignition temperature Average	Crossing Temperature Individual	Crossing Temperature Average
100	45	(85 (86	85.5	(235 (222	228.5
90	33.5	(80 (81	80.5	(225 (228	226.5
84	29.5	(76 (81 (79	78.7	(227 (231 (234	230.7
79.2	26	(84 (84	84	(235 (242	238.5
66	22.5	(78 (78	78	(224 (216	220
58	18.3	(76 (74 (77	75.3	(216 (215 (218	216.3
45	16	(78 (74	76	(219 (212	215.5
32	12.1	(72 (72	72	(206 (208	207
20	8.6	(73 (74	73.5	(198 (197	197.5
10	7	(68 (64	66	(190 (190	190
0	0	(67 (67	67	(105 (103	104

is shown graphically in figures 4, 5, and 6.

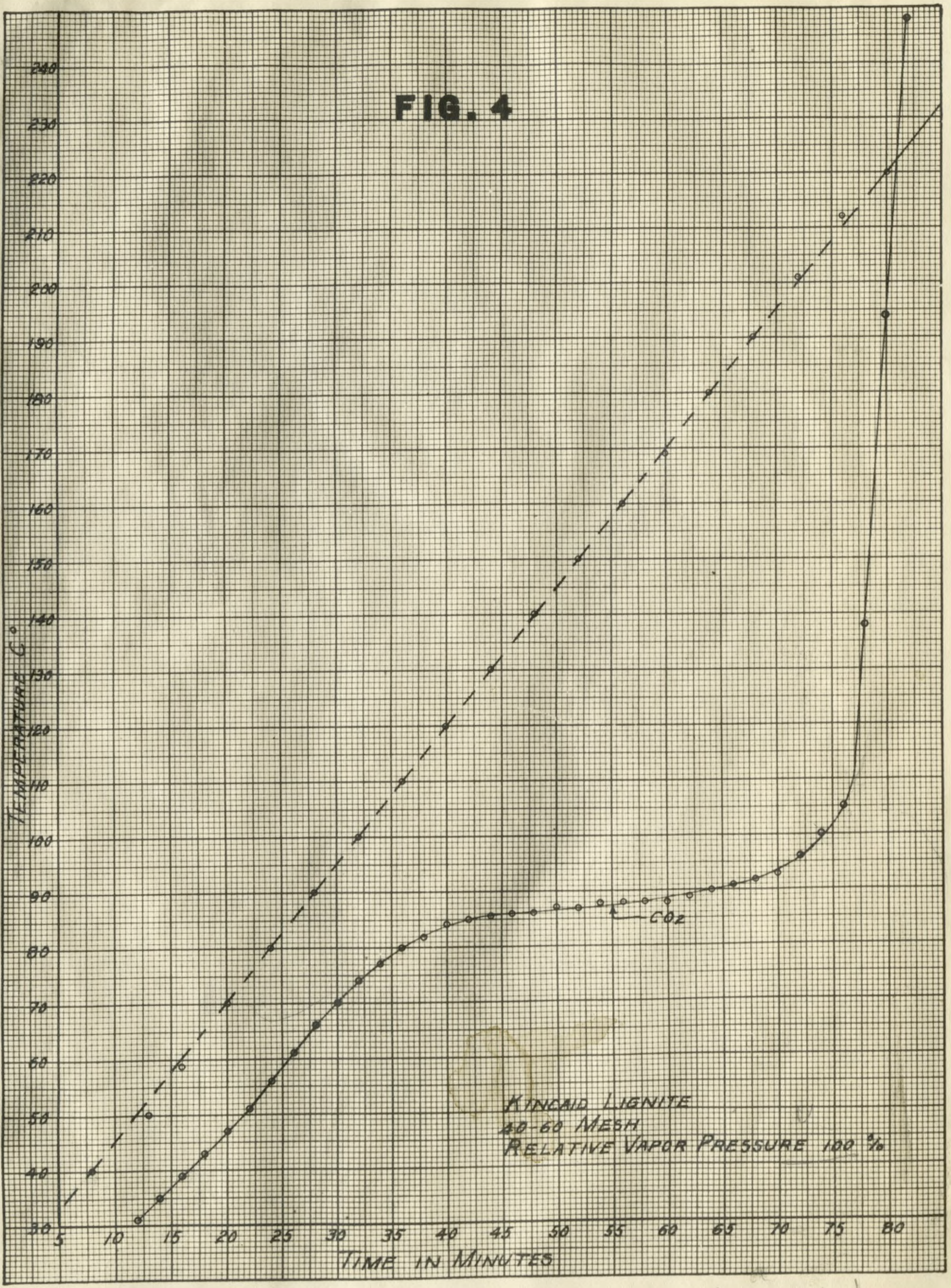
In connection with this series of tests a comparison was made of the heating curves using wet and dry oxygen. Results are tabulated in table 8 below.

