COAL TESTS UNDER STEAM BOILERS

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BY

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THESIS

FOR THE DEGREE OF MECHANICAL ENGINEER

IN THE
GRADUATE SCHOOL
OF THE
UNIVERSITY OF ILLINOIS
PRESENTED JUNE, 1906

K87

UNIVERSITY OF ILLINOIS

June 1, 1906

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

HENRY KREISINGER, B. S.

ENTITLED COAL TESTS UNDER STEAM BOILERS

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE

OF Mechanical Engineer

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120877

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Investigation of Boiler and Furnace.

INTRODUCTION.

This thesis is a collection of the writer's notes, and special observations of the steaming qualities of the coals which were tested under the boilers of the United States Geological Survey Coal Testing Plant, located at the World's Fair Grounds, St. Louis, Mo. It is not intended to be a complete report of the data and results of all the boiler trials, but rather a discussion of the relations between the general conditions of the boiler trials and their economic results. With that object in view, the data and the results themselves which are usually contained in a report were omitted, and instead of these many temperature charts, plotted from special observations, and the discussion thereof has been taken in. The writer thought himself justified in omitting the tables of data and results because these will be published by the Government. Any one interested in the results of any test mentioned in this work, can refer to the Government report by the number of the test.

All the boiler trials were made with the object of testing the value of different coals for steaming purposes. Keeping this object in mind more attention was given to the processes in the furnace than to the operation of the boiler.

In the description of the apparatus used in the boiler trials, more space is given to such details which have any influence on the combustion of the coal. The description and manipulation of such instruments as were used for taking temperature measurements in the different parts of the furnace, furnace gas samplers and analyzers, are given much more thoroughly than the description and manipulation of instruments used for other purposes.

DESCRIPTION OF UNITED STATES GEOLOGICAL SURVEY STEAM PLANT
AND APPARATUS USED IN BOILER TRIALS.

THE STEAM PLANT.

The steam plant was located in the middle of the United States Geological Survey property. It was housed in a building of 54 ft. by 94 ft. floor space. Of this, 42 ft. 9 in. by 54 ft. was taken up by the boiler room, and 51 ft. 3 in. by 54 ft. by the engine room. The building itself was a skeleton frame work of wood, covered with corrugated sheet-iron. Along the east wall of the boiler room were built three small rooms which were used by the boiler division for a chemical laboratory, a locker room and an instrument room. The floor space of these rooms was 11 ft. by 11 ft., 10 ft. by 11 ft. and 9 ft. by 11 ft. respectively. A portion of the instrument room, 4 ft. by 6 ft., was enclosed by a light tight partition and used as a dark room. There was a stone pier with a top surface, 2 ft. by 3 ft. built in the dark room. On the north side of the boiler room were four coal bins, each having a capacity of 25 tons of soft coal. The bottoms of these bins were at an angle of 45 degrees so that the coal rolled out of them by gravity, the chutes being high enough that an iron cart used in tests could be brought under and filled. Pl. 1, shows the outline of the steam plant.

The equipment of the boiler room consisted of two Heine Safety Boilers, of 210 H. P. each, one 100 H.P. Frost fire-tube boiler, one Smith Vaile steam feed-pump, one Stilwell feed-water heater, and two Penberthy injectors. The feed-pump and the feed-water heater were loaned to the United States Geological Survey by the Platt Iron Works Company, of Dayton, Ohio. The injectors were used to feed the two Heine boilers on which the boiler trials were made. The steam pump and the feed-water heater were used only for the Frost fire-tube boiler which furnished steam for several exhibits in the Mining Gulch, and was not used in the boiler trials. The Frost boiler was removed in December, 1905. An Allis-Chalmers Corliss engine belted to a 200 K. W. Bullock generator was placed in the engine room. The location of the above equipment is shown in Pl. 1.

The steam generated in either of the Heine boilers was piped into a common header from which it was taken to the two briquetting plants, the coal washery, the gas producer, or was used by the Corliss engine which drove the Bullock generator. The current from the generator was used to run several motors in the various plants, and for such lights as were necessary in the various departments of the Coal Testing Plant.

It was desirable during a boiler trial to keep as steady a load on the boiler as possible. For this purpose a water rheostat was used to regulate the load on the generator, and consequently the load on the boiler. The rheostat was located outside the engine room, behind the switchboard as shown in Pl. 1. This arrangement was used only during the year 1904.

When more steam was generated than could be consumed in the plant, it was let out into the atmosphere, for which purpose the header was provided with a special blow-off pipe. The escape of steam from this blow-off was regulated by a throttling valve which could be operated by means of two sprocket wheels and a chain from the floor in front of the boiler.

BOILERS.

The two boilers used in boiler trials were Heine standard horizontal water-tube boilers. They were loaned to the United States Geological

Survey by the Heine Safety Boiler Co. of St. Louis. The boilers were exactly alike in respect to construction, size, setting, and piping, so that the description of one applies also to the other.

The construction of the boiler is partly shown in Pl. 2. The boiler consisted of a steam drum to each end of which were riveted large headers, properly stayed with hollow stays. Into the inner side of the headers were expanded eleven horizontal rows of water-tubes. The tubes were parallel to the drum. The outer sides of the headers were provided with hand-holes for cleaning the boiler, or replacing defective tubes. These hand-holes were stopped by caps which were fitted with rubber gaskets, and placed against the holes from the inside of the header. The holes in the stays were large enough for the passage of a 3/8 in. pipe, used for blowing the soot off the water tubes.

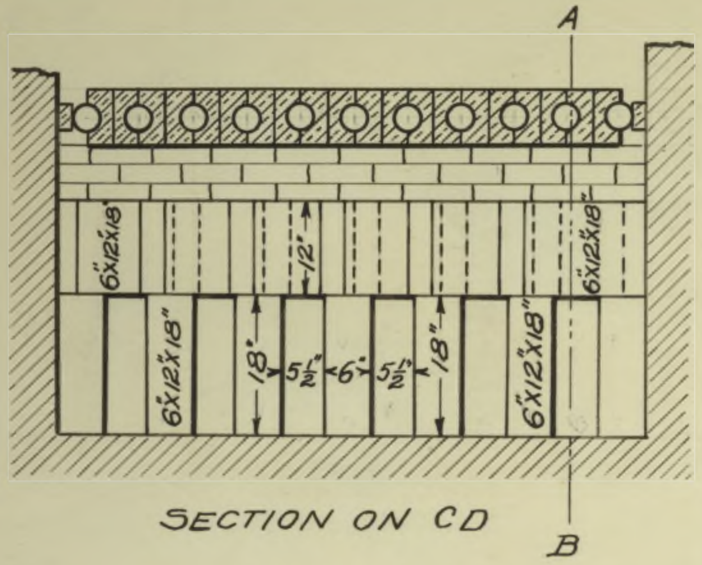
Inside of the drum was a 10 in. mud-drum suspended about 4 in. above the lower shell and extending about two-thirds of the entire length of the steam drum. Feed-water was introduced into the higher end of the mud-drum, and to its lower end a blow-off pipe was connected to remove the sediment. The steam was taken out at the front end of the steam drum, where a deflection plate was bolted to the shell to prevent water from being carried by violent ebullition into the outlet. A perforated box of steel plate was placed over the outlet, tending to further separate the moisture from the steam.

Both boilers were set up at first with plain grates for hand firing. In May 1905, boiler No. 2, was equipped with a McClave rocking grate. Each boiler was provided with a separate stack. The boilers had an inclination of one in twelve with the horizontal, the front end being the higher.

Pl. 2, shows the details of the setting. The side walls were 20 in. thick up to the top row of the water-tubes, and had an air space of 2 in. in the middle. Above that, the walls were 13 in. thick and solid. The part of the steam drum projecting above the boiler setting was covered with a layer of common brick. The boiler was provided with the usual full front setting with large sheet-iron doors to allow easy access to tubes, three fire doors and three ash doors. The rear of the boiler was left uncovered. One course of fire brick lined the inside of the boiler setting and was also laid over the steam drum at the top of the rear end where the hot gases entered the hood. The black dots marked B in Pl. 2 are bolts extending through the whole length of the wall, preventing it from cracking. Two inch pipes provided with removable caps were bricked in both side walls of each boiler, in place indicated by letters B, C, D, E, and F in Pl. 2. These pipes extended from the outside of the walls into the various chambers enclosed by the setting, and were used for measuring draft or temperature in any of the chambers. A rectangular hole extending into the furnace was made in each side wall as shown in Pl. 2. Through these holes the temperature of the fuel bed was measured, and also gas samples were collected. In Pl. 2, in the longitudinal section, the spaces at C and D, left open for the passage of the gases, were during the first eighteen trials 42 and 30 in. respectively. After that C was reduced to 30 and D to 18 in. This change was made to lower the temperature of escaping gases.

COMBUSTION CHAMBER BAFFLING WALL.

There was a baffling wall in the combustion chamber built of special fire brick. The object of this wall was to divert the gases from their straight course in order to better mix the free oxygen with the unburnt vola-



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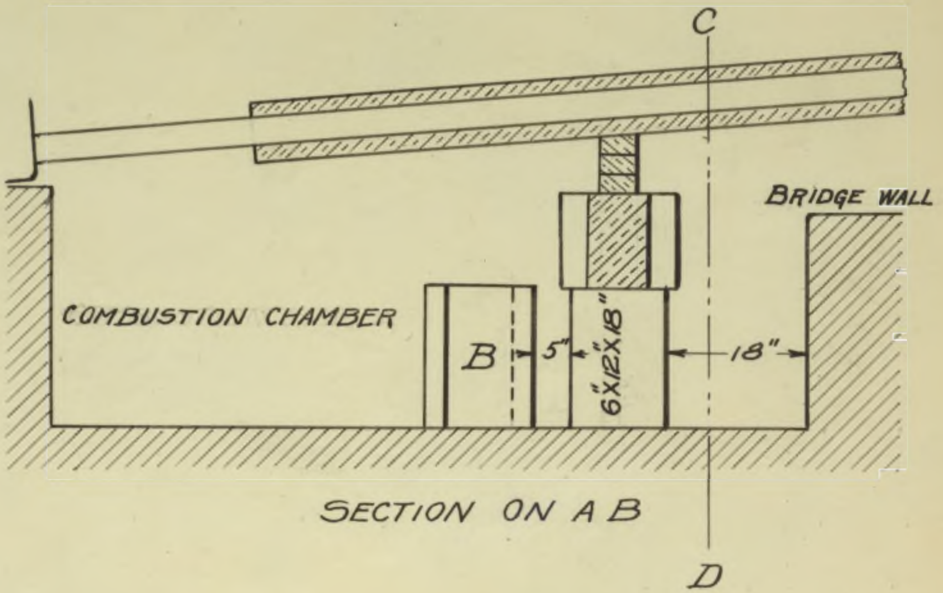

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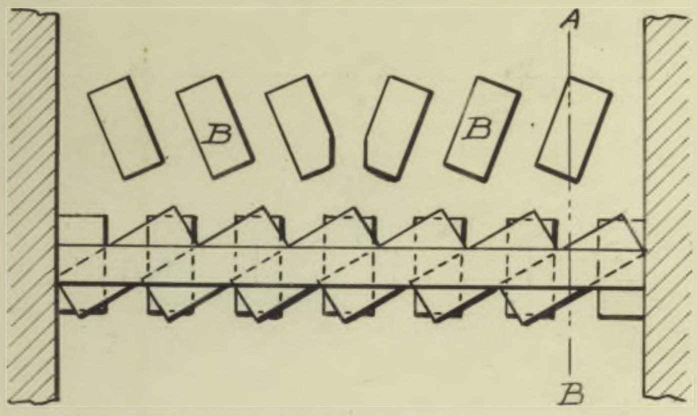


TOP VIEW

FIG. 1.

COMBUSTION CHAMBER
BAFFLING WALL

tile matter of coal. It was also to act as a regenerator, absorbing heat when the temperature of the gases was high, and giving it out when the temperature was low, thus tending to keep the temperature of the distilled unburnt gases above their ignition temperature. This combustion chamber baffling wall was put up in connection with the Hughes Automatic Smoke Preventer, with which each boiler was equipped. However the wall did not last long, melting down after about ten tests had been made on each boiler, and was not put up until May, 1905.

During April and May, 1905, several attempts were made to build a baffling wall out of ordinary fire brick. All these attempts failed, the baffles melting down after two or three days run. It was concluded that only large blocks made of the best material could for any length of time withstand the high temperature and the slagging action of the gases. A baffling wall, as shown in Fig. 1, was then built of large fire brick, 18 in. by 12 in. by 6 in., said to be made of the best material that could be obtained. This wall was built in three sections. The bottom consisted of seven blocks set up with their greatest dimension vertical, forming pillars for an arch of six similar blocks laid diagonally across. The space between the arch and the tiled roof was filled with small bricks of good material, so that the space between the pillars was the only passage left for the gases. The intention was to bounce the one stream of gases against the upper solid portion of the baffle, and break it into many small streams thus bringing the unburnt volatile matter and free oxygen together. It is probable that eddies caused by the obstacle in the path of the gases greatly aid the mixing. The blocks B (Fig. 1), were set in front of the opening in the baffle, to further mix the gases. A baffling wall of this construction lasted nearly four months.

THE HUGHES AUTOMATIC SMOKE PREVENTER.

The Hughes Automatic Smoke Preventer is shown in Pl. 3. It is an apparatus for automatically introducing an excess of air over the fire for a short interval after firing. While the first fire-door is being opened, a chain is being wound upon the small pulley A, the ratchet R is pulled down, the counterweight B is swung up, and a plunger working in oil in cylinder C is lifted up. At the same time the valve E, which has its stem connected with the pin of B, is opened, and admits steam into the furnace through the jets at F. When the fire-door is closed, the chain is unwound from A, the counterweight and the plunger slowly descend, closing the dampers D, and the steam valve E. The time during which the dampers D and the steam valve E remain open, can be adjusted to any length by partly opening or closing the valve H, the valve K being kept open continually. By decreasing or increasing the opening of H, the oil which is under the plunger, will flow slower or faster through the tube T above the plunger, thus permitting a slower or faster descension of the plunger. If valve V is shut, the smoke preventer can be operated without using the steam jets. The steam jets were never operated.

THE PIPING.

The piping of the boilers is partly shown in Pl. 4. The main taking the steam from the boiler into the header was a 6 in. pipe 12 ft. long. Of this length the vertical portion above the boiler was 2 ft. 6 in. long and included a 6 in. by 6 in. by 4 in. T. To the stem of the T was connected, by means of a 4 in. L,a 4 in. pop safety valve. The horizontal portion of the main is 7 ft. 6 in. long and terminates in an angle-valve above the header, thus allowing only 10 ft. of the 6 in. main, and the 4 in. L making a connection with the safety valve, all except the L well covered with magnesia covering,to drain back into the boiler. The header was an 8 in. pipe and was drained through a 3/4 inch pipe into a steam trap. From the header a 6 in. pipe led to the Corliss engine.

Each boiler was fed first by a 2-inch Penberthy injector. As the injectors could not be throttled to feed the boilers continually at uniform rate, they were replaced by 1 1/2 in. injectors. The steam connections for the injectors were made to the main of the same boiler the injector was feeding. A 2 in. pipe was used for this purpose. On boiler No. 1 this piping was 33 ft. 6 in. long, and on boiler No. 2, 24 ft. long. The water connections between the injectors and the boilers were also of 2 in. pipe of about the same length as the respective steam piping. A thermometer-cup was inserted in each of the water-pipes about 6 ft. from the boiler. Connections of 2 in. pipe were also made between each feed-water pipe and the steam pump' These connections were used only when the boiler was to be refilled after washing. During a boiler trial this piping leading to the steam pump, was disconnected by taking out a flanged nipple. All steam piping and piping carrying hot water from the injector was covered with magnesia sectional covering. In the back of the boiler, piping was provided for blowing off sediment collected in the mud-drum and on the bottom of the header. The flanged nipple shown in Pl. 4 was to be removed during a boiler trial and the drip, if any, caught and carried back to the feed tank.

During the first few trials some coals were tested which clinkered rather badly. The clinkers fused into the grate and it was difficult to remove them. To remedy this evil a system of piping was put in the ash-pit and steam was blown under the grate.

FORCED DRAFT APPARATUS.

The forced draft apparatus consisted of a 4 in. by 4 in. vertical steam engine directly connected to a 60 in. blower. It was so erected that the blower could discharge the air into the closed ashpit of either boiler. The air conduit was a wooden trough of 20 by 24 in. cross section, and 22 ft. long; it was sunk into the ground, its top being level with the boiler-room floor. The damper opening in the ash-pit was 12 in. by 32 in. In Pl. 1 and 2, the dotted lines show the air conduit and the damper opening in ash-pit. The steam engine and blower was loaned to the Coal Testing Plant by the B. F. Sturtevant Co., of Boston, Mass., and erected in August, 1905.

TABLE OF DIMENSIONS OF BOILER AND SETTING.

Type of boiler,	Heine water-tube, hand fired,
Size,	210 H. P.
Inside diameter of drum,	42 in.
Length of drum out to out of heads,	21 ft. 7 in.
Thickness of shell of drum,	0.47 in.
Thickness of shell of headers,	0.50 in.
Number of tubes,	116
Outside diameter of tubes,	3.5 in.
Internal diameter of tubes,	3.26 in.
Length of tubes exposed,	17 ft. 10 1/2 in.
Cubical capacity of steam drum,	201.8 cu. ft.

Cubical capacity of headers,	37.5 cu. ft.
Cubical capacity of tubes,	120.8 cu. ft.
Total cubical capacity,	360.1 cu. ft.
Water heating surface of drum,	43 sq. ft.
Water heating surface of headers,	91 sq. ft.
Water heating surface of tubes,	1897 sq. ft.
Total heating surface,	2031 sq. ft.
Superheating surface,	None

When water stands in the middle of the gauge-glass, boiler contains, as determined by actual weighing at 60° F.,

17,913 lbs. of water,	287 cu. ft.
Steam space in drum,	73 cu. ft.
Width of furnace,	6.16 ft.
Length of furnace,	6.58 ft.
Mean height of furnace,	26 in.
Kind of grate bars, . . (boiler No. 1)	Plain
Kind of grate bars, . . (boiler No. 2)	Rocking
Grate surface,	40.55 sq. ft.
Dimensions of air spaces, in plain grate,	1/2 in. by 17 1/2 in.
Ratio of area of grate to area of air spaces in plain grate,	40:17
Ratio of area of grate to area of air spaces in rocking grate,	7:3
Diameter of stack,	37.5 in.
Area of stack,	1104 sq. in.
Height of chimney above grate,	113.25 ft.
Length of flues connecting to stack,	None

Ash-pit below grate surface,	25 in.
Area of draft over bridge wall,	888 sq. in.
In April 1905, reduced to,	648 sq. in.
Area of draft in back pass,	1070 sq. in.
Area of draft between tubes,	1612 sq. in.
Area of draft entering upper chamber,	640 sq. in.
Ratio of heating surface to grate surface,	50.1:1
Ratio of smallest draft area to grate,	1:9.1
Length of boiler setting,	19 ft. 4 in.
Width of boiler setting,	9 ft. 6 in.
Height of boiler setting,	11 ft. 10 in.

THE TESTING EQUIPMENT.

The testing equipment used in boiler trials consisted of the following apparatus and instruments:

Two platform scales for weighing coal,
One car for weighing coal,
Two platform scales for weighing water,
Two tanks for measuring water,
Two feed-tanks,
Two separating calorimeters,
One throttling calorimeter,
Two flue gas box samplers,
Six leveling bottles for collection of samples of flue gases,
Two Orsat apparatus for analyzing flue gases,
A set of apparatus for analyzing flue gases for hydrocarbons,
Three water-jacketed flue gas samplers,

One pyrometer for flue gas temperature,

One recording pyrometer for flue gas temperature,

Two pyrometers for furnace temperature,

Two Calendar recording instruments,

Two millivoltmeters,

A set of thermometers for taking outside, boiler room, and feed-water temperature,

One standard steam pressure gauge,

One recording steam pressure gauge,

One gauge tester with set of weights,

Three draft gauges,

One recording draft gauge,

Four sampling cans,

One coal sizing screen.

THE PLATFORM SCALES.

The four platform scales were loaned to the United States Geological Survey by Fairbanks, Morse & Co. of Chicago. The two scales used for weighing coal were of 2000 lbs. capacity. They were sunk in level with the floor of the boiler room, seven ft. in front of each boiler. The two scales used for weighing water were of 1000 lbs. capacity, and were placed upon a wooden platform, four ft. above the floor.

THE COAL WEIGHING CAR.

The coal weighing car was built by Fairbanks, Morse & Co. The size of the sheet-iron box was 4 1/2 ft. by 2 1/2 ft. by 13 in. deep, and could hold 700 lbs. of bituminous coal. The box was so constructed that one of the sides could be swung down level with the bottom, and coal could be conveniently fired from it. The car could be easily wheeled off the scale platform to any part of the boiler room for refilling.

TANKS.

The two measuring tanks were made of galvanized sheet-iron, and their special feature was a conical bottom. This form of bottom permits a quick emptying of the tank. The top of the tank had a shape of an inverted funnel. The cylindrical shell projected high enough over the top to catch the overflow and drain it into a wooden trough provided for it. The capacity of each tank was about 630 lbs. of water.

The feed-tanks were plain cylindrical vessels made of galvanized sheet-iron, and stiffened at the bottom and at the top by angle-iron.

Pl. 4 shows the wooden platform and the arrangement of the feed-tanks and measuring tanks with the over-flow attachment.

CALORIMETERS.

In most of the boiler trials a Schaeffer & Budenberg separating calorimeter was used to determine the moisture of the steam. Pl. 4 shows the calorimeter connected to the steam main. The amount of moisture separated from the steam could be read directly in 0.01 lbs. from a metallic scale attached to the glass tube where the moisture was collected. The pressure gauge of the calorimeter was so graduated that the discharge of steam from the calorimeter in ten minutes could be read directly in pounds for any given pressure. The graduation was tested by actually condensing and weighing the discharged steam, and found to be correct within the limit of the calorimeter. However, when the calorimeter had been in use for a longer time, the gauge, on account of its short connection to the calorimeter, became hot and gave higher pressure and higher discharge reading. This fault was remedied by placing a syphon made of 1/4 in. pipe between the gauge and the calorimeter. The plug-cock closing the glass tube where moisture was collected leaked and was replaced by 1/4 in. globe-valve.

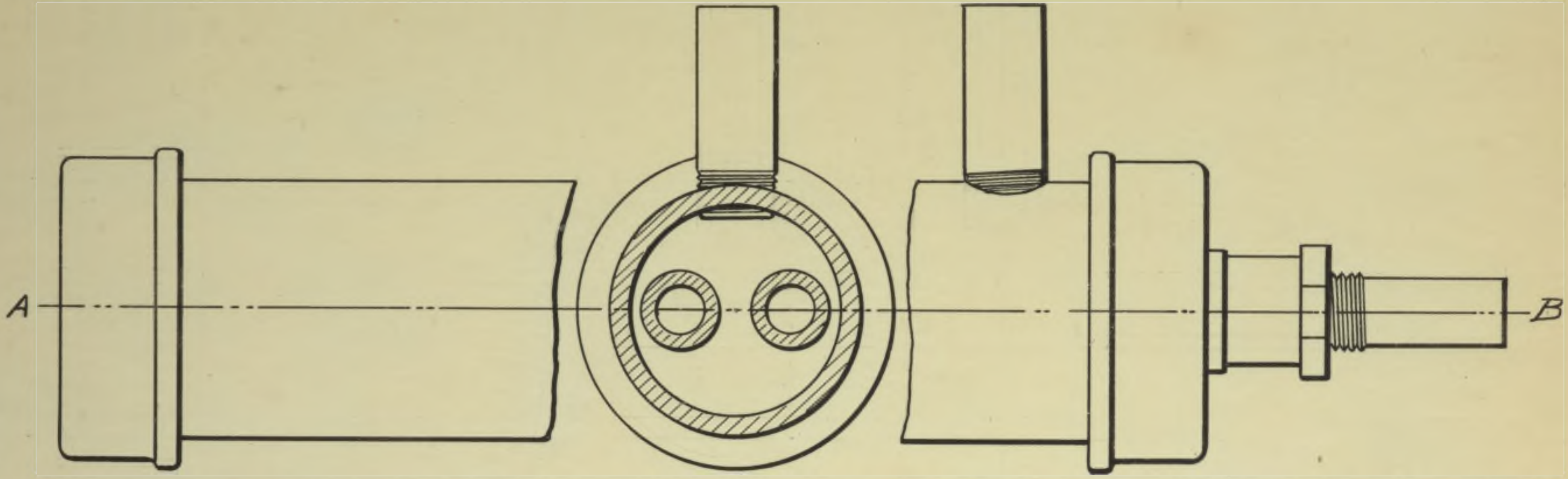
The Schaeffer & Budenberg throttling calorimeter was used only in a few boiler trials.

THE GAS SAMPLERS.

Two devices were employed in sampling the flue gas at the base of the stack,--a sampler box as recommended by the American Society of Mechanical engineers, and a single perforated tube.

Pl. 4 shows the flue gas sampler box with accessories, the collecting tubes of which were inserted in the uptake, one course of brick below the hood, so as to intercept the gases just before entering the stack. The attempt was made to conform as nearly as possible to the recommendations of the code of the American Society of Mechanical Engineers. The aspirator was connected to the small pipe leading from the 3 in. cubical box shown on the bottom side of the sampler box.

The single tube used in sampling flue gas was a 1/2 in. pipe 7 ft. long with 1/16 in. holes drilled 6 in. apart along its entire length. This tube was inserted into the hood as close to the brick walls as it was practicable. The end which was inserted into the hood was plugged, the gas being taken only through the 1/16 in. holes. The other end was connected to the gas collector and aspirator as described farther. By taking simultaneous samples it is possible to gain a correct idea as to the advantage of one device over the other.



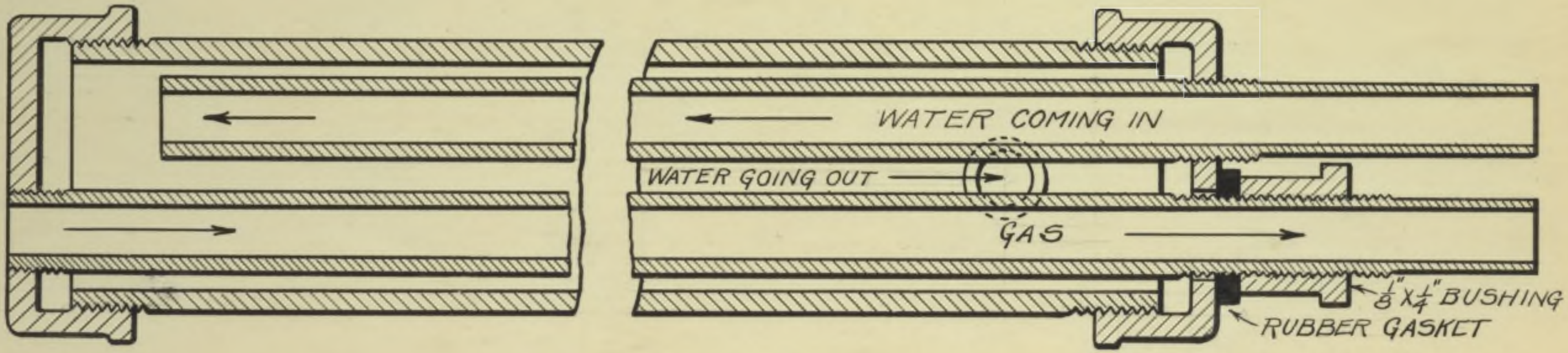


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FIG. 2.
WATER JACKETED FLUE GAS SAMPLER.

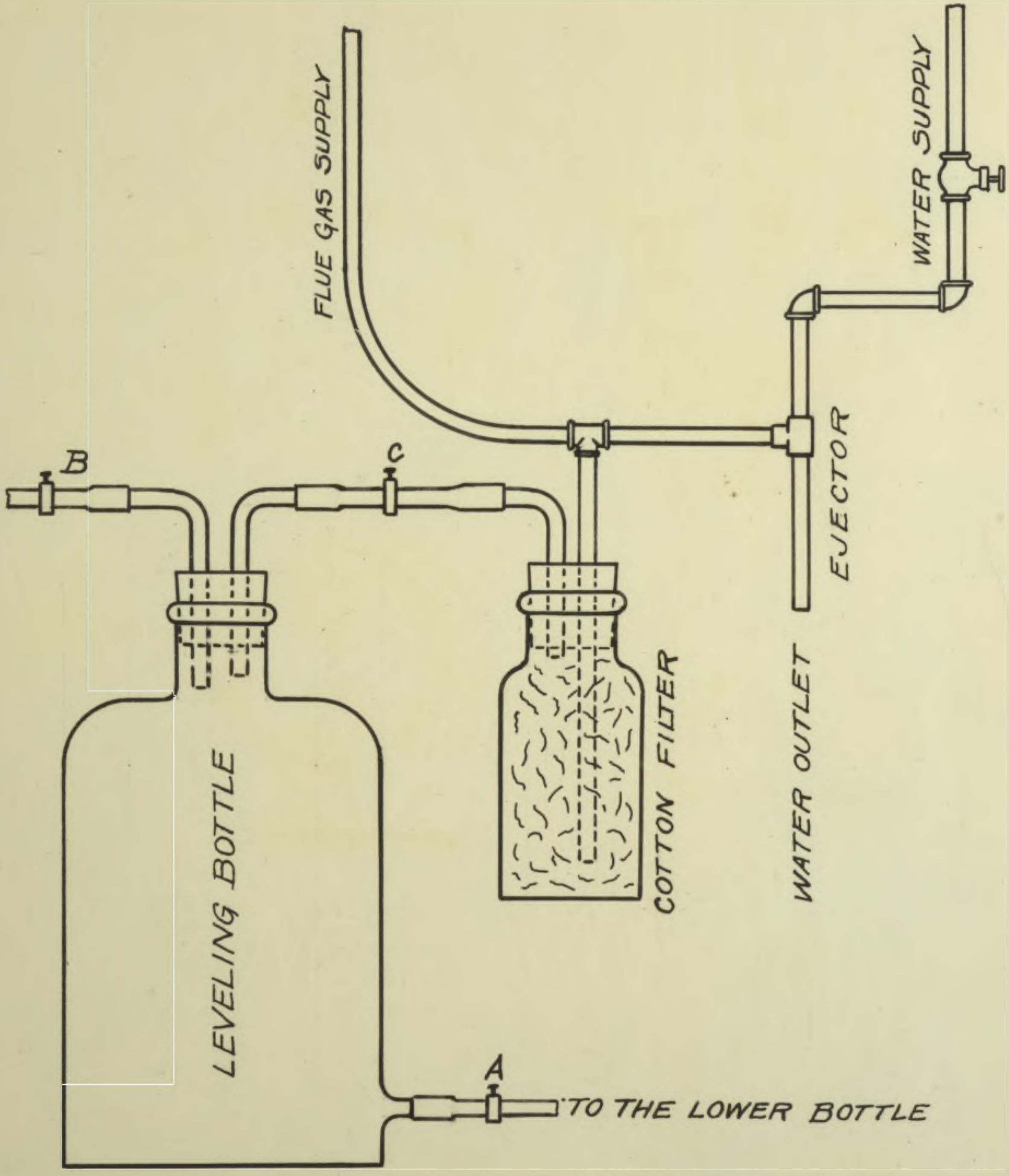

FIG 3.
GAS COLLECTOR

WATER JACKETED GAS SAMPLER.

A water jacketed flue gas sampler constructed as shown in Fig. 2, was used to collect samples of gas from the furnace and the combustion chamber. The sampler was made of 1 1/4 in. pipe closed on the ends by caps as the outside shell, with 1/4 in. pipes for the gas and water inside, and was 3 ft. long.

GAS COLLECTORS.

The gas collectors consisted of two 2-gallon leveling bottles and a filter. One leveling bottle and the filter are shown in Fig. 3. The filter is a small bottle filled with cotton. The flue gas passes through a glass tube to the bottom of the bottle, then as it passes through the cotton it is cleaned of its imporities, and leaves the filter through the tube near the stopper. The two leveling bottles are connected with a flexible rubber tubing attached to the tubular opening A, near the bottom. By first filling the bottle which is connected to the filter with water, then stopping the pinch-cock B, lowering the other bottle and opening pinch-cocks A and C, the flue gas is drawn through the filter into the bottle. The time it takes to fill the bottle with gas can be set to any length by adjusting the pinch-cock A. In the case under consideration this time was set to one hour. The gas is taken into the Orsat apparatus by connecting the latter to B, closing C, and displacing the gas by water from the other leveling bottle. To insure a steady supply of fresh flue gas, a continuous flow was induced by a small water aspirator, which was connected as shown in Fig. 2.

ORSAT APPARATUS.

An ordinary Orsat apparatus was used for analyzing the flue gases.

The measuring tube was graduated into 0.2 c.cm., and 0.1 c. cm. could be easily estimated.

APPARATUS FOR DETERMINING HYDROCARBONS.

The apparatus for analyzing the flue gases for hydrocarbons consisted of one 100 c.c. measuring burette graduated into 0.2 c. c., four pipettes with absorbing solutions, one exploding pipette, an electrical induction coil used to ignite the gases in the exploding pipette, and a battery of three or four cells to run the induction coil. The following is the method of analyzing the flue gases as used in some of the boiler trials:

From a gas sample, collected as previously described, a volume of 100 c. c. is carefully measured off in the measuring burette. This gas is then passed successively into the four pipettes with solutions, each time noting its volume before passing it into the next one. First CO_2 is taken out with KOH solution, and then O with pyrogallic acid. Next the gas is passed into a pipette with fuming sulphuric acid and is allowed to stand five minutes or more; the acid absorbs the illuminates (C_nH_m). After taking the gas from the sulphuric acid pipette, it must be passed again into the KOH solution before noting its volume. This must be done to rid the gas of the sulphuric acid fumes, as otherwise the volume of the gas would read too high. The gas is next passed into Cu_2Cl_2 solution and allowed to stand ten minutes or more until all CO is absorbed. The percentage by volume of each of the above gases taken out is given by the difference of volume before and after passing it through the respective solutions. The CH_4 and H are next to be determined. To one-third of the remaining gas is added 10 c.c. of hydrogen and enough air to make it exactly 100 c. c. This mixture is exploded in the explosion pipette by an electric spark from the induction coil, then taken back into the burette and the exact contraction noted. The explosion induces the following reaction in the mixture:

Between CH_4 and O

$$CH_4 + 4\ O = CO_2 + 2H_2O.$$

Between H and O

$$2H + O = H_2O.$$

The amount of CO_2 formed by the reaction is exactly equal to CH_4, so that by running the gas through KOH solution the percentage of CH_4 in the flue gas is determined. The last term of the first and second equation is water vapor which condenses and causes the contraction. To get the true contraction due to free hydrogen alone, the water formed by the burning of H of CH_4 must be subtracted. The first equation shows that the volume of the water vapor thus formed is equal to twice the volume of CH_4. Since hydrogen forms two-thirds of the water vapor (H_2O), the amount of hydrogen present in the flue gas, plus the amount of hydrogen added is then equal to two-thirds of the total contraction minus twice the amount of CH_4. By subtracting the known amount of added hydrogen, the unknown amount of free hydrogen in the flue gas is obtained. If only one-third of the flue gas left after absorption of CO is used to determine CH_4 and H_2, the results obtained as above must be multiplied by three.

This is a method ordinarily employed for analyzing producer gas, and is accurate enough for that purpose. However, for analyzing flue gases where CH_4 and H_2 occurs only in small traces, this method is questionable. CH_4 and H_2 often occur in a quantity which is out of the limit of accuracy of this method. It often happens that even the added hydrogen is not all exploded so that CH_4 and H_2 in the flue gas remain undetermined. It is desirable that a more accurate and reliable method for analyzing flue gases for hydrocarbons be devised.

FLUE GAS PYROMETERS.

A mercury pyrometer having compressed nitrogen above the mercury column was at first employed for measuring the flue gas temperature. Its range was from 212° F. to 1000° F. In Pl. 4, the pyrometer is shown in the hood where the temperature was measured. This pyrometer was made by Hohmann & Maurer Manufacturing Co., of Rochester, New York.

In July, 1905, the Mercury pyrometer was displaced by a Bristol recording air pyrometer. This instrument had an 8-inch dial, and 12 hour clock movement. Its range was from 100° F. to 800° F. It was from time to time checked with the mercury pyrometer and found to agree with the latter very closely. This recording pyrometer was made by The Bristol Recording Instrument Co.

FURNACE PYROMETERS.

For measuring the furnace and the combustion chamber temperatures a Wanner optical pyrometer and a thermo-electric couple connected either to a millivoltmeter or to a Calendar recording instrument, were used.

WANNER OPTICAL PYROMETER.