Table 8

	Ignition point	Crossing temperature
Dry Oxygen		
Dry coal	67	104
Wet coal	89	218
Saturated Oxygen		
Dry coal	70	111
Wet coal	85.5	228.5

An inspection of table 8 shows very little difference in the rate at which wet and dry oxygen react with coal and also that oxygen saturated at room temperature does not carry enough moisture to greatly effect the shape of the heating curves.

FIG. 4



where we set up

FIG. 5

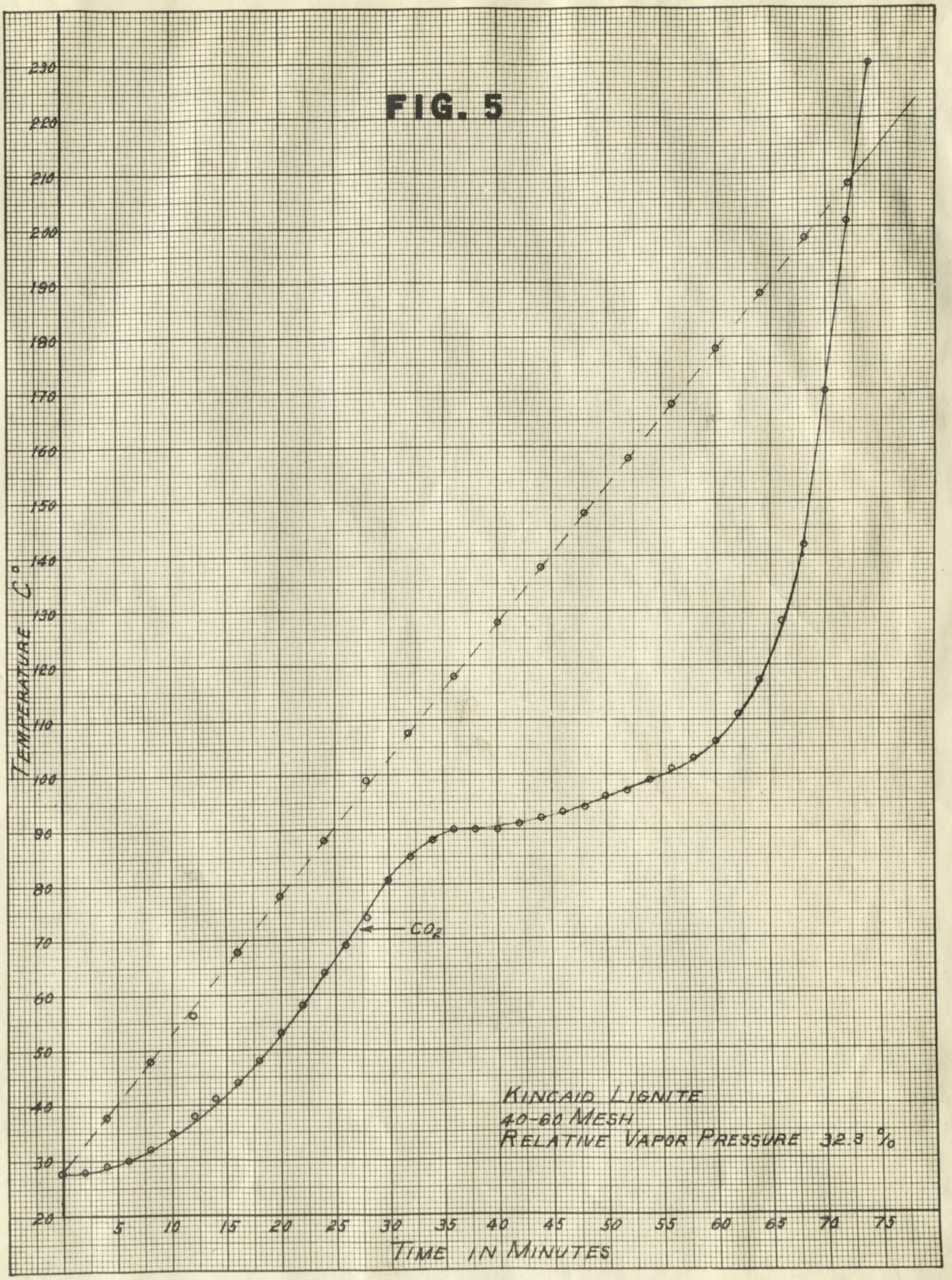
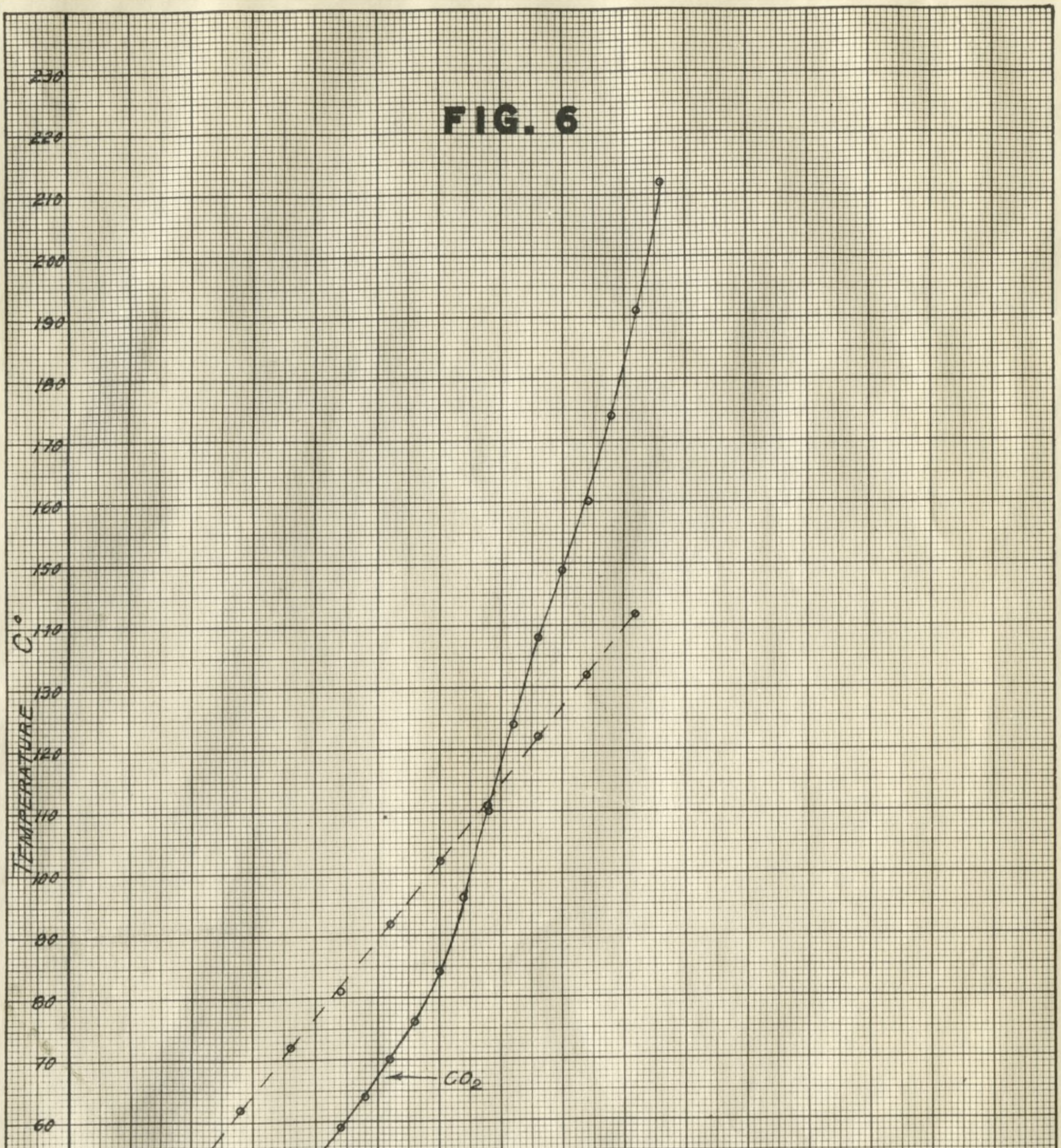

230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
TEMPERATURE C°
CO_2
KINCAID LIGNITE
40-60 MESH
RELATIVE VAPOR PRESSURE 32.8 %
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
TIME IN MINUTES

FIG. 6


230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
TEMPERATURE C°
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
TIME IN MINUTES
CO₂
KINCADE LIGNITE
40-60 MESH
RELATIVE VAPOR PRESSURE 0 %

Relative comparison of the tendency of coals to oxidize at various temperatures.

To investigate the relative tendency of a coal to oxidize at various temperatures a few experiments were conducted in a manner which differed somewhat from the general procedure adopted in all the previous work of this investigation, in that the temperature of the furnace was kept constant and the use of the coal temperature above that of the furnace was observed, both dry coal and dry oxygen being used. Various temperatures maintained by the furnace were 70°, 80° and 90° C. all of which are above the CO_2 point of dry lignite. The results shown graphically in figure 7 indicate that under the special conditions of radiation between coal and furnace, the critical oxidation temperature of dry lignite lies between 80° and 90° centigrade.

At this point in the investigation the action of air compared with that of oxygen on lignite was also studied. Results show no marked difference in the points of evolution of CO_2 from coal when heated in air or oxygen. As should be expected, the rate of self-heating of the coal was more rapid in oxygen than in air. In connection with this series of tests the effect of heating lignite in an atmosphere of nitrogen was also studied. Using dry nitrogen and dry lignite CO_2 was evolved at temperature of approximately 105° C.

Figure 8 indicates that the appearance of CO_2 was accompanied by an endothermic reaction which was in evidence until a temperature of 165° C. was attained. These results are not in accordance with those obtained by Hollings and Cobb[13] who heated bituminous coal in an atmosphere of nitrogen and observed marked exothermic reactions between the temperatures 150° and 250° C. No such reaction can be observed in the heating curves of lignite. There is a slight change in slope of the heating curve shown in figure 8, but this was attributed to the increased temperature gradient between furnace and coal as a result of the endothermic reaction between the temperatures 110° and 165° C.

Effect of ageing on ignition temperature of lignite.

Throughout a period of eight weeks a series of tests were made on a sample of lignite to study the effect of ageing on ignition temperature. The sample was collected, ground to 40-60 mesh and screened in the wet condition. It was first run "as received", then exposed to air in the laboratory and tested at different intervals throughout the following eight weeks by heating in an atmosphere of saturated oxygen as described in the general procedure. The results shown in table 9 indicate a high CO_2 point for the wet coal. With loss of moisture the CO_2 point is at first correspondingly decreased then tends to be raised again by the subsequent ageing. Figures 9 and 10 are plotted from data taken in tests on the coal at two stages of the ageing process. The shape of the heating curve was not noticeably effected after the second day of ageing. Figure 10 clearly indicates the presence of an exothermic reaction between the point of evolution of CO_2 and the flat portion of the curve resulting from vaporization of the water. This was characteristic of all the heating curves of