Of the two instruments, the Wanner optical pyrometer was the more reliable and much more convenient to use. The working of this instrument is based upon the relation which exists between the temperature of a hot body and the intensity of light which the hot body emits. By measuring the intensity of the light, the temperature can be computed from the law which

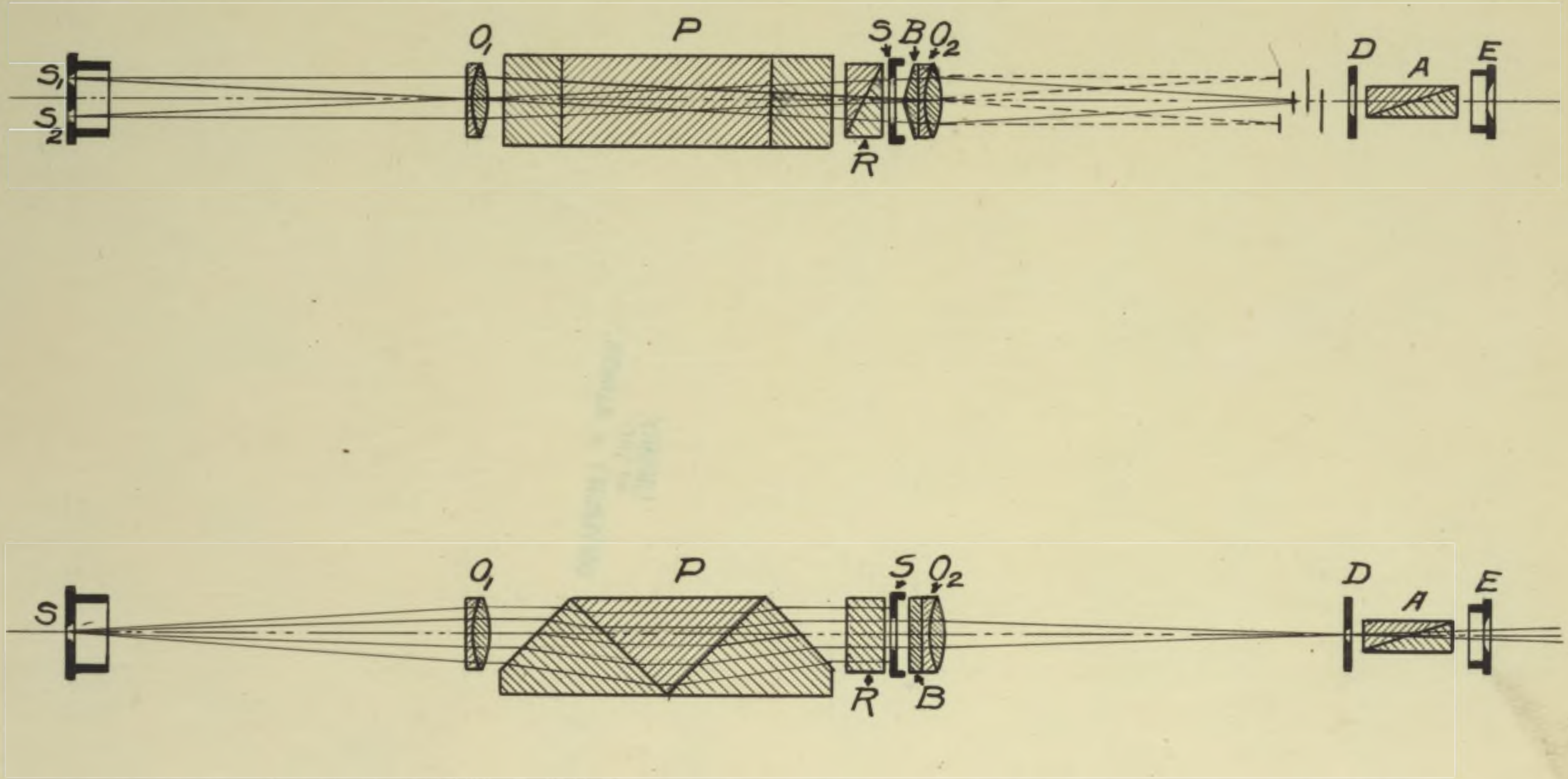

FIG. 4.

THE CONSTRUCTION OF THE OPTICAL. PART OF WANNER'S PYROMETER.

is known to exist.[#] In reality the instrument is a photometer which compares the light emitted by a body whose temperature is to be measured with a light of steady intensity. The comparison light is a 6-volt incandescent lamp, illuminating a glass mat surface. The light from the hot body and the incandescent lamp is passed into the photometric telescope, each of them illuminating one half of the field of the telescope. Monochromatic red light is produced by means of a direct-vision spectroscope and a screen, cutting out all but a narrow band in the red. The photometric comparison is made by adjusting to equal brightness both halves of the telescopic field by means of the polarizing arrangement.

Fig. 4, shows two sections through the axis of the photometer, at right angles to each other. The slit S_1 is illuminated by the light from the incandescent lamp reaching S_1 after diffuse reflection from a right-angled prism placed before S_1. Light from the body whose temperature is to be measured enters the slight S_2. The two beams are rendered parallel by lens O_1 and each is dispersed into a continuous spectrum by the direct vision prism P_1. Each of these beams is next separated by a rochon prism R into two beams polarized in planes at right angles. Considering only the red light there are now four images formed by the lens O_2 and distributed about the slit D. In order to bring two red images oppositely polarized exactly before this slit, a biprism B is interposed whose angle is such as to effect this for two images only. There are now in the field of view before the nicol analyzer A, two contiguous red fields, composed of light polarized

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[#] For the theoretical discussion of optical pyrometry see Bulletin No. 2, Bureau of Standards, United States Department of Commerce and Labor. Article on Optical Pyrometry by C. W. Wardner and G.K. Burgess.

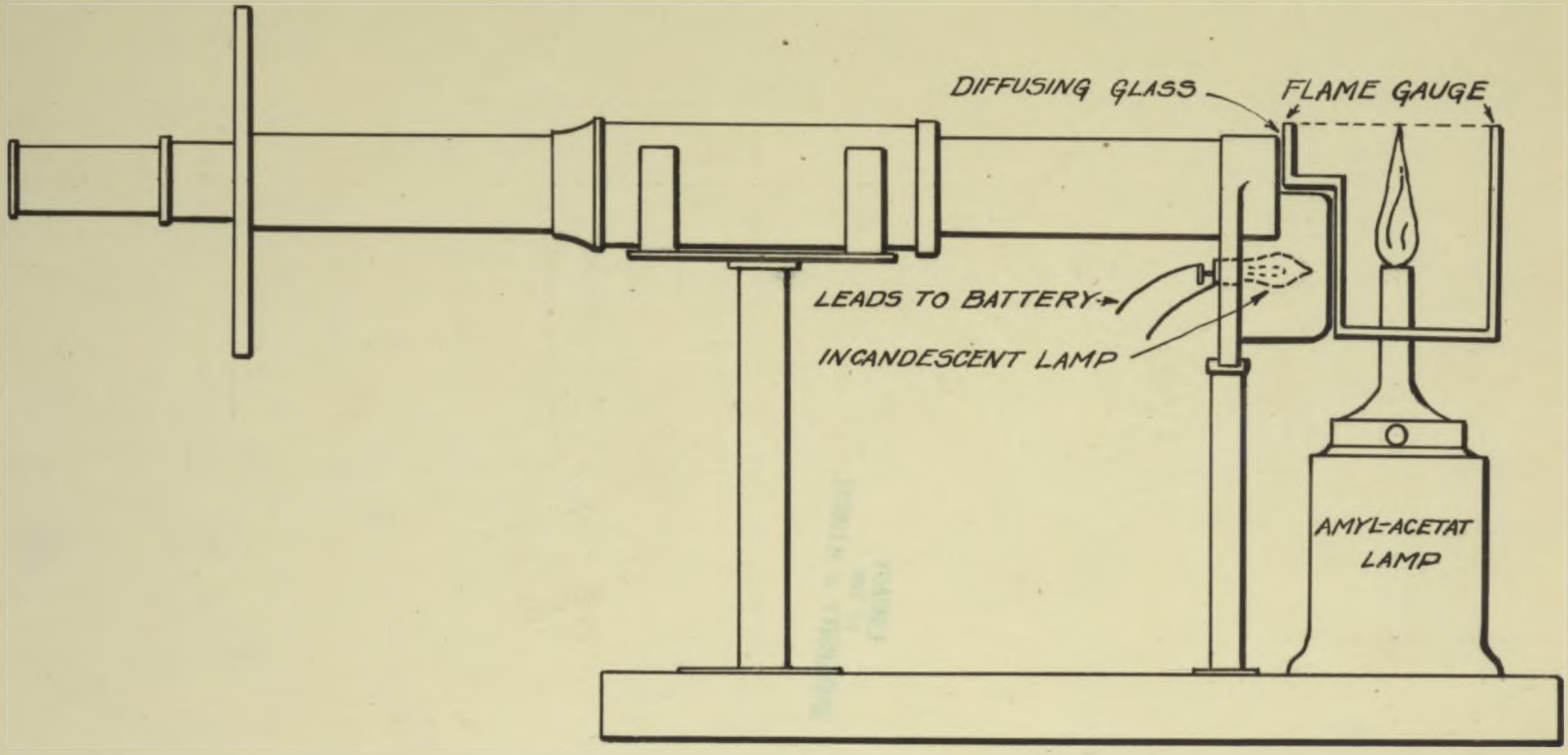

FIG. 5.

WANNER OPTICAL PYROMETER IN POSITION FOR STANDARDIZING.

in planes at right angles, the light of one coming from the slit S_1, and the other from S_2. The other images are cut off from the slit D. If the analyzer is at an angle of 45°, with the plane of polarization of each beam, and if the illumination of S_1 and S_2 is of the same brightness, the eye will see a single red field of uniform brightness. If one slit receives more light than the other, one half of the field will be brighter with a distinct sharp line of division between the two halves. The two halves may be brought to equal brightness by turning the analyzer carrying a graduated scale, which is calibrated in terms of temperature.

If the analyzer is turned through an angle, Φ, to bring the two halves of the field to the same brightness, the relation between the two intensities from S_1 and S_2 is:

$$\frac{J_1}{J_2} = \tan^2\Phi$$

It is necessary that the comparison light has exactly the same standard intensity. The brightness of the incandescent lamp varies with the current passing through it. Therefore, it is necessary to check the electric lamp frequently with a standard and constant source of light. Fig. 5 shows the pyrometer in position for standardizing. An amyl-acetate lamp and a ground-glass diffusing screen is placed before the slit S_2, thus furnishing the standard light. The analyzer is then set at the previously determined normal point, and the distance of the electric lamp from slit S_1 adjusted with thumb screw T (Fig. 5.). If the incandescent lamp is as far from the slit S_1 as it will go and the slit is still too bright, the brightness of the incandescent lamp can be reduced by inserting resistance into the circuit.

SOURCES OF ERRORS IN USING THE PYROMETER.

It has been shown by C. W. Waidner, and G. K. Burgess that the amyl-acetate flame as used with this pyrometer, can be relied upon to give an intensity of illumination whose constancy expressed in terms of temperature is better than 0.5 per cent. The same authorities state that variations in height of the flame if they do not exceed 3 mm., together with fluxtuations in atmospheric conditions, will not produce errors in temperature estimation exceeding 1%. The uncertainty of setting the nicol due to lack of sensitiveness of the eye to exactly match the two halves of the photometric field, is also about 1%, or somewhat better with practice. The adjustment of the electric lamp to standard intensity at the point on the scale chosen as normal point, when proper care is taken regarding the diffusing screen, can be made to within 1% expressed in temperature. This source of error does not affect relative results in any one series for one setting to the normal point.

The most serious source of error, except when special precautions are taken, is the variation in brightness of the electric comparison lamp due to variation in the current furnished by the three cell storage battery, the percentage change in light being of the order of six times the percentage change in current through lamp. Breaking the circuit and then making it again may cause an apparent temperature change of over 20° C.

The writer has found that for a series of observations lasting from 1/2 to 2 hours, it is better to standardize the instrument and take all readings without breaking the circuit, than to break the circuit after every single reading. Before standardizing the instrument, the amyl-acetate lamp should be burning from five to ten minutes to get a steady flame.

For most of the readings recorded in this work a 20 ampere hour storage battery was used.

THERMO-ELECTRIC COUPLE PYROMETER.

The thermo-electric couple as it came from the maker consisted of a platinum and platinum rhodium junction enclosed in a porcelain tube of 3/8" bore, and 5/8" outside diameter. However this porcelain tube could not stand the high temperature and particularly the slagging action of the furnace gases. The slag accumulated on the surface of the tube, and seemed to change the composition of the porcelain. The tube partly melted and then broke off after it had been inserted for two hours in the combustion chamber where nothing could strike it. A water-jacketed iron pipe, similar to the gas sampler shown in Fig. 2 was tried instead of the porcelain tube. In this case the two wires were insulated from each other and from the pipe by small glass tubing; the junction of the wires projected three inches from the end of the iron pipe, and was held in two stems of penny clay pipes. This rigging lasted in the combustion chamber over a week, and gave fairly satisfactory results. During this time the couple was continually connected to the Calander recording instrument. However, these records had a value only as far as the relative temperatures were concerned. For absolute temperature it could not be depended upon, because it was difficult to apply any scale or rule to the record when the junction of the couple was one fused mass of slag. It was also found that the variations in temperature shown by this couple were lagging from six to eight minutes. A couple fitted with a water-jacketed iron pipe had to be rigidly connected to a water supply, and on that account it could not be used for measuring temperatures in different parts of the furnace. For this purpose a plain 1/2 in. iron pipe was used. The junction of the wires was, as before, held in two clay pipe stems, which were projecting about 2 in. from the end of the iron pipe. The clay-pipe stems had to be used also for insulating the wires inside of the iron pipe for a length of about a foot on account of the high temperature to which this end was subjected. A thermo couple prepared in this way could be exposed to the high temperature of the furnace only long enough to get the projecting junction hot and take the reading; this usually took fifteen to twenty seconds, after which the instrument had to be withdrawn and cooled off. Even with this care the iron pipe lasted only for 30 to 50 single readings, after which the burnt iron pipe had to be replaced by a new one. This instrument could be depended upon only for relative temperatures in different parts of the furnace.

After all the trouble and difficulties that are met with in using a thermo-electric couple for measuring furnace temperatures, only the temperature of a very small locality where the instrument is inserted is measured. The temperature midway between the side walls may be much higher than it is 8 in. from the side walls where the couple reaches.

The optical pyrometer is more apt to take the average temperature of a strip across the furnace from wall to wall. Furthermore, it gives temperature changes instantaneously and gives them in absolute measure, which even in case the flames appear hotter than they really are, can not be off more than 150° F. or about 7%. This error is probably more than offset by the fact that the furnace is not a perfect black body.

CALENDAR RECORDING INSTRUMENTS.

There were two Calendar recording instruments. One of these was to be used with a thermo-electric couple, and the other with an electrical-resistance pyrometer. Owing to the fact that the pyrometers as sold, do not stand the furnace temperature for any length of time, these recording instruments were not given a fair trial, and therefore shall not be considered in detail in this work.

MILLIVOLTMETERS.

Two millivoltmeters were used in connection with the thermo-electric couples. One of these instruments was purchased of The Cambridge Scientific Instrument Co. of England. It was graduated directly in degrees C; the range was from 0 to 1600° C. The other instrument was purchased of Charles Engelhardt of New York, and had a scale divided into degrees F., and also into millivolts. The range was from 0 to 2800° F., and from 0 to 16 millivolts.

PRESSURE GAUGES.

At first a Crosby standard pressure gauge was used for all test readings. The dial was 8 in. in diameter, and one division was equal to one pound. The range was up to 200 pounds. The gauge was connected to the steam drum by 1/4 in. pipe in such a way that the center of the gauge was at the same height as the highest portion of the pipe connection, so that no corrections had to be made for water pressure. In July, 1905, a Crosby recording pressure gauge was purchased and was used after that for all test readings. It was daily checked with the standard gauge. The recording gauge had an 8 in. dial and 24-hour clock movement.

GAUGE TESTER.

From time to time the standard gauge was tested with a Crosby steam gauge tester. The apparatus consists of a small cylinder in which works a well-fitted plunger. The cylinder connects with a U shaped tube ending in a pipe tapped for attaching the gauge. The tube and the cylinder are filled with oil. A known weight added to the plunger produces an equal pressure on the gauge. The friction is overcome by giving the weight and the piston a slight rotary motion. A set of weights is so arranged that the pressure on the gauge can be increased by five pounds at a time.

DRAFT GAUGES.

The intensity of draft at various places of the boiler setting was measures by Ellison draft gauges which were furnished by the Engineering appliance Co. of Chicago. The draft gauge consists of a cylindrical bulb, to the bottom of which is sealed a glass tube having an inclination of 1 to 10 to the horizontal. This is placed securely in an aluminum frame, with the glass tube along a graduated scale. The frame is provided with a water level for leveling the instrument. When used, the gauge must be carefully leveled and securely fixed, and enough oil is poured into the bulb so that the level in the inclined tube stands at zero point on the scale. Refined kerosene oil is used for this purpose, because it does not evaporate, and quickly responds to any slight change in the draft. By leading a flexible tube from the mouth of the bulb to any of the openings in the boiler setting, the intensity of draft at that particular place was indicated by the oil level, and could be read from the scale directly in inches of water. One division on the scale was about 0.1 inch. long, but since the tube was inclined, each division was equivalent to 0.01 in. of water column. The pipe openings into the boiler setting at points where draft readings were taken, were closed by wooden plugs through which 1/8 in. pipes passed.

In addition to the Ellison inclined tube draft gauges a Bristol recording draft gauge was used for recording the draft at the base of the stack. This instrument had an 8-in. dial and 12-hour clock movement. The range was from 1 1/2 in. of water vacuum to 3 in. of water pressure. It was connected with a 1/4 in. pipe about 40 ft. long to the boiler settings in such a way that either the draft in the hood or ash pit could be recorded.

All the recording instruments were fastened to the wall,R, in the instrument room (See Pl. 1). The millivoltmeters when in use were placed upon the stone pier in the dark-room.

SAMPLING CANS.

The cans used for sampling coal and ash were made of galvanized sheet iron, and were provided with a well fitting cover. They were 18 in. in diameter by 3 ft. high.

SIZING SCREEN.

The size of coal was determined by running a sample of it through a revolving screen. The screen was a hollow-cylinder, 12 in. in diameter and 6 ft. long, made of perforated sheet steel. For a length of 24 in. the perforations were 1/8 in., the next 15 in. in length the perforations were 1/4 in., and the next 10 in. in length, 3/8 in. the next 9 in. in length, 1/2 in., the next 8 in. in length 3/4 in. and the remaining 6 in. 1 in.

METHOD OF CONDUCTING BOILER TRIALS.

The boiler trials were conducted according to the standard code of the American Society of Mechanical Engineers. From time to time small changes were made in the method, so as to make the latter more suitable to some particular conditions. It was the effort on the part of men conducting the boiler trials to adhere to the code rather by spirit then by letter.

The object of the boiler trials was to determine the relative values of different coals for steaming purposes. With that object in view more attention was paid to the furnace and coal combustion than to the boiler as steam generator. The length of the boiler trials was in most cases 10 hours or as near to it, as it was possible to close the trial with nearly the same conditions as the test was started. However, in case of shortage of coal, some trials were as short as 4 hours. The alternate method of starting the test was used throughout. Ordinarily the fires were cleaned from one to two hours before starting a test. After the cleaning the coal on which a test was to be made, was fired often and at regular intervals, in order to get the furnace into regular running condition. About 15 minutes before starting the test the firing ceased, and the fires were burned down. When starting the test the fire was from 2 to 4 in. thick. The depth was ascertained by leveling the fire and noting to what depth the prongs of the rake sank into the fuel bed. When closing the test the same order was followed, so that about the same weight of coal was burned after cleaning before closing the test, as was burned before starting it. Care was also taken to have the same load, same draft, and if possible the same steam pressure and same height of water in the gauge glass. The first two readings were much more important than the last two. While corrections could be easily made for difference in pressure and water level, it was very difficult to make corrections for difference in load or draft. It was found that as much as 5 in. difference in the water level can be made by varying the load on the boiler.

During a test the coal cart was placed on the scale, and the coal was fired from it, the time of each firing as well as the amount of coal fired was recorded. A sample of two shovel-fulls, selected at six different parts of the car load were taken every time the cart was filled, and put in air-tight sampling can. The ashes, and clinkers were weighed separate-after each cleaning. A sample of about 5% of the net weight of refuse was taken from each wheelbarrow-full. The thickness of fire was estimated and recorded every time the fires were raked. The time of starting and finishing the cleaning of fires, as well as any difficulties encountered in cleaning, were also recorded. A brief description of the appearance of the coal, and its characteristics while burning were noted on the coal and ash sheets.

Water was measured in the two measuring tanks, which were placed upon a pair of scales on top of the wooden platform (see Pl.4). The time of emptying the measuring tanks into the suction tank was recorded. The temperature of the feed water was taken in the measuring tanks immediately before emptying them.

The steam pressure, flue gas temperature, draft in the hood, draft in the furnace, height of water in suction tank, height of water in gauge glass, combustion chamber temperature, outside and boiler room temperatures were recorded every 20 minutes; after August, 1905, the first three were recorded automatically. The height of water in the suction tank and in the gauge glass was also recorded every time the coal cart was emptied. The temperature of the feed water entering the boiler, and the quality of steam was ascertained every hour. There was a peculiar behavior of the quality of the steam; when much steam was taken out of the boiler, the moisture of the steam was very low (often less than 1%), when no or little steam was taken out of the boiler, the steam was very wet(as much as 10% of moisture). Upon calibrating the calorimeter it was found correct. Regular flue gas analysis for CO_2, O_2 and CO was made every 30 minutes. Special gas samples were collected from the surface of the fire or from the rear of the combustion chamber; these samples were usually analyzed also for hydrocarbons and hydrogen. The blackness of the smoke was recorded for a period of 10 minutes once in every hour, by comparing it to Ringelman smoke charts.

Up to about September, 1905, the flue gas box sampler was used for collecting the flue gas sample at the foot of the stack. During that time it was often necessary to blow the soot out of the sampler with steam, and paint it to stop the air leaks. In spite of these precautions the gas sample taken with it was frequently diluted. The sampler could not be depended upon for gas analysis. Every day a few samples had to be collected through the single tube sampler to learn the condition of the box sampler.

During the night the box of the sampler became filled with air, which could be drawn out only gradually, so that the first two or three gas samples in the morning always ran high in free oxygen. Another fault of even a good air-tight box sampler is that it does not show any sudden changes in the fire. The volume of the box is so great that the good gas of one hour is mixed with the poor gas of the next hour, and inversely, so that nearly the same gas analysis is obtained for two very different conditions of fire. It therefore does not give the man who controls the fires any information about the changes in the furnace. For these reasons the box sampler was abandoned in September, 1905, and the simple single tube sampler, which can be easily kept in good condition, was used after that.

DISCUSSION OF RESULTS AND VALUE OF BOILER TESTS.

Are the results of boiler trials a true indication of the relative value of the coals for steaming purposes, or, is the true value of coal for steaming purposes indicated by the chemical analysis, and calorific determination? This question is put in because some so-called "fuel expert" or engineers condemn the boiler test and advocate the proximate analysis and calorific determination.

There are five principal factors modifying the value of a coal for steaming purposes, when burning the coal in one particular set of apparatus. These factors are: pounds of steam made per pound of coal; horse power of boiler that can be developed with the coal; ease in handling the fire; the effect of the coal upon the deterioration of the apparatus in which it is burned, and the cost of removing the ashes. The last factor depends upon the location of the plant. Only the first and in some cases the second factor can be more or less accurately predicted from proximate analysis and calorific determination. All of the first four factors can at present be determined for one set of apparatus only by actually testing the coal under the particular boiler, and in the particular furnace equipped with the particular stoker.

The "proximate" analysis of some coal promises high evaporation, and high horse power; the ash and sulphur is low, so that no trouble is anticipated from the clinkers. However, if such coal is tested under a steam boiler, it may be found that the coal cakes badly, the fire takes much attention on the part of the fireman, and the capacity on account of the caking, is much lower than was expected. Or, it may be that the clinkers, even if in small quantity, will fuse into the grate and choke the access of air to the fire. Cleaning the fire in such a case is very difficult, often requiring over half an hour of hard labor on the part of the fireman. Thus both, efficiency and capacity of the boiler are decreased. Fusible clinkers frequently attack the grate bars in such a way that the grate corrodes, and is destroyed in a few days' run. Thus an actual boiler test may turn all the first four factors against the coal.

In the present state of knowledge of the chemical composition of coal it is always advisable to test the coal from a new vein or locality by a boiler trial, to determine its behavior on the grate, or on any particular stoker; the different grades from the same locality may then be ascertained by "proximate" or better by ultimate analysis.

It follows from what has been said that until a physical or chemical method is developed to determine all of the four factors in the laboratory, the boiler tests are not only justified but necessary. However, the great fault of determining the steaming value of a coal by actual boiler trials is that the determination applies only for the particular boiler and its setting; for other set of appartus such determinations are more or less modified.

The results of the boiler trials made at the U. S. G. S. Coal Testing Plant give comparative steaming values of the coals tested, for hand fired furnace and boiler similar to that of the Heine. Some coals would perhaps give better results on a chain grate stoker or some other mechanical stoking device than they showed on a plain grate with hand firing, while others might not show as well. The fact that the overall boiler efficiency is, with but few exceptions, within narrow limits speaks well for the comparative results of the boiler trials. The results are much more comparative for coals of of the same class than for coals of different classes. Each class of coal requires a furnace of some particular construction in which it will give the best results. Thus in Heine furnace good results are obtained with coals burning with flame of medium length. For coals burning with very long flame, a longer combustion chamber is required than the Heine furnace has; while the high fixed carbon coals would give better results in a furnace having no combustion chamber at all, or in an internally fired boiler. The low horse power developed with some of the high fixed carbon coals, was due to the small size in which the coal reached the boiler room.

INVESTIGATION OF COAL.

CLASSIFICATION OF COAL.

The coals tested under the steam boilers of the U. S. G. S. Coal Testing Plant may be classified, as is often done, into Anthracite or hard coal, semi-bituminous, bituminous or soft coal, and Lignites. This classification is generally made on the basis of the chemical analysis of the coal, however, it can be made also on the appearance of the coal and its behavior on the grate while burning. It is rather the last two that the writer takes for the basis of his classification in this work. Often another class of coal is made between the anthracite and semi-bituminous, called the semi-anthracite. However, since its appearance and behavior on the grate is not much different from the semi-bituminous, the semi-anthracite may be classed with the latter.

ANTHRACITE COAL.

Of the anthracite class only the Arkansas hard coal was tested under the steam boilers. The coal is of crystalline structure, that is, the coal is formed of irregular crystal-like bodies of many surfaces. By handling over conveyor the small bodies gradulally break off the lumps, and the latter assume somewhat shperical shape. The coal has a dark gray color of metallic luster. It is rather brittle and will not stand much handling over a conveyor. The chief impurities are slate and iron pyrites. The slate occurs in thick layers easily detachable from the coal, and can be removed by washing. The pyrites occur in thin layers which adhere to the coal, and therefore can not be so easily removed by washing as the slate. Both, the slate and the pyrites occur in large quantity.

In an ordinary Heine furnace with a plain grate and natural draft not exceeding .6 in. of water, the coal burns very slowly, and it is difficult to obtain much over 60% of the boiler capacity. The fire has a yellow color and appears very much like a ruffled gold leaf. It burns with a very short yellow flame and does not smoke. With conditions as above, best results are obtained by carrying a fire about 5 to 6 in. thick, and firing 80 to 100 lbs. of coal every 10 or 12 minutes, using the spreading method of firing. The fire does not get hot enough to fuse the ash and make clinkers; therefore the fire can be cleaned without any difficulty.

SEMI-BITUMINOUS COAL.

The semi-bituminous coal tested under the steam boilers came from the states of Pennsylvania, West Virginia, Virginia, Maryland, and Kentucky in the east, and the state of Arkansas in the west. It is of a crystalline structure, similar to the Arkansas anthracite, however the small crystals are bound together much more loosely, which makes the coal very brittle, in fact, it is so brittle that coal which left the mine as lump, is very often reduced by transportation and handling to slack before it reaches the boiler room. Its color varies from dull sooty black to dark gray of metallic luster. The eastern semi-bituminous coal is usually low in ash, its chief impurity being slate, which occurs in thin layers adhering to coal and therefore is not easily washed out. The sulphur is generally invisible and low in percentage. However small the amount of sulphur may seem to be, it is often high in proportion to the ash, and sometimes causes serious trouble by making fusible clinkers which attack the grate bars. (See article on sulphur). The Arkansas semi-bituminous contains much more impurities than the eastern coal.

In the Heine furnace with plain grate and natural draft, the coal if not toosmall, burns moderately fast. If in slack form,as is usually the case, it burns slowly and unevenly. The characteristics of the coal while burning are, short white flame after firing, little or no smoke, high temperature in the fuel bed, and caking. The caking is especially bad if the coal is in the slack form; the whole top of the fire bed fuses together and stops the passage of air. In a few places the caked mass cracks and allows the air to pass through. In such places the coal burns out leaving holes in the fire through which excess of air rushes into the furnace. To avoid the holes in the fire, the caked up coal must be often broken up by raking. In some cases it is necessary to rake the fire every twenty minutes. The caking of the coal in the fire is the greatest trouble in burning the semi-bituminous coal under a steam boiler.

The best method to fire the semi-bituminous coal is to carry a high fire, 12 to 14 in. thick, firing about 60 lbs. of coal on a grate of 40 square ft. at a time, every 4 or 5 minutes. Either spreading or the alternating method of firing can be used. The fire must be raked as often as necessary to keep the fire level. The high fuel bed decreases the bad effect of uneven fire. It is difficult to obtain rated capacity on a water tube boiler such as the Heine boiler, when small sizes of semi-bituminous coal are fired.

BITUMINOUS COAL.

The class of bituminous coal is the largest. Almost every state in the Union which has any coal at all, mines some bituminous coal. The three largest fields of bituminous coal are: the Eastern or Appalachian field which takes in the states of Pennsylvania, West Virginia, Ohio, Kentucky, Tennessee, and Alabama: the Central or Illinois field, taking in almost wholly the state of Illinois, the south-west corner of Indiana, and a small portion of the north-west of Kentucky; and the Western or Missouri field which extends into Iowa, Nebraska, Kansas, Indian Territory, and Arkansas. The best bituminous coal for steaming purposes comes from the eastern field; it is no doubt the best coal for making steam. Next in quality is the coal from the Illinois basin. The best coal of this field is mined in the southern portion of Illinois. The coal of the western field comes the last in quality. Some good bituminous coal is mined in Arkansas, and Indian Territory.

In general the bituminous coal has a structure consisting of layers of black shining coal, alternating with layers of dull brown or dull black soft substance. If fractured through the layer of the dull substance, the fracture looks and feels like charcoal.

The eastern coal is of a very black and shining color, and when taken in hand does not soil the fingers. By impact of two pieces a metallic sound is given out. It fractures in planes parallel to the layers of the structure, perpendicular to these layers, and often diagonally across these layers, forming sharp edges. The surface of the fracture is generally smooth and shining. The coal is very hard and stands transportation and handling very well.

The coal of the Illinois field is not so bright as is the eastern coal. Its characteristics are small, white, more or less transparent flakes of gypsum and calcite. These flakes occur in planes at right angles to the layers of structure. The coal fractures in planes parallel, and at right angles to the layers of structure, but seldom diagonally, so that small pieces of the coal have the shape of rectangular prisms. The coal is hard and stands handling and transportation. The chief impurities are slate, and iron pyrites. The slate usually occurs in thick layers, is easily detached from the coal and therefore can be removed by washing. The pyrites occur sometimes in thin layers, sometimes in thick layers or large balls. In the first case the pyrites can be partly removed by washing and in the second case most of it can be washed out.

The coal from the western coal field appears very much like the Illinois coal. The impurities are somewhat higher in the western coal than in the Illinois coal. Excepting the Iowa and some of the Missouri coal, the coal from the western coal field has very little of the gypsum flakes.

The characteristics of bituminous coal while burning are: very free and quick combustion, long yellow flame, and dense black smoke if improperly fired. Most of the eastern bituminous coals crack like popcorn after firing. The free combustion, the long flame, and the black smoke are due to the large amount of volatile matter in the coal.

The following is the series of processes which take place in the furnace in ordinary hand-firing. When fresh coal is spread over the fire bed, it chokes the passage of the air. First the moisture in the coal is evaporated, and then the volatile matter is more or less quickly distilled off. Both of these processes absorb heat and lower the temperature of the furnace. Every new charge of coal is then immediately followed by lack of air and lower temperature in the furnace, both unfavorable conditions for burning smoke. That the temperature is really lowered for most coals during and immediately after firing can be seen in charts Nos. 13, 16 and 18. The distilled volatile matter then partly burns with a long flame, and partly escapes unburned, owing to the insufficient supply of air, and low temperature.

Often there is enough air admitted into the furnace, but it is not mixed with the gases before they are cooled down by the cold boiler tubes. The above bad conditions grow worse as the fresh charges of coal are made heavier. It then follows that if smaller charges are made oftener, that the supply of air will be choked less, the reduction of furnace temperature will be less, and less volatile matter will be driven off at a time. However, in order to burn the volatile matter at all, combustion space and time must be provided for it, so that it can mix with the air and burn. A baffling wall such as shown in Fig. 1 built between the furnace and the combustion space, will not only greatly help the mixing, but also serve as a heat regenerator tending to keep the temperature above the ignition point of the smoking ingredients. There can be no hope to prevent the occurrence of smoke unless a fire-brick roof furnace and large combustion chamber are provided. In the Heine furnace the best results as to economy and prevention of smoke can be obtained by firing 50 to 60 lbs. of coal per 40 sq. ft. of grate area every 2 to 4 minutes. With eastern bituminous coal the intervals between firing are longer and with Illinois coal shorter. The coal should be spread alternately only on half of the fire bed and in the manner shown in sketch:

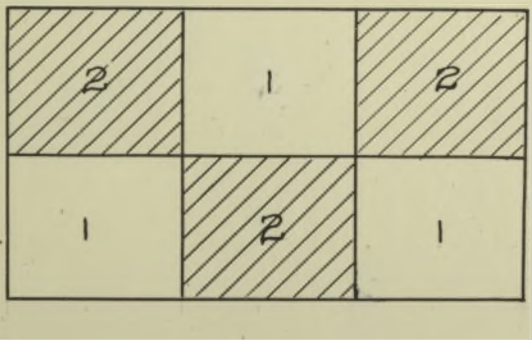

FIG. 6.

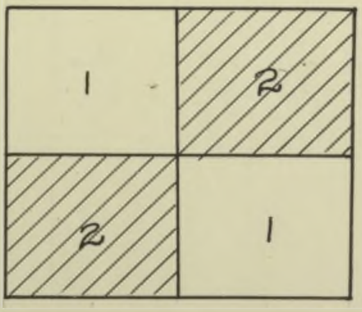

FIG. 7

If the furnace has three doors, the spaces marked 1 and 2 are alternately covered with coal as shown in Fig. 6. Two door furnace is fired as shown in Fig. 7. This method of firing has the advantage over the side alternate firing and the "front and rear alternate firing" that it divides the gases into three streams, and intermingles them with three streams of heated air from the bright hot fire. It can be seen from the sketch that the surface of contact of the gases and the hot air is double that of either of the two mentioned methods. The gases are further mixed by the impact against the baffle wall and as they pass through it into the combustion chamber. The baffling wall and the combustion chamber must be well above 2000^0 F. if smoke is to be burned.

Generally the air supplied through the grate is not sufficient for the volatile matter, and additional air must be supplied above the fire. This can be done by leaving the fire doors partly open (from 1 to 2 in.) for a short interval after firing. The time during which the fire door should be left open varies with different coal from 1 to 2 minutes. An automatic device which will admit the air after firing is much more regular in operation and more convenient for the fireman. For coals from the Illinois basin the best thickness of fire varies from 5 to 10 in., and for eastern coals as high as 14 in. The best thickness of fire must be determined experimentally for each coal and even for different sizes of the same coal.

With a thin fire too much air is likely to flow into the furnace, because it is difficult to prevent the formation of holes in the fire. A thick fire bed is sometimes the cause of imperfect combustion and excessive smoke. It follows then, that the man who controls the fire should give a good deal of his attention to the smoke and the analysis of the flue gases.

A thick fire offers a higher resistance to the passage of the air, and therefore a higher draft should be carried with the thicker fire. A draft of .3 to .7 of an inch of water at the end of the boiler passage is sufficient for any bituminous coal.

The fire should be disturbed as little as possible. Only when the coal cakes or the fire is uneven a rake should be applied to break the cakes, or level up the fire. If clinkers lie tight on the grate shutting off the air supply, a slice bar can be driven under the clinkers and pull them loose from the grate. However, the clinkers must never be lifted up and mixed with the fire. If slicing the fire does not help, the fire must be cleaned. While large pieces of free ash on the grate do not harm very much, in fact, in some cases they seem to do good, clinkers are always harmful and should be removed as often as practicable.

To sum up, the best method of firing bituminous coal by hand, is: fire little at a time and often; fire only on one half of the fire bed, and spread the coal in such a way as to facilitate the mixing of the gases with the air; leave fire door partly open after firing if smoke is too dense; carry as thick a fire as the flue gas composition and the smoke will permit.