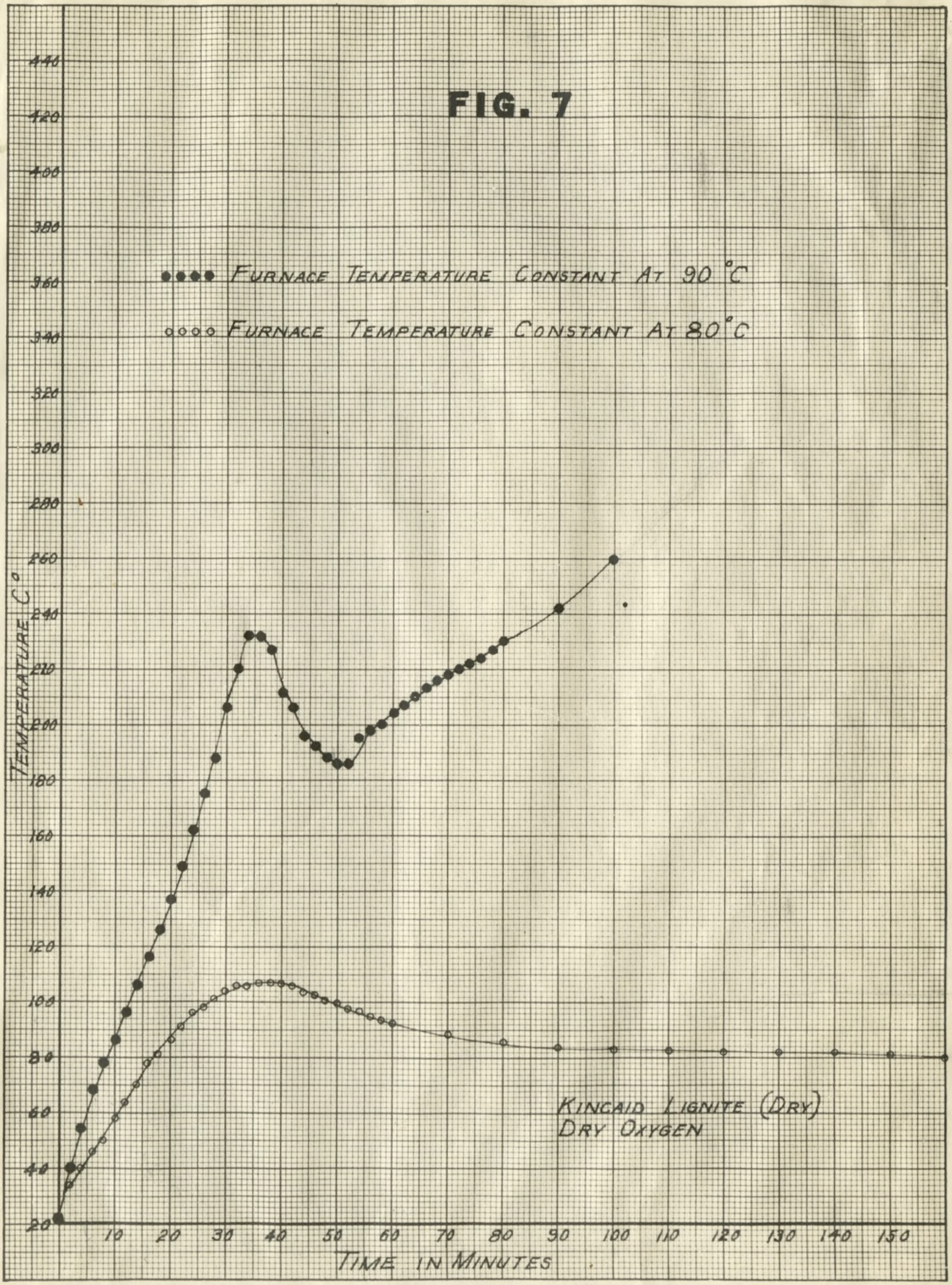
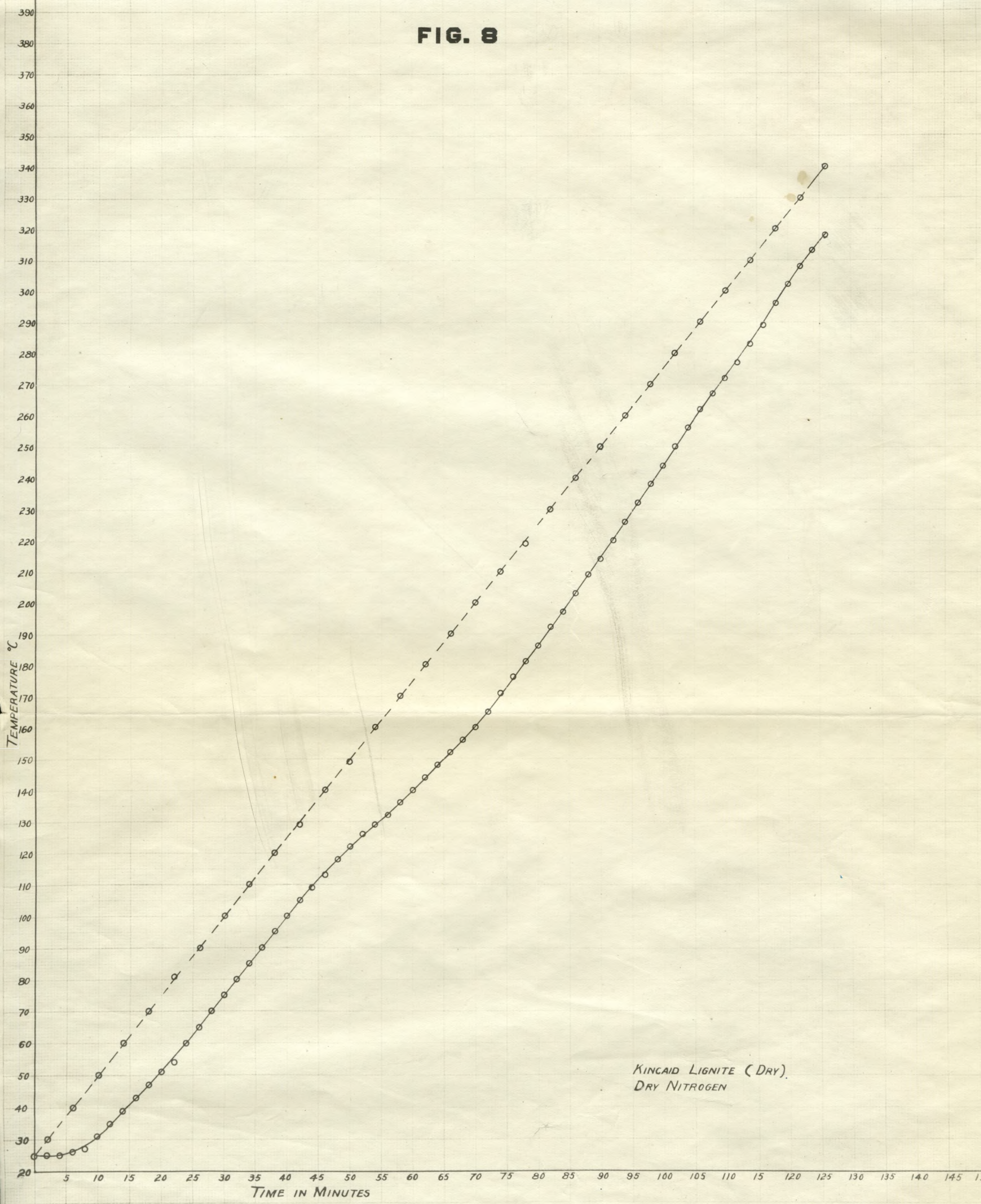