LIGNITES.

The lignites tested at the U. S. G. S. Coal Testing Plant for steaming purposes, came from widely separated regions, and varied greatly in appearance. The North Dakota lignite was soft but tough woody structure of light brown color. The fibers of partly decayed and partly carbonized wood were plainly visible. It could be cut into shavings as easily as wood. The moisture was nearly 40% and the ash about 6%. The Kansas and some Texas lignites were also of brown color, however, the wood structure was not so prominent in them. The Kansas lignite was very high in ash. The Wyoming lignite was of a dull gray color, and laminated structure somewhat resembling soft coal. The Washington and some Texas lignites when moist had bright, black color, smooth fracture, and had an appearance somewhat like eastern anthracite coal. All lignites when exposed to dry weather rapidly lose their moisture, crack and crumble.

In the fire all lignites crumble into very small pieces or dust shortly after firing and then burn slowly with a short white flame. Most of the lignites burn without smoke; a few burn with light gray smoke.

For steaming purposes the best results can be obtained with lignites by using forced draft, or high induced draft. At the Coal Testing Plant fairly good results were obtained with difference of pressure from 1 1/2 to 2 in. of water, between damper and ash pit. It is best to fire about 200 lbs. of coal every 6 or 8 minutes, on a grate of 40 sq. ft. of area. Lignites high in ash should be burned on a rocking grate, so that the ash may be removed from fire without stopping for cleaning the fires. Ash from lignites is generally white, and very light. Clinkers are formed only in small quantity and are easily removed from the fire.

When burned with proper apparatus the lignites are fairly good fuel for making steam, and it is not so difficult to obtain the capacity of boiler with tolerably good efficiency, as it is often thought.

THE CHEMICAL COMPOSITION OF COAL.

The chemical composition of different coals varies greatly not only in the percentage of the different elements, but also in the combinations in which these elements exist in the coal. Professor S. W. Parr, of the University of Illinois, gives the following formula for a hypothetical molecule of coal exclusive of moisture, sulphur and ash which are incidentals in coal.#

For high fixed carbon eastern coal------ $C_{28}H_{26}O$;

For coal of the Illinois field - - - - - $C_{25}H_{18}O_3$.

This molecule of coal when subjected to heat is decomposed in the following way:

Coal = Coke + Volatile Matter.

(1) $C_{28}H_{26}O = C_{22} + 6\ CH_4 + H_2O$.

(2) $C_{25}H_{18}O_3 = C_{20} + C_5\ H_{12} + 3\ H_2O$.

Actually the molecule of coal is perhaps much more complex. The above expressions show that the volatile matter varies in composition with the coal. The volatile matter of high fixed carbon eastern coal is different from that of Illinois coal, and its distillation in fire is accompanied by different chemical reactions. The smoking property of Illinois coal may perhaps be due more to the chemical composition of the volatile matter than to its quantity. The heavier hydrocarbons are much harder to burn completely than the lighter ones. By studying the composition of the volatile matter of smoky coals, a key could be found for the solution of the problem of burning smoke.

Equation 1 and 2, shows that part of the volatile matter is water, which is in combination in the coal and can not be driven out by drying. This water, which Professor Parr calls the "water of composition", is wrongly counted as combustible by many steam engineers. An error more or less significant is made on that account in working out the results of boiler

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See University of Illinois Bulletin, No. 20, Vol. 1, "The Coals of Illinois; Their Composition and Analysis," by Professor S.W.Parr.

trials. In using the ultimate analysis for computing the "combustible", correction should be made for hydrogen not available for combustion.

SULPHUR.

Sulphur is an undesirable element in coal. It generally occurs in combination with iron as iron pyrites, and in combination with calcium as calcium sulphate or gypsum. The pyrites can be readily recognized by their heavy weight, bright brass-like color, and crystalline structure. The calcium sulphate occurs in thin, small, white flakes, more or less transparent. Of the two sulphur compounds the pyrites are generally contained in larger quantity in coal and are always harmful, because they increase the tendancy of the coal to clinker. The clinkering is especially bad if the percentage of ash is small in proportion to the sulphur. In such cases the pyrites and the ash fuse together and form a thin layer of solid clinkers which effectively stop the passage of air through the grate. Owing to the fact that no cold air can pass through the grate, and to the nearness of the hot fuel bed, the grate bars become heated. The clinkers then melt down into the air spaces and the sulphur seems to combine with the iron of the grate. Any attempt to slice the fire fails, and only slow and very difficult cleaning of the fires will remove the clinkers. The writer has seen cases where the cleaning of fires took from 40 minutes to one hour, and then the grate was not perfectly clean. Ordinarily with coals forming loose clinkers, the cleaning of fires took from seven to twelve minutes. The heat warps the grate bars, and the sulphur has such corrosive actioh on the hot iron that a new set of grate bars is destroyed in the course of but a few days.

Coals, Virginia No. 4, West Virginia No. 14, West Virginia No. 15

and most of the Kansas coals acted in the above manner. These coals contain from 0.3 to 6% of sulphur and from 3.5% to 10% of ash. They clinker badly because the ash is low in proportion to the sulphur contents. When such coals as the above are burned on a plain or a rocking grate, the clinkers may be kept cool by blowing steam under the grate. It is said that as the steam passes through the hot clinkers it is decomposed into hydrogen and oxygen. This decomposition is a cooling process, and the heat needed to effect it, is taken from the grate and the hot clinkers, thus keeping the latter cool and preventing it from fusing into the grate.

The above method of preventing the clinkers from melting into the grate was found to work satisfactorily with all the coals high in sulphur and ash. However, for coals low in ash this method proved to be insufficient. In such cases crushed limestone spread over the thin clean fire bed, immediately upon starting the test, was found to be a certain remedy for melting clinkers. The crushed limestone was used for the second tests of West Virginia No. 14 and Virginia No. 4. The cleaning of the fires of the first set when limestone was not used took 45 and 30 minutes respectively. On the second test when limestone was used the cleaning of fires took 8 and 10 minutes respectively.

To make a general statement it will not be far from right to say that the tendency of a coal to clinker varies directly as the sulphur (iron pyrites) and inversely as the ash in the coal.

THE WASHING OF SULPHUR FROM COAL.

Generally speaking, coals from which pyrites can be washed out, are improved by washing. If however only the ash is reduced, and most of the sulphur is left in, the coal is rendered worse by washing. The possibility of washing out the sulphur depends upon its distribution in the coal. If the sulphur (pyrites) occurs in large balls as shown in Fig. 8, or, in thick layers as shown in Fig. 9, it can be separated from coal and washed out. If however, the sulphur occurs in very thin layers or flakes, as in Fig. 10, or if it is distributed through the coal in very small invisible particles, it can not be separated from the coal, and therefore it is impossible to wash it out.

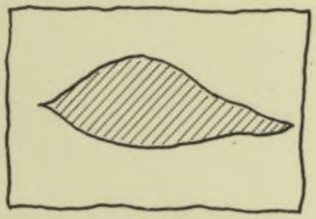

FIG. 8.

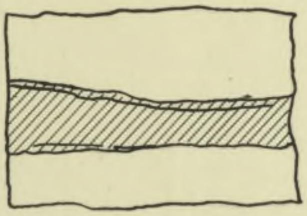

FIG. 9.

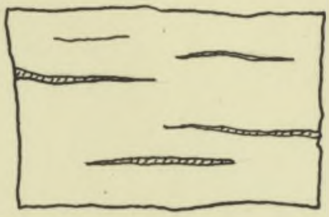

FIG. 10.

INVESTIGATION OF THE BOILER AND THE FURNACE.

THE BOILER AND THE FURNACE.

The boiler with its setting consists mainly of two parts: the furnace and the boiler proper. The furnace is the heat generator, and the boiler the heat absorber. In practice both of them are imperfect in their functions. A perfect furnace would be one which would burn coal completely. A perfect boiler would be one which would absorb all the heat evolved in the furnace. It follows then, that the furnace efficiency is the heat evolved, divided by the heating value of the coal fired; and the boiler efficiency is the heat absorbed by the boiler, divided by the heat evolved in the furnace. The combined efficiency of the furnace and the boiler is the heat absorbed by the boiler divided by the heating value of the coal fired. Another over-all efficiency commonly used in practice is one in which the denominator is the heating value of the coal fired minus the combustible in ash. It is the latter over-all efficiency which the writer used in plotting the charts in this thesis.

If the wording in the above definitions are slightly changed, another set of efficiencies is obtained. The efficiency of the furnace is the heat made available for the boiler divided by the heating value of the coal fired. The efficiency of the boiler is that portion of the heat absorbed, which is available for power purposes (engine or turbine), divided by the heat made available by the furnace. The over-all efficiency of the furnace and the boiler is the heat made available for power purposes, divided by the heating value of the coal fired. The fact is that steam engines are blamed for wasting heat which the second law of thermodynamics forbids them to utilize. This last set of definitions may be called the thermodynamic efficiencies.

To illustrate the above definitions let us represent the different heat values on the temperature entropy plane. Assuming that 16.5 lbs. of air is used per pound of carbon, and that the boiler room temperature is 70° F., the thermodynamic process is about as shown in Chart 1, Fig. 2. The air enters the ashpit at A, 530° F. abs. temperature. As it passes through the grate and part of the fuel bed it is heated practically at constant pressure to B about 1960° F. abs. before its oxygen begins to unite with the carbon. At B the combustion begins and at the same time the weight of the gas increases by the amount of carbon which is burned, until at C, a temperature of 3260° F. abs. the combustion is completed and the weight of the gas has increased to 17.5 lbs. The process from B to C is at constant pressure, however, the entropy is increasing a little faster on account of the increasing weight of the gases. Point C represents the condition of the gases somewhere at the end of the combustion chamber. As the hot gases pass through among the water tubes of the boiler, the heat is being absstracted at constant pressure. The lowest possible temperature to which the gases can be cooled is the point L, the temperature of the steam in the boiler.

In the chart we have the following quantities of heat. The area A B C J H represents the heat evolved in the furnace, and the area C D L M J represents the limit of the heat available for the boiler. The remainder of the heat is below the temperature of steam and therefore can not be absorbed by the boiler. In the chart the temperature of the steam is taken as 784° F. abs. corresponding to 95 lbs. abs. pressure, the limit of the heat available is then about 89% of the total heat evolved.

In chart 1, Fig. 1, the area A'B'C'F'E' represents the heat absorbed by the boiler. Of this heat the portion represented by the area A'B'C'D' is the limit of the heat available for the engine. This heat available for the engine is 29% of the total heat absorbed by the boiler so that in the limit the combined "thermodynamic" efficiency of the furnace and boiler is 26%. Thus we see that of the 100 B.T.U. put in the furnace only 26 B.T.U. can in the limiting case be available to the engine. The greatest drop in the heat available is in the transmission of the heat from the furnaces gases into the boiler water. There is a great drop of the temperature and an increase of entropy which always is a loss. By the use of high steam pressure, or, highly superheated steam more heat is made available for the engine. Our boilers are not as efficient for power purposes as the figures obtained from boiler trials ordinarily imply.

In the above discussion only the limiting case was considered. In practice there are many losses which reduce the above efficiency to less than 2/3. As the process of heat evolution and heat transmission goes on in the boiler and its setting, the principal sources of loss are about as follows.

(A) Part of the coal drops from the grate into the ash pit and is not burned.

(B) Part of the coal is gasified and the gases escape before they are completely burned.

(C) Part of the heat evolved in the furnace is radicated through the fire doors and through the furnace walls.

Of these three losses the second is the most serious one, and increases after the temperature in the combustion chamber has passed a certain limit. All these tend to move the point C towards B.

(D) In practice it is not possible to cool the gases down to L, the temperature of the steam; the gases leave the heating surface of the boiler at D a temperature of 200 to 300 F° higher than the steam temperature. The area M L D G represents the loss due to this excess of temperature of the escaping gases.

(E) As the gases pass through the boiler setting air leaks in and increases the weight of the gases, causing an increase of the entropy. The cooling process instead of ending at the point D, ends at the point E. The area G D M E F represents the loss due to the leakage. In the figure the points D and E correspond to a flue gass composition of CO_2=14.5, O_2=3.3, CO=0, and CO_2=10.7, O_2=8.1, CO=0, respectively. The total loss in chimney gases is then represented by area H.A.B.C.M.E.F.

(F) The moisture in air and coal as well as the water of composition lowers the final temperature at C and with its high specific and latent heat increases the entropy and consequently the loss up the stack.

In most of the commercial appartus for making steam the process of the heat absorbtion begins before the process of the heat evolution has been completed, in fact the two processes go on together as soon as the temperature of the gases has sufficiently risen above the temperature of the steam. This is especially true to a great extent with all furnaces having no fire-tile roof and no combustion chamber, and with all internally fired boilers. Even in a furnace of the Heine type a considerable portion of the heat is absorbed by the boiler through the fire-tile roof. Such abstraction of heat before combustion is completed, necessarily reduces the final temperature of the combustion. The theoretical temperature obtained by burning one pound of carbon with 16.5 pounds of air is given by the equation,

$$Q = MC_p(T_1-T_2)$$

Where Q = Heating value of one pound of carbon,

M - Weight of the gases of combustion,

C_p- Specific heat of the gas at constant pressure,

T_2- The initial temperature of the air,

T_1- The final temperature of the gases after the combustion.

If T_2= 70°F, C_p=.24, and Q=14500, then T_1=3520°F.

Actual temperature measurements show that the final temperature of combustion in the furnace nevers reaches 3500°F, even if less air is used per pound of carbon. These conditions under which abstraction of heat from the furnace gases while the process of combustion is going is economical, will be discussed later on.

THE GRATE AND THE COMBUSTION CHAMBER.

The Heine furnace consists of the grate, and the combustion space. The combustion space extends from the top of the fuel bed to the opening into the water tube chamber; the "combustion chamber" is the rear portion of the combustion space. The function of the grate and fuel bed is to distill the volatile matter, and partly to burn the fixed carbon of the coal. The function of the combustion space is to burn the volatile matter. With coals high in fixed carbon combustion is nearly complete a short distance from the top of the fuel bed; with high volatile matter coals the combustion is incomplete even at the rear of the combustion chamber. Samples of furnace gas collected at the top of the fuel bed are very often rich in combustible ingredients. Below is given the chemical composition of the gas collected with the water jacketed sampler at the top of the fuel bed, and also from the combustion chamber. The samplers projected about 10 in. into the furnace. One of them being inserted through the opening E, and the other through the opening A, the end of the former resting on the top of the fuel bed.

Test - 362.

Samples collected at the surface of fuel bed.

Time	CO_2	O_2	CO	H_2	CH_4	C_nH_m
8:40	6.1	0.0	17.9	7.8	3.6	0.2
10:40	10.8	5.6	2.2	0.0	0.0	0.0

Samples collected from combustion chamber.

Time	CO_2	O_2	CO	H_2	CH_4	C_nH_m
8:30	11.4	7.7	0.0			
10:30	14 .4	3.0	0.0			

Test - 364.

Samples collected at the surface of fuel bed.

Time	CO_2	O_2	CO	H_2	CH_4	C_nH_m
8:15	8.4	8.9	2.0	0.0	0.0	0.0
12:30	5.7	0.0	20.0	6.0	2.7	0.0

Samples collected from the combustion chamber.

Time	CO_2	O_2	CO	H_2	CH_4	C_nH_m
8:30	12.6	6.0	0			
12:30	12.6	5.6	0			

Test - 367.

Samples collected at the top of the fuel bed.

Time	CO_2	O_2	CO	H_2	CH_4	C_nH_m
7:30	4.4	7.4	9.5	1.2	2.4	0.8
9:30	5.4	0.0	23.6	7.8	1.2	0.2
11:20	5.2	0.2	23.6	5.4	1.8	0.0

Samples collected from the combustion chamber.

Time	CO_2	O_2	CO	H_2	CH_4	C_nH_m
7:30	13.3	0.0	0.9			
9:30	15.5	0.6	0.7			
11:30	14.6	0.2	1.0			

It is difficult to say whether the samples collected with the water-jacketed sampler are true samples of the furnace gases. Some constituents of the gas may decompose and reunite in different way when suddenly cooled by the water cooled surface. Chemical analyses of gas collected at the end of the combustion chamber seldom show much CO, or any H_2 and CH_4.

Samples collected at the base of the stack show dilution of 25 to 30 per cent. The following are the chemical analyses of some gas samples collected simultaneously at the base of the stack and in the rear of the combustion chamber through the hole E

Test - 305.

Samples collected from combustion chamber.

Time	CO_2	O_2	CO	CH_4	Sum
9:00	13.4	4.6			18.0
9:30	15.0	3.6	0.0	0.4	19.0
10:30	14.4	3.1	0.0	0.0	17.5
12:30	15.4	1.8	0.0		17.2
1:30	14.6	3.2	0.0		17.8
Average	14.5	3.3	0.0		17.8

Samples collected at the base of the stack.

Time	CO_2	O_2	CO	CH_4	Sum
9:00	10.0	9.2	0.0		19.2
9:30	11.0	7.8	0.0		18.8
10:30	11.2	7.6	0.0		18.8
12:30	11.0	7.9	0.0		18.9
1:30	10.5	7.9	0.0		18.4
Average	10.7	8.1	0.0		18.8

The above analyses give 17.5 and 23.2 lbs. of gas per pound of carbon respectively.

It is important that if the fire is controled by the flue gas analysis, the samples should be collected before the gas is diluted. As it is almost impossible to have a perfectly air tight boiler setting, it is perhaps best to take the sample from the combustion chamber.

VARIATION OF TEMPERATURE IN FUEL BED, OVER FIRE, AND COMBUSTION CHAMBER.

In charts 2 to 19 are shown the variations of the temperatures in the fuel bed, over the fire, and in the combustion chamber. The temperatures were taken with the Wanner Optical pyrometer which was standardized before and after each series of observations. Excepting the first two charts every series of readings was taken without disconnecting the pyrometer from the battery after the standardization. The temperature of the fuel bed was taken through the opening A (PL.2) in the side wall, the temperature over the fire through the opening B, and the temperature in the combustion chamber through the opening E. The time of each reading is indicated on each chart. Every series of readings was taken when the fire was in the average condition of the day's run.

The charts show clearly the variation of temperature with each firing. In the combustion chamber the temperature invariably rises immediately when firing begins, reaches its maximum shortly after firing ceased, and then drops down as fast as it has risen. The rise and drop of the combustion chamber temperature shows that as soon as fresh coal is thrown over the fire, the volatile matter is distilled from the coal, and burns in the combustion chamber. As soon as all the volatile matter is distilled and burned the temperature in the combustion chamber drops. The rise of the combustion chamber temperature further shows that the length of time necessary to distillé the"volatile matter" of Illinois and Ohio coal is from two to three minutes, while high fixed carbon coal like W. Va. #19, and Pen. #7, chart 17 and 19, distill their volatile matter in one to two minutes. The combustion chamber temperature is higher for high volatile matter coals than for high fixed carbon coals. By frequent firings the depression in the temperature curves can be made narrow, and the average temperature raised. This is done in case higher capacity is required.

Charts 5 and 6 give second curves which are used as a check on the relative temperature in the combustion chamber. These curves give the temperature of the escaping water from the water jacketed gas sample. These temperatures were taken simultaneously with the optical pyrometer readings. Except for a small lag in the water temperature, the two curves agree very well. In the two lower curves the temperature should follow the line A B C instead of going up to D. The rise in the temperature at D is due to the decrease of the head in the water supply pipe, caused by water being drawn into the measuring tanks for feeding the boiler.

The variation of the fuel bed temperature, and especially the temperature over the fire is directly opposite to that of the combustion chamber temperature. The temperature over the fire drops when firing begins and stays low about a minute after firing has ceased. The drop of the fuel bed temperature is probably due to the fact that when the fire door is open less air is forced into the furnace through the fuel bed and combustion is slower and more incomplete. The drop of the temperature over the fire is largely due to the distillation of the volatile matter, and partly to the evaporation of the moisture in the coal, both of these are cooling processes. The temperature over the fire and the combustion chamber temperature are dovetailed.

Charts 12 to 17 show one interesting feature. With Ohio #8, which is rather high in volatile matter, the combustion chamber temperature is much higher than the temperature over the fire; while with the W. Va. #19, a high "fixed carbon" coal, the combustion chamber temperature is lower than the temperature over the fire. This fact shows the advisability of large combustion chamber for coals high in volatile matter.

Below is a table of the proximate analyses of four coals, and a table of the temperatures in the three different places in the furnace. The temperatures in the table are the averages of 60 to 70 readings.

Test No.	Coal	F. C.	V. M.	M.	Ash	S.
287	Ohio #8	47.10	35.76	8.70	8.44	2.44
306	Ill.#23	39.69	32.37	14.49	13.45	4.62
307	Pen. #7	58.78	21.79	5.80	13.63	2.22
385	W.Va#19	70.43	20.59	2.44	6.54	0.92

Test No.	Coal	Temp. of fuel bed	Temp. above fire	Temp. in Comb. Cham.
387	Ohio #8	2634°F.	2230°F.	2805°F.
306	Ill. #23	2618	2321	2500
307	Pen. #7		2575	2200
385	W.Va.#19	2875	2460	2341

The tables show that the combustion chamber temperature rises with the percentage of "volatile matter", and the fuel bed temperature with the fixed carbon. Coal W. Va. #19 would evidently make a better smithing coal than steaming coal under Heine boiler.

THE EFFECT OF THE COMBUSTION CHAMBER BAFFLING WALL ON THE TEMPERATURES.

It has been said in the description of the baffling wall, that the construction of the latter was so chosen, as to have the one stream of gases impinge against a solid part of the wall and break into many small streams, thus effecting mixing. It was intended to obtain a splashing effect similar to that seen when a stream of water is directed against a solid wall. That some such effect was attained was indicated by the high temperature taken through the opening D, which was invariably the highest in the combustion space. Each of the following temperatures is the average of the readings taken with the Wanner pyrometer at five different places of the furnace.

Test - 359

Temp. of fuel bed A	Temp. above fire B	Temp. over bridge wall C	Temp. at the base of baffle D	Temp. in comb. cham. E
2470°F.	2586°F.	2826°F.	2989°F.	2447°F.

Each individual reading was taken successively in the opening A, B, C, D and E, so that the above averages give simultaneous temperatures.

An exposed platinum & platinum-rhodium couple connected to a galvanometer reading in C°, gave the average temperature of six readings in each opening as given below.

A	B	C	D	E
913	---	1075	1280	1035

These temperatures taken with the thermo-electric couple have only relative value as the appartus was not calibrated. The theromo couple used is the one described on page 23. The galvanometer had been recently repaired and the division on the scale were not true degrees centigrade.

CHARTS OF RESULTS.

Charts 20 to 29 were plotted with the object of finding the relations which exist between the conditions of a boiler trial and its economic results. The number of tests used in plotting the curves varies from 106 to 125. The reason why no tests previous to test 190 were used in plotting was because systematic measurement of combustion chamber temperature was not started until with test 190. The figure at each point indicates the number of tests which were averaged to obtain the value of the point. Other points on the same vertical line are averages of the same number of tests. In every chart the tests are averaged in vertical strips. The values used in plotting are the same as will be given in the government report under the same heading.

The average diameter of the coal was obtained by multiplying the per cent of each size by its diameter, adding these products and dividing the same by 100.

$$\text{Average diameter} = \frac{\sum \text{per cent of each size x its diameter.}}{100}$$

BOILER EFFICIENCY AND COMBUSTION CHAMBER TEMPERATURE.

It has been said that the boiler efficiency E is the heat absorbed by the boiler dividid by the heat evolved in the furnace, or, referring to chart 1, Fig. 2,

$$E = \frac{C_pMT_1 - C_pMT_2}{C_pMT_1} = \frac{T_1 - T_2}{T_2 \;\text{—}\; T_1},$$

Where T, is the final temperature of combustion, T_2 the temperature of the escaping gases, M the weight of the gases when combustion is complete and also the weight of the escaping gases, and C_p the specific heat of the gases at constant pressure. As T_1 is very nearly the temperature in the combustion chamber, we would expect a marked increase in the over all boiler efficiency with the increasing combustion chamber temperature. However, such is not the case; chart 20 shows that the increase in over all boiler efficiency (72*) is only about 2% for an increase in combustion chamber temperature from 1900 to 2800°F.

Chart 21 shows that with rising combustion chamber temperature the flue gas temperature rises also, and consequently the loss in dry chimney gases increases. For the temperature of 1900°F in the combustion chamber, the average flue gas temperature is 553°F, and for the temperature of 2800°F in the combustion chamber, the average flue gas temperature is about 693°F. The increase of the boiler efficiency for this rise in combustion chamber temperature then should be:

$$E - E' = \frac{3260 - 1153}{3260} - \frac{2360 - 1023}{2360} = 8\%$$

Of course the radiation loss from the furnace is greater with higher combustion chamber temperature, however, this loss does not increase more then 2 or 3 per cent. If we turn to chart 22 we may perhaps find a solution how the 3 or 4 per cent of heat is lost. As the combustion chamber temperature rises, the amount of free oxygen falls, and naturally the incomplete combustion of carbon increases. If there is complete combustion of carbon, there is very likely incomplete combustion of the hydrogen and hydrocarbons.

It must not be inferred that less air is used in combustion because the combustion chamber temperature rises. The inverse is true; the combustion chamber temperature rises becauses less air is used in combustion. In chart 22, the drop in the amount of air used in combustion is from 23.2 to 18.5 lbs., for the rise in combustion chamber temperature from 2000 to 2700°F. This drop of the amount of air per pound of carbon would give a rise of 600°F in the combustion chamber temperature as computed from the equation $T_1 - T_2 = \frac{Q}{C_pM}$. This is a rather close agreement for a roughly plotted curve and uncertain flue gas analysis.

The fact that the incomplete combustion increases with rising combustion chamber temperature follows directly from Vant Hoff's principal of mobile equilibrium.

"If the reaction absorbs heat, it advances with rise of temperature; if the reaction evolves heat it retrogrades with rise of temperature; if the reaction neither absorbs nor evolves heat the state of equilibrium is stationary with the rise of temperature."

The reaction between carbon, hydrogen, and hydrocarbons on one side and oxygen on the other evolves heat, and is therefore retrograded with the rise of combustion chamber temperature. This reaction is further retrograded by the decrease of free oxygen. Thus the increase in the boiler efficiency due to high combustion chamber temperature, is nearly offset by the drop of the furnace efficiency.

The following quotation taken from P. Duhem's "Thermodynamics and Chemistry" pages 58-61, also supports the supposition that incomplete combustion increases with high combustion chamber temperature.

"When oxygen and hydrogen, mixed in equal equivalents burn, there is formed a certain quantity of vapor, but a certain quantity of hydrogen and of oxygen remain in a state of liberty. With a special arrangement, the gases which feed the oxyhydrogen flame may be drawn partly off, and it is found that the hottest parts always contain uncombined oxygen and hydrogen.

If this experiment is repeated with a burner of oxygen and carbonous oxide, it is readily seen that the flame is far from uniquely made of carbonic acid; in the hottest part of the flame two thirds at the most of the gases oxygen and carbonous oxide are combined; it is only in the coolest part of the flame that the combustion is total.

These various experiments put beyond doubt the following propositions:

At a high temperature water and carbonic acid are decomposed but the decomposition is not complete; an equilibrium is set up when the mixture formed by the compound and its component gases has reached a certain composition; the mixture in equilibrium contains a less proportion of the compound considered in the proportion as the temperature is higher.

Conversely, at a high temperature oxygen and hydrogen combine, carbonous oxide and oxygen from carbonic acid, but the combination is not total; it tends toward a state of equilibrium at which it stops; in this equilibrium state the proportion of the gases which have escaped combination is the greater as the temperature is higher."

The statement that the incomplete combustion increases when combustion chamber temperature rises, seems to be in direct contradiction with one of the requirements for burning smoke. This requirement as given on page 41 states that the combustion chamber temperature must be well above 2000°F if smoke is to be burned. This requirement is based upon actual observation. It has been noted that whenever a test was started with a comparatively cold combustion chamber, it was impossible to burn the smoke until the combustion chamber temperature rose above 2000°F. The apparent concontradiction may be explained in this way.

The heat evolving chemical activity between any element and oxygen increases when the temperature rises, until a temperature is reached at which the chemical activity or "velocity of reaction" is maximum. Beyond this temperature the velocity of reaction decreases as the temperature rises until a temperature is reached when the reaction ceases or reverses. It is a well known fact that at sufficiently high temperature water vapor decomposes, and although both oxygen and hydrogen are present they will not unite beyond this temperature. CO_2 is an unstable gas at high temperature, and if free carbon is present CO_2 is reduced to CO. It follows then that there is such a thing as too high a temperature for good combustion.

The temperature of maximum velocity of reaction between any one element or combination of elements varies with the nature of the latter. Thus the temperature which is favorable to the combustion of one element is unfavorable to some other. It may be that the temperature favorable for the combustion of C_5H_{12} in smoky coal is far beyond the most favorable temperature for burning H, C, or CH_4. If the velocities of reaction of C, H, CH_4 and C_5H_{12} were plotted on temperature as abscissae, the curves would perhaps look as shown in Fig. 11. The curves are not plotted to any scale, and show only the general shape.

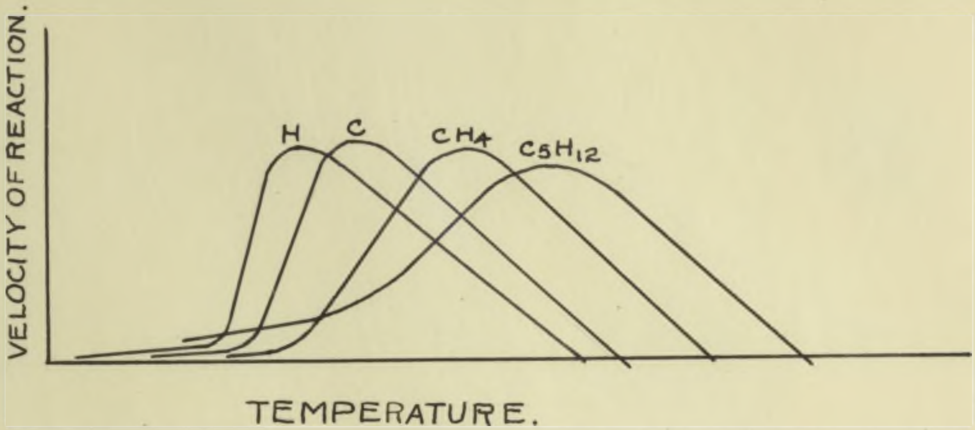

FIG. 11.

Thus the apparent inconsistancy between the requirement for burning smoke and the incomplete combustion of other combustibles in coal can be explained. Similar inconsistancy is often found in books on steam boilers. In one it is stated that to prevent clinkers from melting into the grate steam is blown into the ashpit. The steam is decomposed by the high temperature of the fuel bed thus colling the clinkers by the decomposition. In the same book it is advised that fire brick arches be built in the combustion chamber to maintain a high temperature to aid the combustion. Thus the author used the same high temperature for directly opposite purposes without any explanation.

It is difficult to say what reactions take place in the furnace, or in what combination the gases exist. The chemist must come to the boiler room and help the engineer to study the processes in the furnace.

It may be said here that the absorbtion of heat by the boiler from the furnace gases while the combustion is going on is in some cases beneficial to the performance of the whole appartus, because it keeps the temperature of the furnace gases down near the temperature of the common maximum velocity of reaction. This supposition suggests why in some cases it is economical to make smoke. If the heat absorbtion is carried too far, the temperature of the furnace gases may be brought down to the other side of the temperature of the maximum velocity of reaction. It is better to keep the temperature somewhat on the hotter side of the maximum velocity of reaction because in that case more heat is made available for the boiler.

From what has been said about the temperature of common maximum velocity of reaction a deduction can be drawn that for every coal there is one definite temperature at which the furnace gives the maximum efficiency. This temperature depends on the chemical composition of coal.

The top curve of chart 23 shows the variation of combustion chamber temperature with the over all boiler efficiency. The points are so scattered that it is difficult to draw any smooth curve, and probably the straight line AB satisfies all the points the best. This curve is a check on the curve in chart 20. The conclusion which can be drawn from the two curves is that within the two considered limits of the combustion chamber temperature, the over all boiler efficiency (72) is nearly independent of the combustion chamber temperature.

Professor John Perry in his book on steam engines, pages 587 to 591, arrives mathematically at a conclusion that the efficiency of a fire tube boiler is independent of the temperature in the furnace. His definition of boiler efficiency is the heat absorbed by the boiler divided by the heat available for the boiler, or,

if T_1 = the abs. temperature of furnace gases
T = the abs. temperature of escaping gases
t = the abs. temperature of steam.

$$\text{then } E = \frac{T_1 - T_2}{T_1 - t}$$

Perry rejects from his denominator the heat which is below the temperature of the steam, because the second law of thermodynamics does not permit the boiler to absorb it. He takes the following equation which has been proved experimentally to be very nearly correct, for the basis of his mathematical reasoning.

$$H = Cwv\ (T_1 - t)$$

This equation when applied to the steam boiler problem means that the heat transmitted from the gases through the boiler flue into the water is equal to C, a constant, times w, the density of the gases, times v, the velocity of the gases, times $(T_1 - t)$, the difference of temperature of the gases and the water in the boiler.

Take $(T - t) = Q$, T being the abs. temperature of the gases at the distance X from the furnace end of a flue of total length 1 and distance D. Take W lbs. of gases to flow through the flue per second, the specific heat being constant.

$$w = \frac{C}{T}, \qquad v = \frac{C\ W\ T}{D^2},$$

Since the density of the gases varies inversely with the absolute temperature, the velocity varies directly as the weight of the gas passed through in a second, directly as the absolute temperature of the gas, and inversely as the square of the diameter of the tube, then the heat given away per second per unit area is

$$H = \frac{C\ v\ \theta}{T} = \frac{C\ W\ \theta}{D^2}$$

Hence in a short length dx of the flue the heat given away is,

$$-W\ d\theta = \frac{C\ W\ \theta}{D^2} \cdot \pi\ D\ dx = \frac{C\ W\ \theta\ dx}{D},$$

$$\int \frac{d\theta}{\theta} = \int \frac{c\,dx}{D} \, ,$$

$$\log \theta = -\frac{cx}{D} + K ,$$

$$x = 0 , \quad K = \log \theta_0 ,$$

$$x = l , \quad \log \theta_l = -\frac{cl}{D} + \log \theta_0 ,$$

$$\frac{\theta_l}{\theta_0} = e^{-\frac{cl}{D}} , \quad \theta_l = 0_0 e^{-\frac{cl}{D}} .$$

Substituting the value of θ_L in the equation for efficiency we get the final equation,

$$E = \frac{\theta_0 - \theta_0 e^{-\frac{cl}{D}}}{\theta_0} = 1 - e^{-\frac{cl}{D}} .$$

The last equation states that the efficiency of the boiler depends upon the length and diameter of the flue, and is independent of the temperature. However, it must be born in mind that Perry's boiler efficiency is different from the over all efficiency (72*) as used in the government report, and must not be confused with it. The equation merely states that the ratio of the heat absorbed by the boiler, to the heat available for the boiler is constant, reckoning that only that heat in the gases is available which is above the steam temperature. Referring to chart 1, Fig. 2, if the temperature of the gases at C is brought higher, more heat is available for the boiler, and consequently more heat is absorbed by the boiler.

EFFECT OF FLUE GAS TEMPERATURE ON BOILER EFFICIENCY.

In chart 22 the middle curve shows that no relation exists between the flue gas temperature and the over all boiler efficiency (72). It may be said here that the readings of the flue gas temperature are the least reliable data, for the reason that the temperature at different places at the foot of the stack varies greatly with the draft. It is difficult to get the average temperature on that account.

In the same chart the lowest curve shows that very little relation exists between the lbs. of air per lb. of carbon and the over all boiler efficiency.

THE EFFECT OF COMBUSTION CHAMBER TEMPERATURE ON CAPACITY.

Chart 20 shows decisive rise in capacity with the rise of combustion chamber temperature. Since capacity is the rate of absorbtion of the heat by the boiler, this must necessarily be the case if the foundimental equation used in the derivation of Perry's equation for boiler efficiency is true. The heat absorbed per second per unit of heating surface is,

$$H = C\,w\,v\,(T-t).$$

Expressing the values of w, and v in terms of T we have,

$$H = \frac{C}{T} \cdot CT \cdot C\,(T-t) = K\,(T-t).$$

The last equation states that the capacity varies directly as the difference of the temperature of the furnace gases and the temperature of the steam.

CAUSES AND EFFECTS OF HIGH COMBUSTION CHAMBER TEMPERATURE.

The most direct cause of the rise of combustion chamber temperature is the increase in the rate of combustion of the fuel. Chart 25 shows that the combustion chamber temperature rises with the rate of combustion first very rapidly and then at a decreasing rate. Chart 29 shows that the combustion chamber temperature rises with the average diameter of the coal. However, this rise is undoubtedly due to the fact that coarse coal burns faster than small coal.