FIG. 7

●●●● FURNACE TEMPERATURE CONSTANT AT 90 °C
○○○○ FURNACE TEMPERATURE CONSTANT AT 80 °C
KINCAID LIGNITE (DRY)
DRY OXYGEN
TEMPERATURE C°
440
420
400
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
TIME IN MINUTES

FIG. 8



Temperature °C
390
380
370
360
350
340
330
320
310
300
290
280
270
260
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
15
120
125
130
135
140
145
Time in Minutes
Kincaid Lignite (Dry)
Dry Nitrogen

FIG. 9

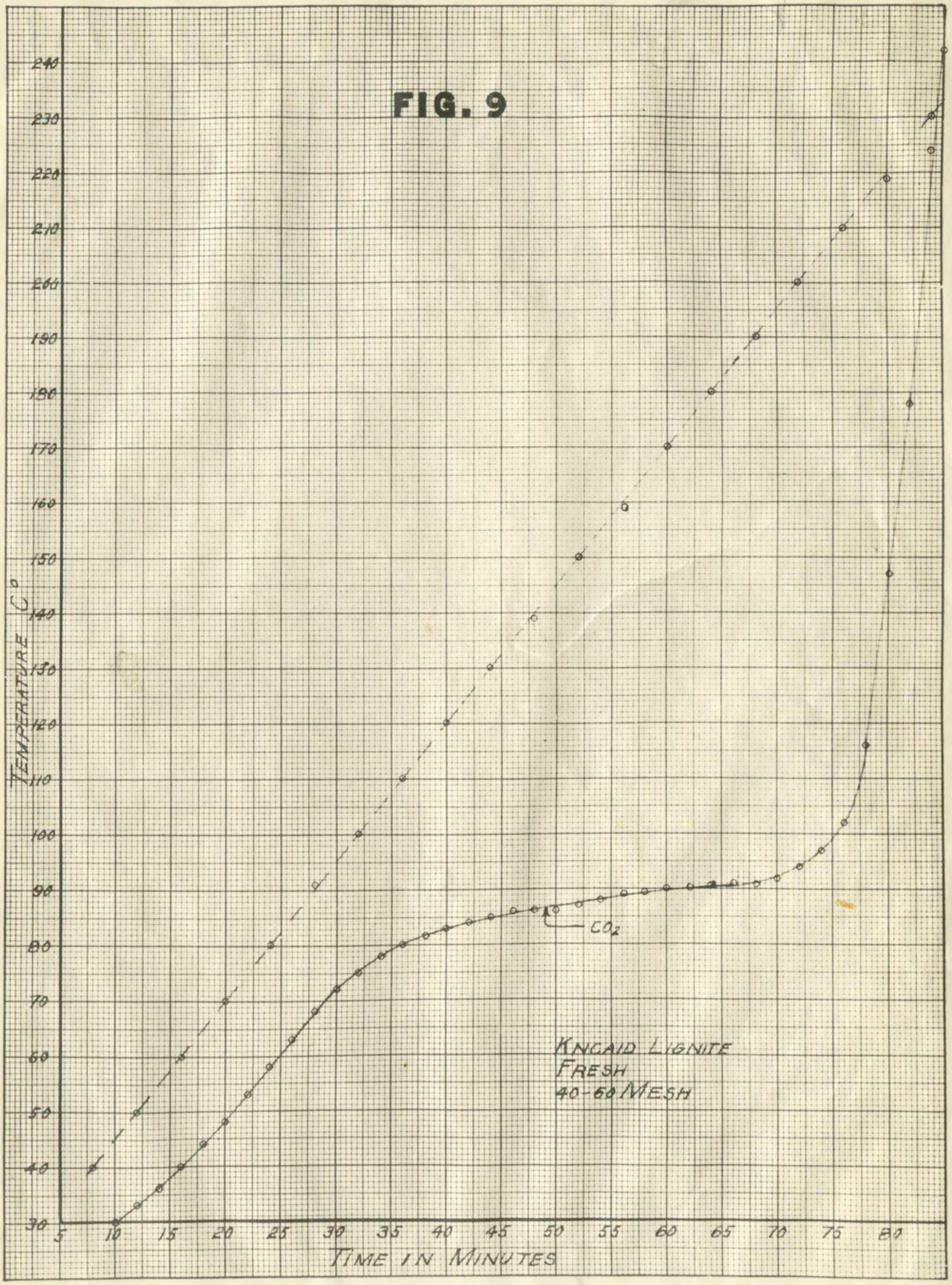
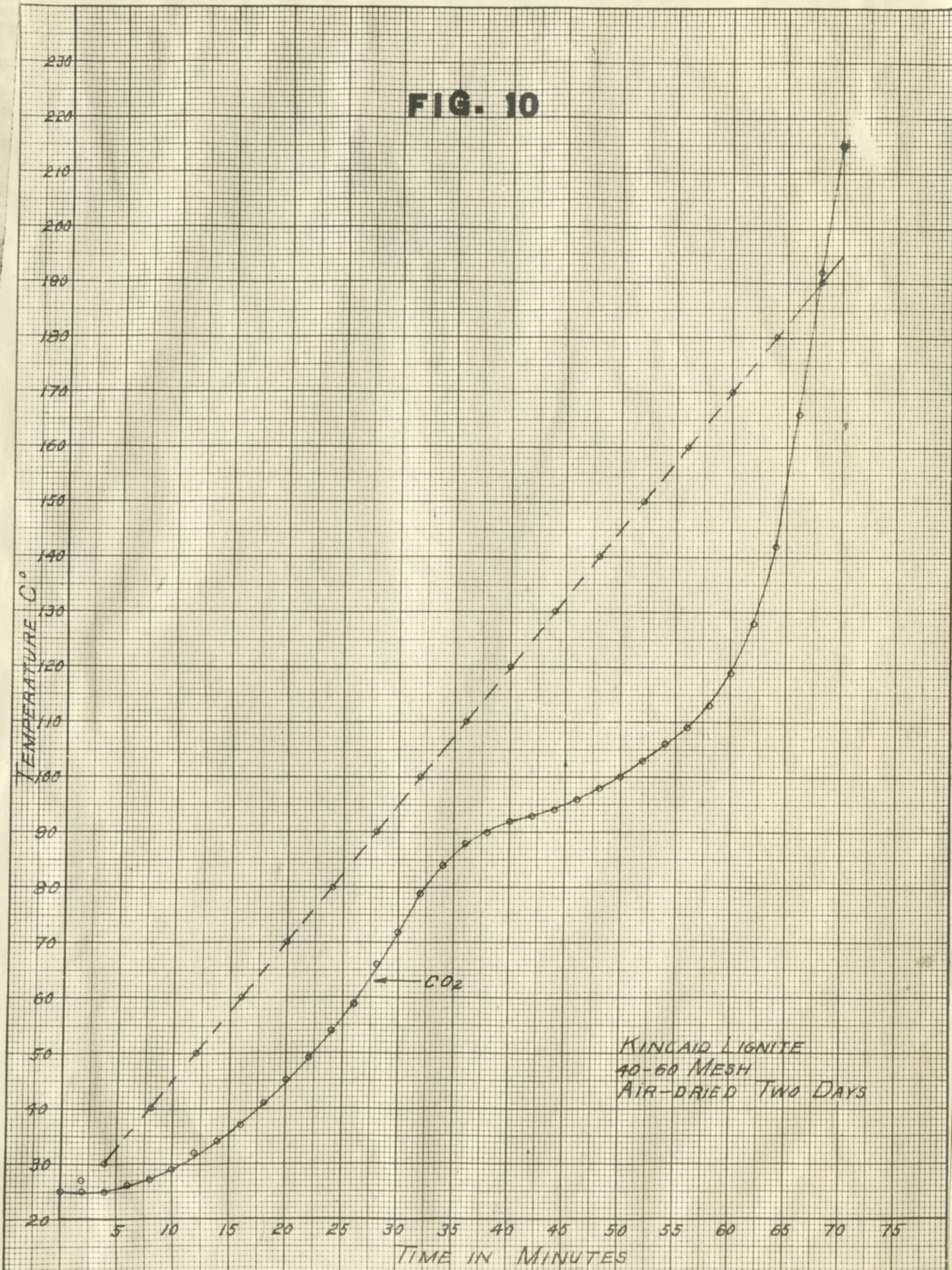