In chart 24 the combustion chamber temperature rises with the "fixed carbon" of the coal, up to about 58 per cent, and then drops again. In this case the temperature rises because the heating value of the coal rises with the fixed carbon. Beyond 58 per cent of fixed carbon the rate of the combustion of the coal is slower as the"fixed carbon" increases, and therefore, the combustion temperature falls.

Chart 22 shows why the combustion chamber temperature rises with the rate of combustion. The faster the coal is burned the less air is used per pound of carbon, and the higher is the temperature of the product of combustion. The same chart shows that the incomplete combustion of carbon increases with the rise of combustion chamber temperature.

Charts 26 and 28 show the effects of the increase of the rate of combustion and of the rise of combustion chamber temperature on the over all efficiency of the boiler (72*). As the rate of combustion increases the efficiency drops, and the loss in the incomplete combustion of carbon, and the unaccounted for loss increase. Part of the increase in the unaccounted for is due to the increased radiation from the furnace walls; most of it, however, is due to incomplete combustion of combustible gases other than CO. The increased rate of combustion combined with the rise in the combustion chamber temperature increase the velocity of the furnace gases through the boiler setting. As a consequence of the high velocity of the furnace gases, a part of the combustible which is kept by the high combustion chamber temperature in a free state is cooled down before it can combine with oxygen.

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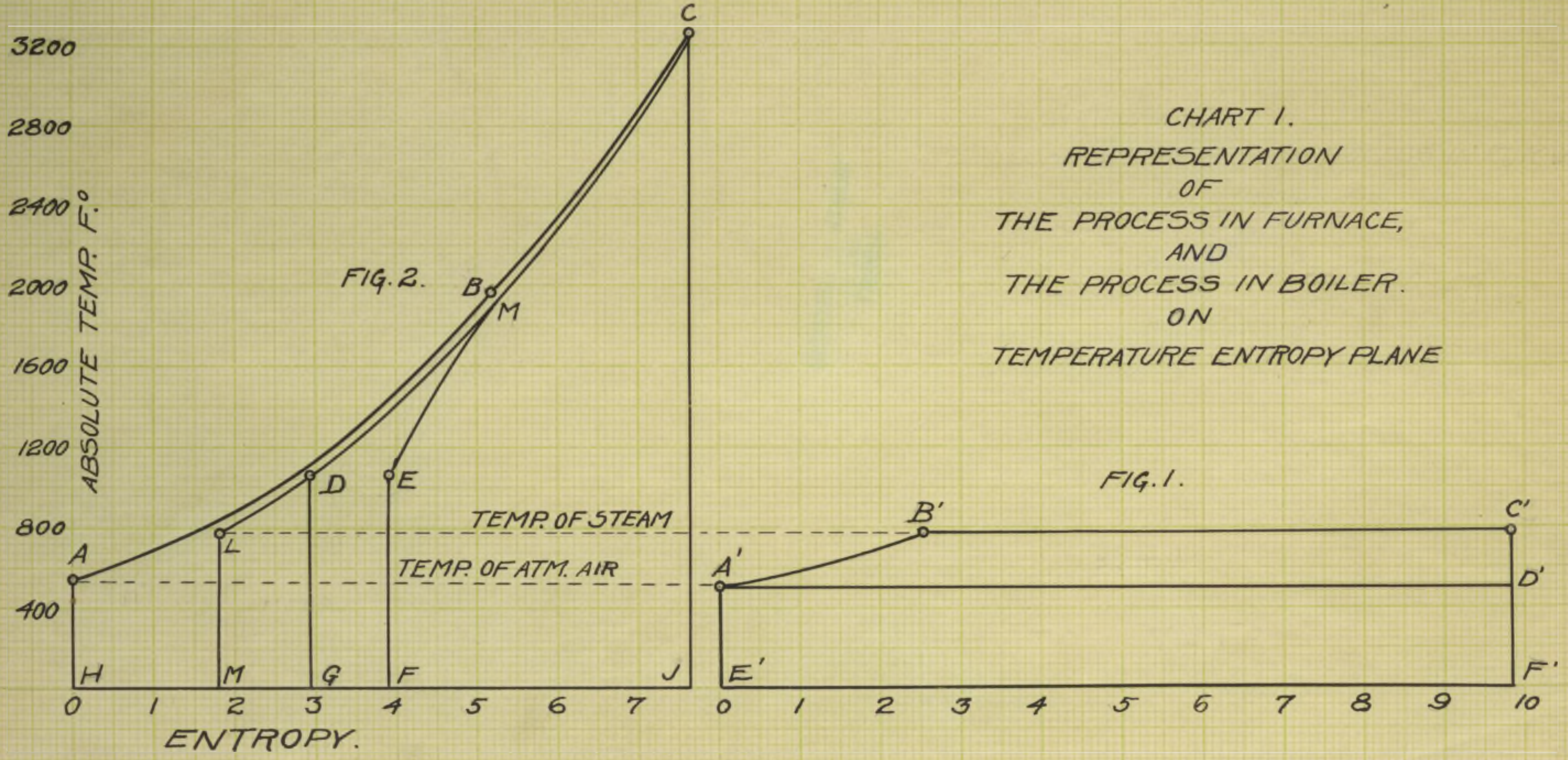


CHART I.
REPRESENTATION
OF
THE PROCESS IN FURNACE,
AND
THE PROCESS IN BOILER.
ON
TEMPERATURE ENTROPY PLANE

EUGENE DIETZGEN CO., CHICAGO.

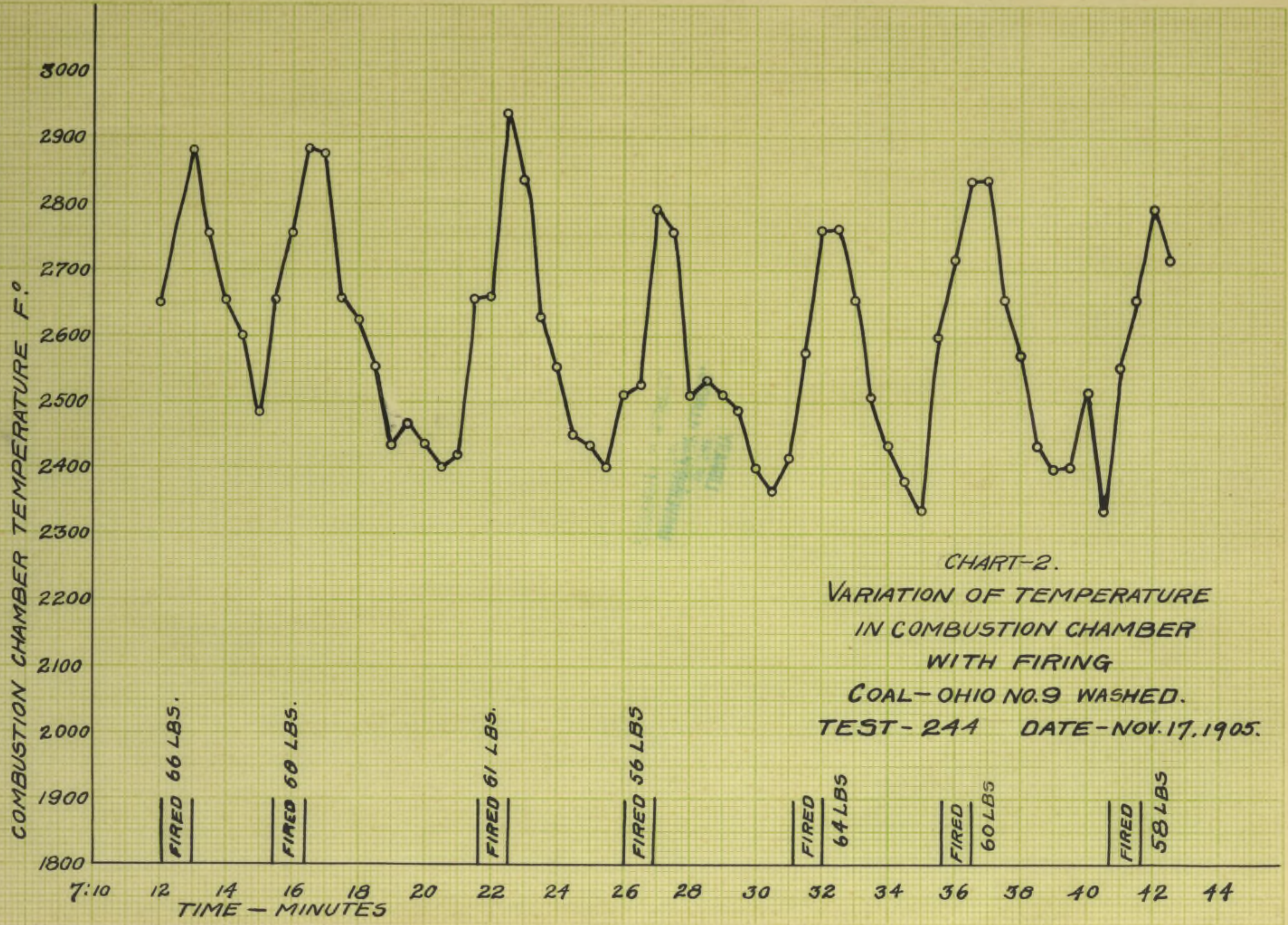


CHART-2.

VARIATION OF TEMPERATURE
IN COMBUSTION CHAMBER
WITH FIRING
COAL—OHIO NO. 9 WASHED.
TEST-244 DATE-NOV. 17, 1905.

EUGENE DIETZGEN CO., CHICAGO.

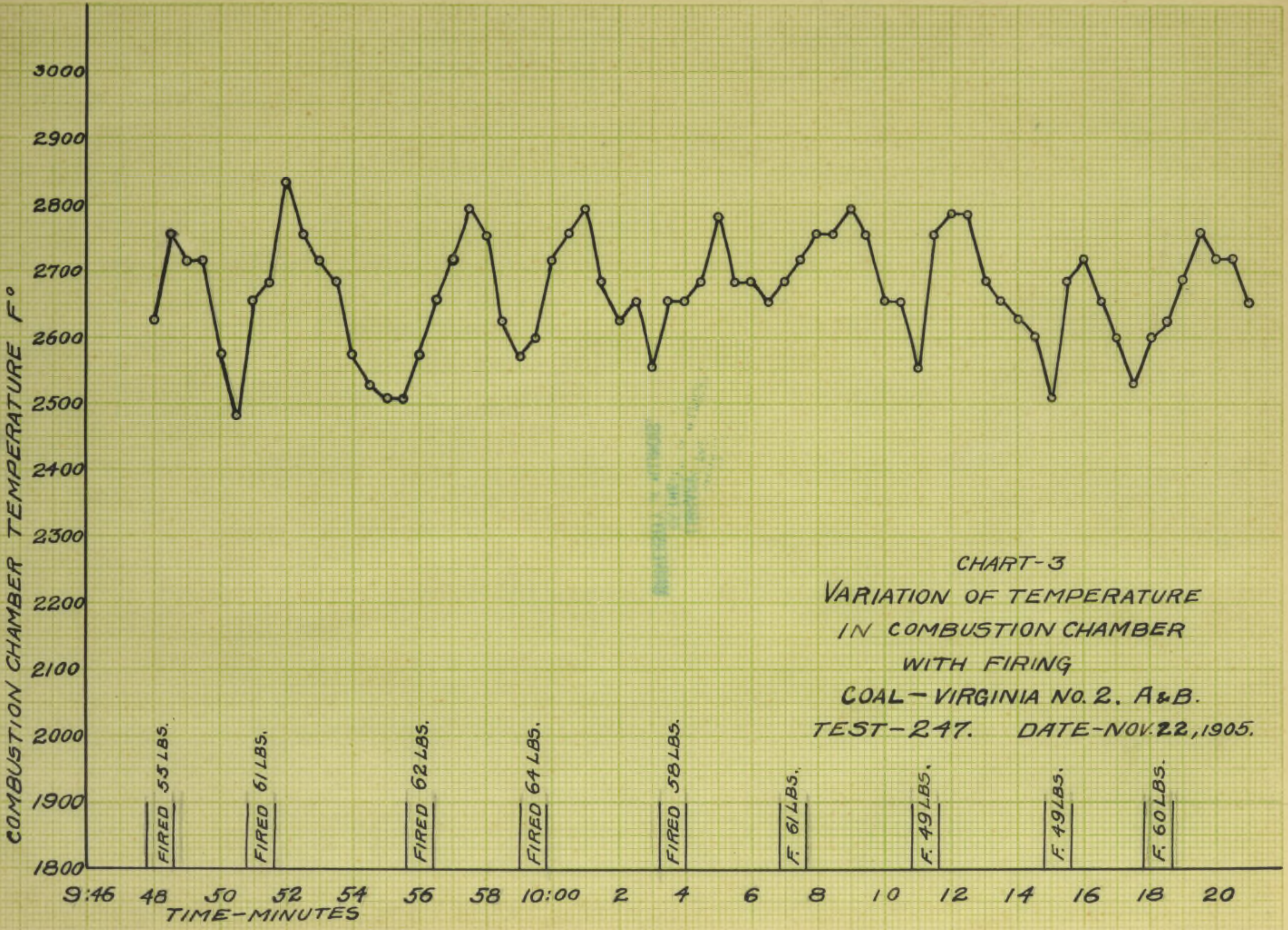


CHART-3
VARIATION OF TEMPERATURE
IN COMBUSTION CHAMBER
WITH FIRING
COAL-VIRGINIA No. 2. A&B.
TEST-247. DATE-NOV. 22, 1905.

EUGENE DIETZGEN CO., CHICAGO.

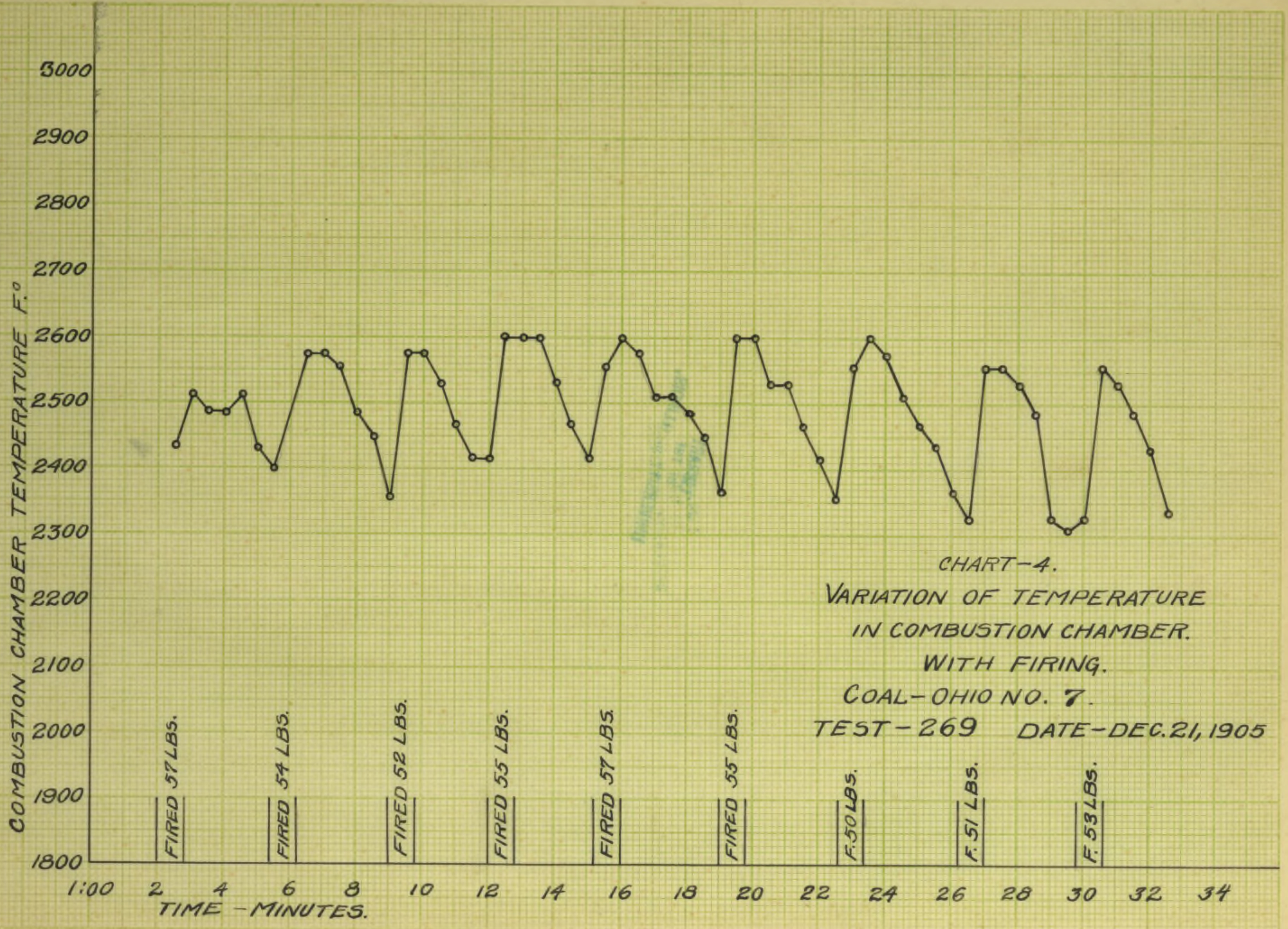


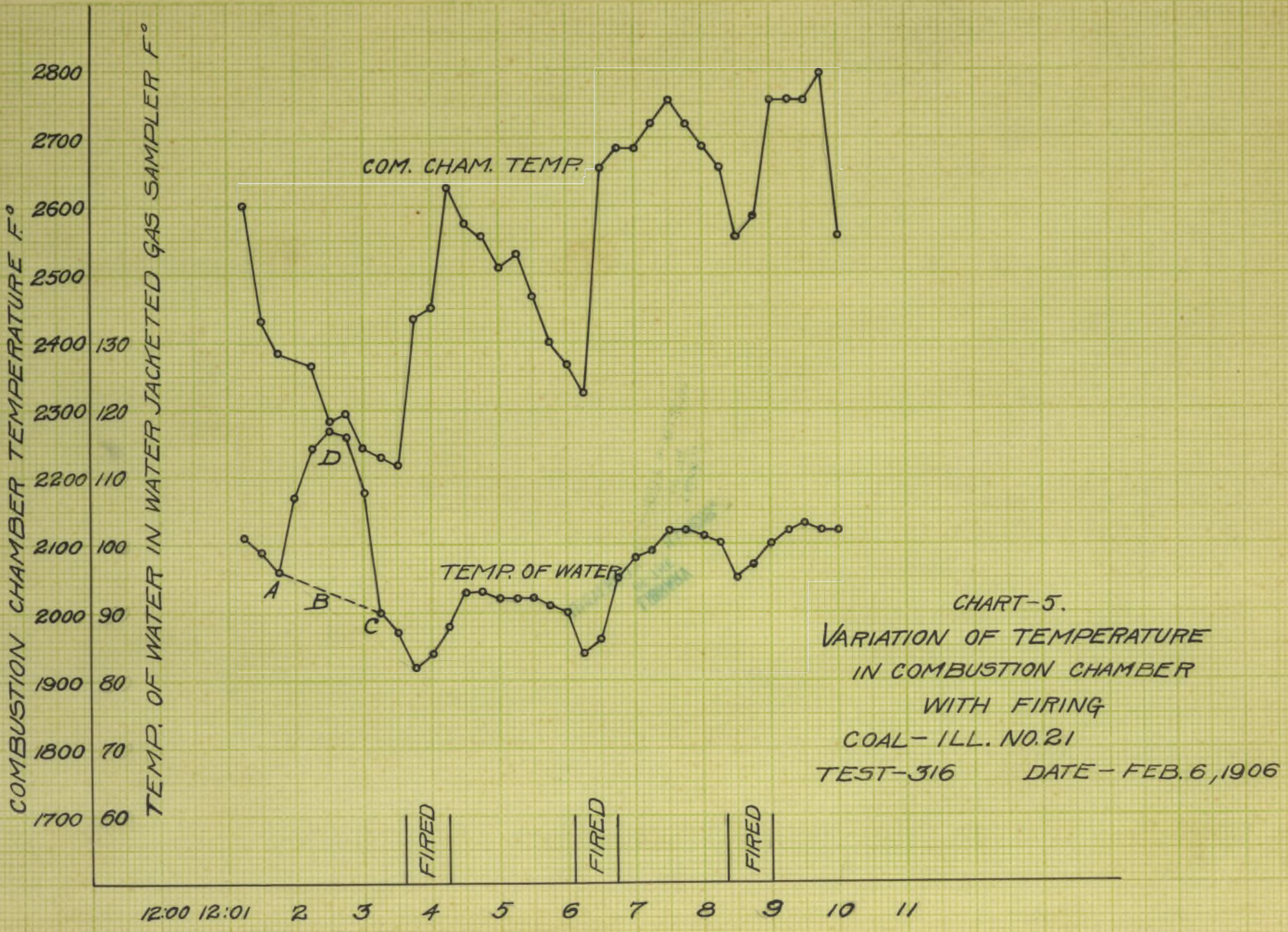
CHART-4.