240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
TEMPERATURE C°
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
TIME IN MINUTES
CO_2
KNCAID LIGNITE
FRESH
40-60 MESH

FIG. 10


230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
TEMPERATURE C°
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
TIME IN MINUTES
CO_2
KINCAID LIGNITE
40-60 MESH
AIR-DRIED TWO DAYS

lignites in which CO_2 appeared before the greater portion of moisture was vaporized and it is, therefore, attributed to ordinary combustion since it was not observed in cases where the CO_2 point was at a relatively high temperature.

Table 9

The effect of ageing on ignition temperature of lignite.

Time of Ageing Days	Ignition Temperature	Crossing Temperature
As received	87	232
1	61	197
2	63	190
4	64	193
7	65	188
14	73	184
56	76	187

Conclusions

1. There is no definite point on the heating curves of lignite which marks the transition from slow to rapid stage of self heating.
2. The point of evolution of carbon dioxide suggests itself as the most logical point to choose as ignition temperature since it can be duplicated with a fair degree of accuracy and marks the beginning of the first stage of combustion that occurs above atmospheric temperature.
3. There appears to be no material difference in the ignition temperatures of lignite taken from different localities in North Dakota.
4. Within the range of 20 to 200 mesh there is a general tendency toward raising of the CO_2 point with decrease in particle size.
5. There is a gradual increase in ignition temperature of coals ranging in rank from lignite to anthracite.
6. Ignition temperature of lignite is raised with increase in moisture content.
7. Ignition temperature of lignite is decidedly effected by exposure of the coal to air after mining.

References

[1] Arms, R. W., The Ignition Temperature of Coal, University Illinois Engineering Experiment Station Bulletin 128, 1922 pp 1.

[2] Parr and Kressmann, The Spontaneous Combustion of Coal, University Illinois Engineering Experiment Station Bulletin 46, 1910, pp. 50.

[3] Wheeler, R. V., The Oxidation and Ignition of Coal, Trans. Chem. Soc. 113 (1918) pp. 945-955.

[4] Arms, R. W., The Ignition Temperature of Coal, University Illinois Engineering Experiment Station Bulletin 128.

[5] Parr and Coons, Carbon Dioxide as an Index to the Critical Oxidation Temperature for Coal in Storage, Journal Ind. and Eng. Chem. 17 (1925) pp. 118.

[6] Haslam and Russell, Fuels and Their Combustion, pp 176.

[7] Rosine, P., The Spontaneous Combustion of Semi-Coke from Brown Coal: Its causes and prevention. Fuel in Science and Practice, Volume VIII, No. 2 (1929) pp. 66.

[8] Haslam and Russell, Fuels and Their Combustion, pp. 66.

[9] Taylor, G. B. and Taylor, H. S., Automatic Volumetric Analysis Carbon Monoxide Recorder, Jour. Ind. and Eng. Chem. 14 (1922) pp. 1008.

[10] Gauger, A. W. and Lavine, Irvin, Unpublished Research.

[11] International Critical Tables. Vol. 1, pp. 67

[12] Gauger, A. W., and Lavine, Irvin, Unpublished Research.

[13] Hollings and Cobb, Thermal Phenomena in Carbonization, J. Gas Lighting 126 (1914) pp. 917.

Acknowledgement.

The writer wishes to acknowledge his indebtedness to Dr. A. W. Gauger, for his great assistance and direction in this work.

FURTHER STUDIES IN THE CARBONIZATION OF NORTH DAKOTA LIGNITE.

1. The Gaseous Products of Low Temperature Carbonization of Lignite.
2. The Effect of Aluminum Chloride Hydrate and Pitch on the High Temperature Carbonization of Pre-Carbonized Lignite.
3. The Effect of Blending with Bituminous Coals on the High Temperature Carbonization of Lignite.

by

James Roscoe Taylor

(B. S. in Chemical Engineering, University of North Dakota, 1929).

A thesis submitted to the faculty of the College of Engineering of the University of North Dakota in partial fulfillment of the requirements of the degree of Master of Science in Chemical Engineering.

University of North Dakota

May 29, 1930.