VARIATION OF TEMPERATURE IN COMBUSTION CHAMBER. WITH FIRING.

COAL-OHIO NO. 7.

TEST-269 DATE-DEC. 21, 1905

EUGENE DIETZGEN CO., CHICAGO.



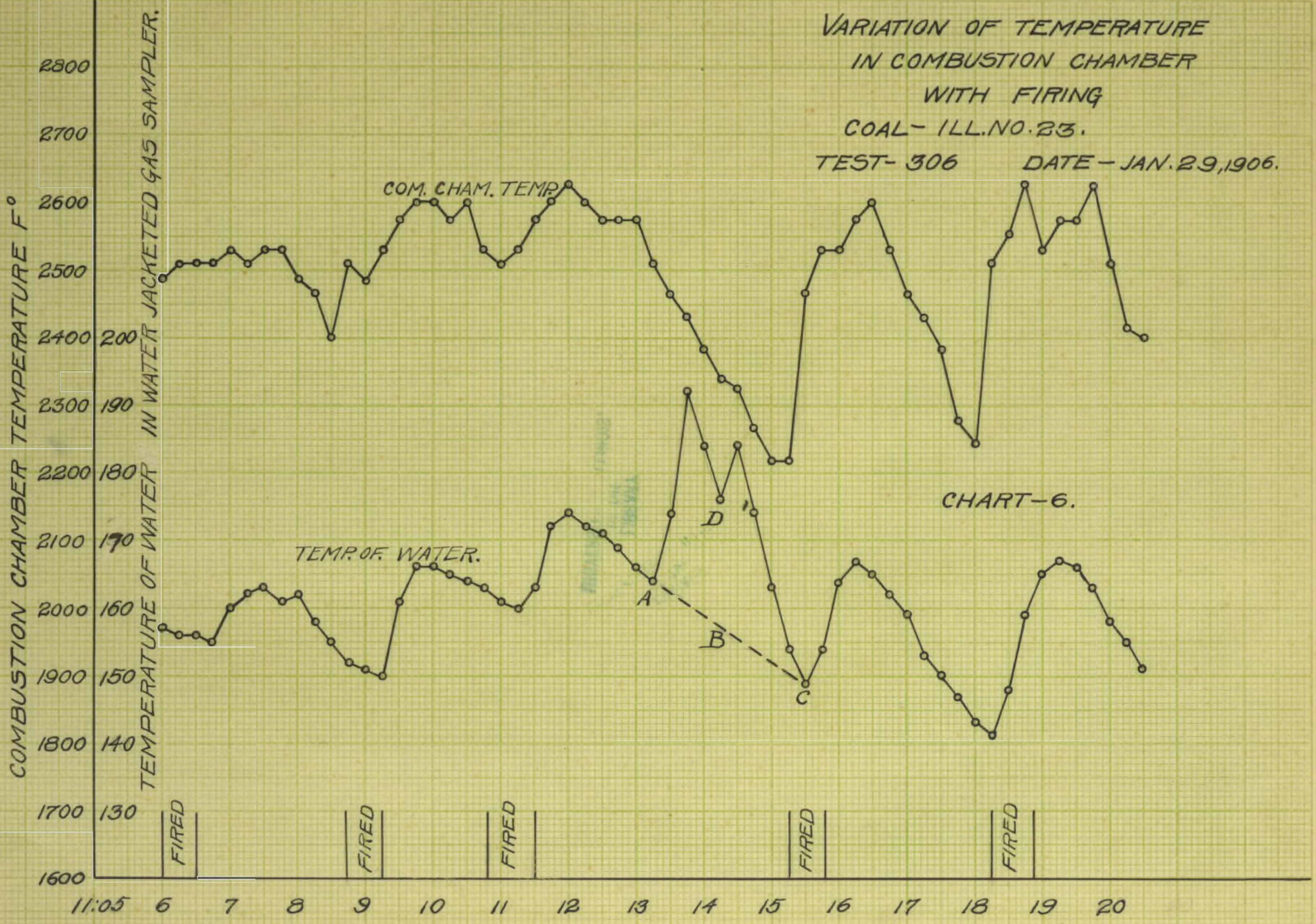
CHART–5.

VARIATION OF TEMPERATURE
IN COMBUSTION CHAMBER
WITH FIRING

COAL – ILL. NO. 21

TEST – 316 DATE – FEB. 6, 1906

EUGENE DIETZGEN CO. CHICAGO.



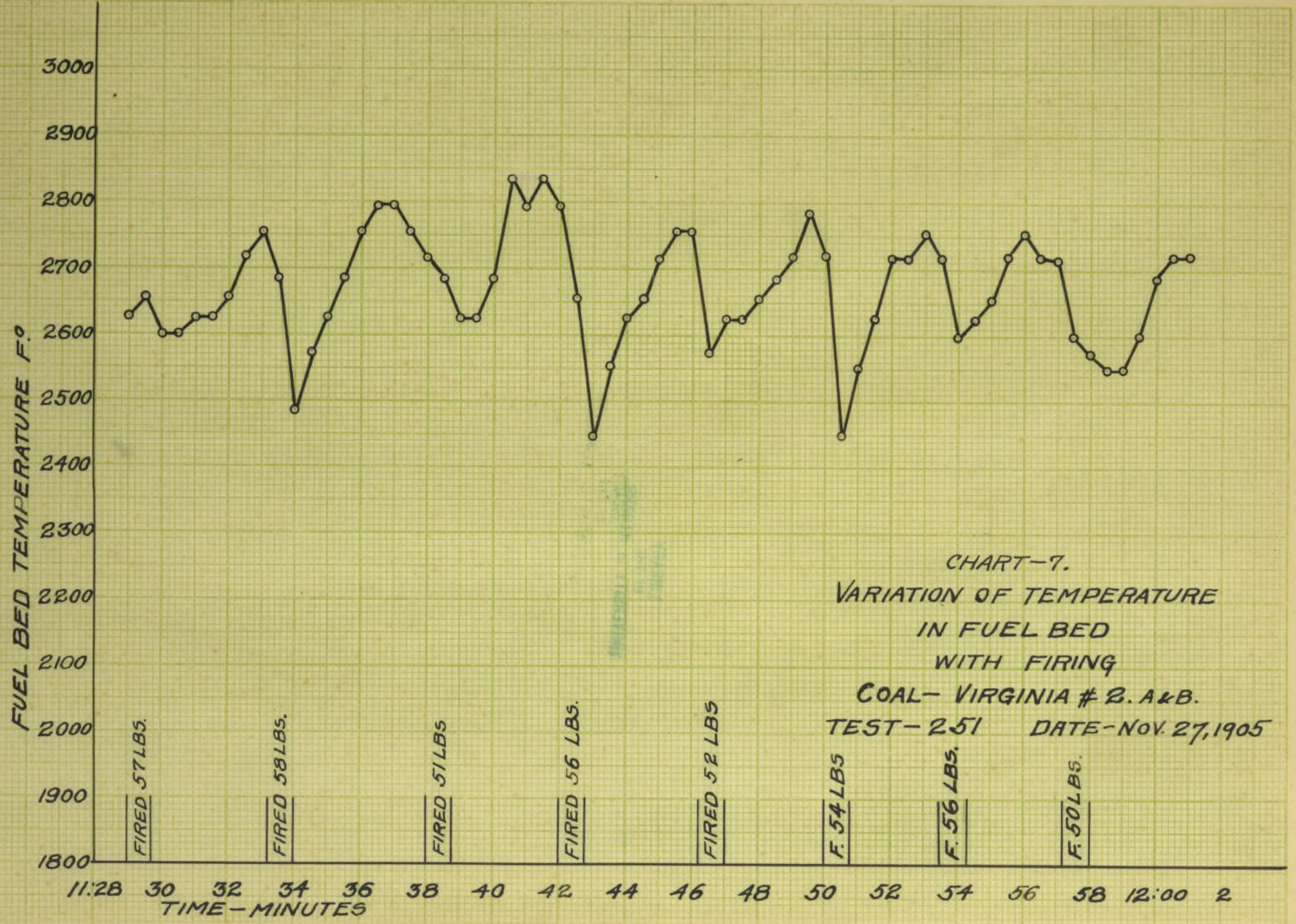
VARIATION OF TEMPERATURE IN COMBUSTION CHAMBER WITH FIRING

COAL – ILL. NO. 23.

TEST – 306 DATE – JAN. 29, 1906.

CHART – 6.

EUGENE DIETZGEN CO. CHICAGO.



CHART—7.
VARIATION OF TEMPERATURE
IN FUEL BED
WITH FIRING
COAL— VIRGINIA # 2. A & B.
TEST—251 DATE—NOV. 27, 1905

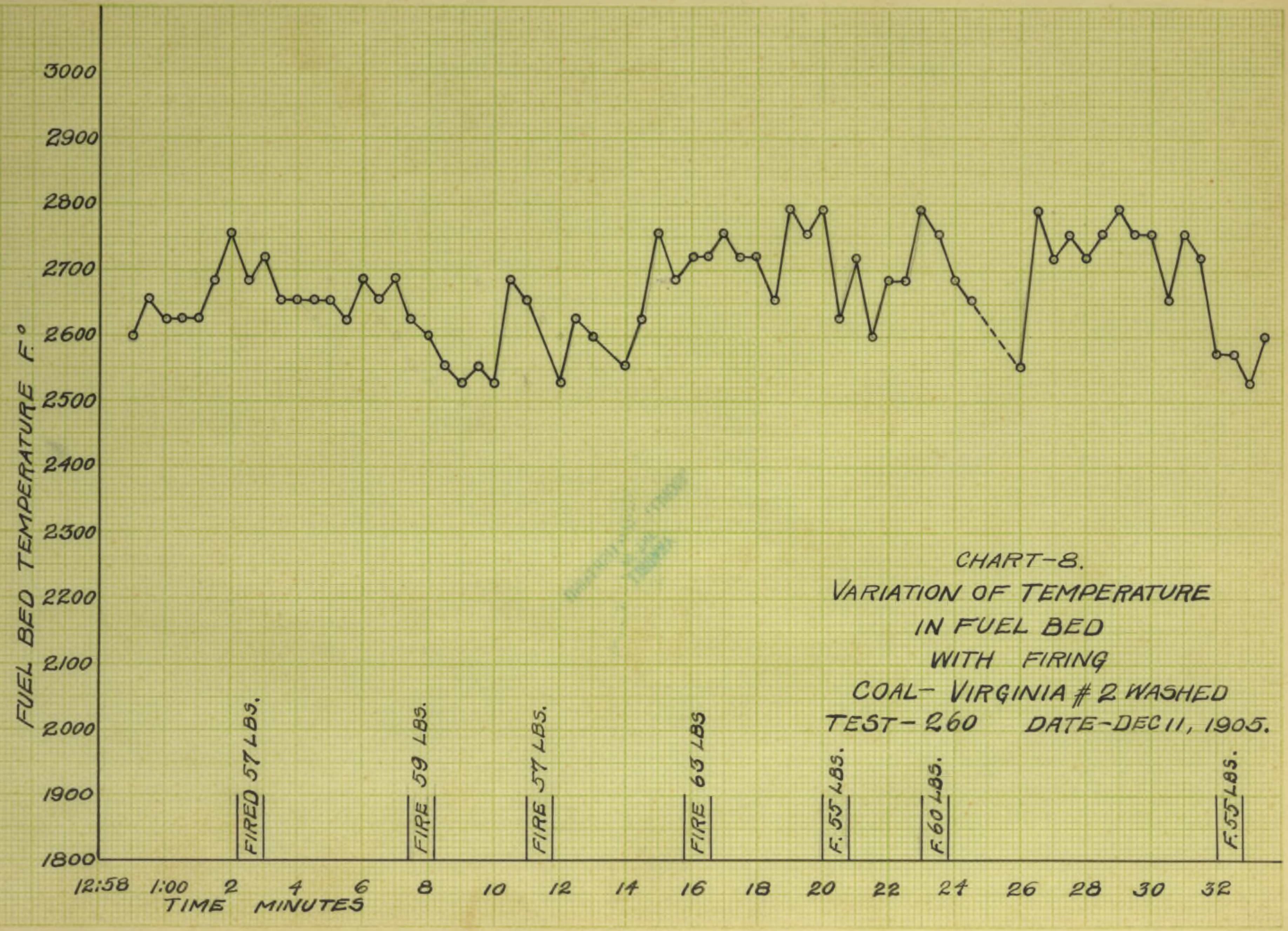
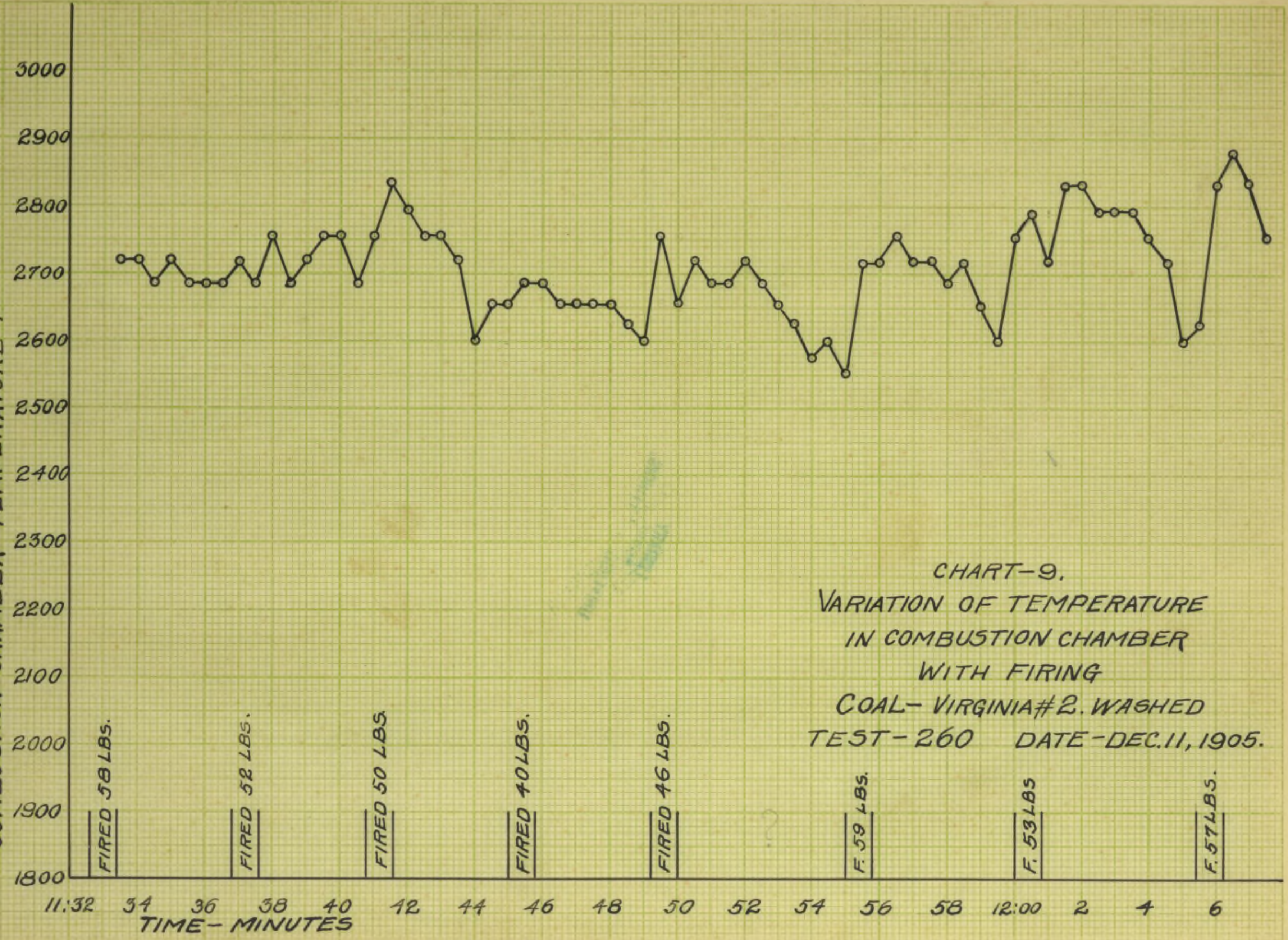


CHART-8.
VARIATION OF TEMPERATURE
IN FUEL BED
WITH FIRING
COAL- VIRGINIA # 2 WASHED
TEST- 260 DATE-DEC 11, 1905.

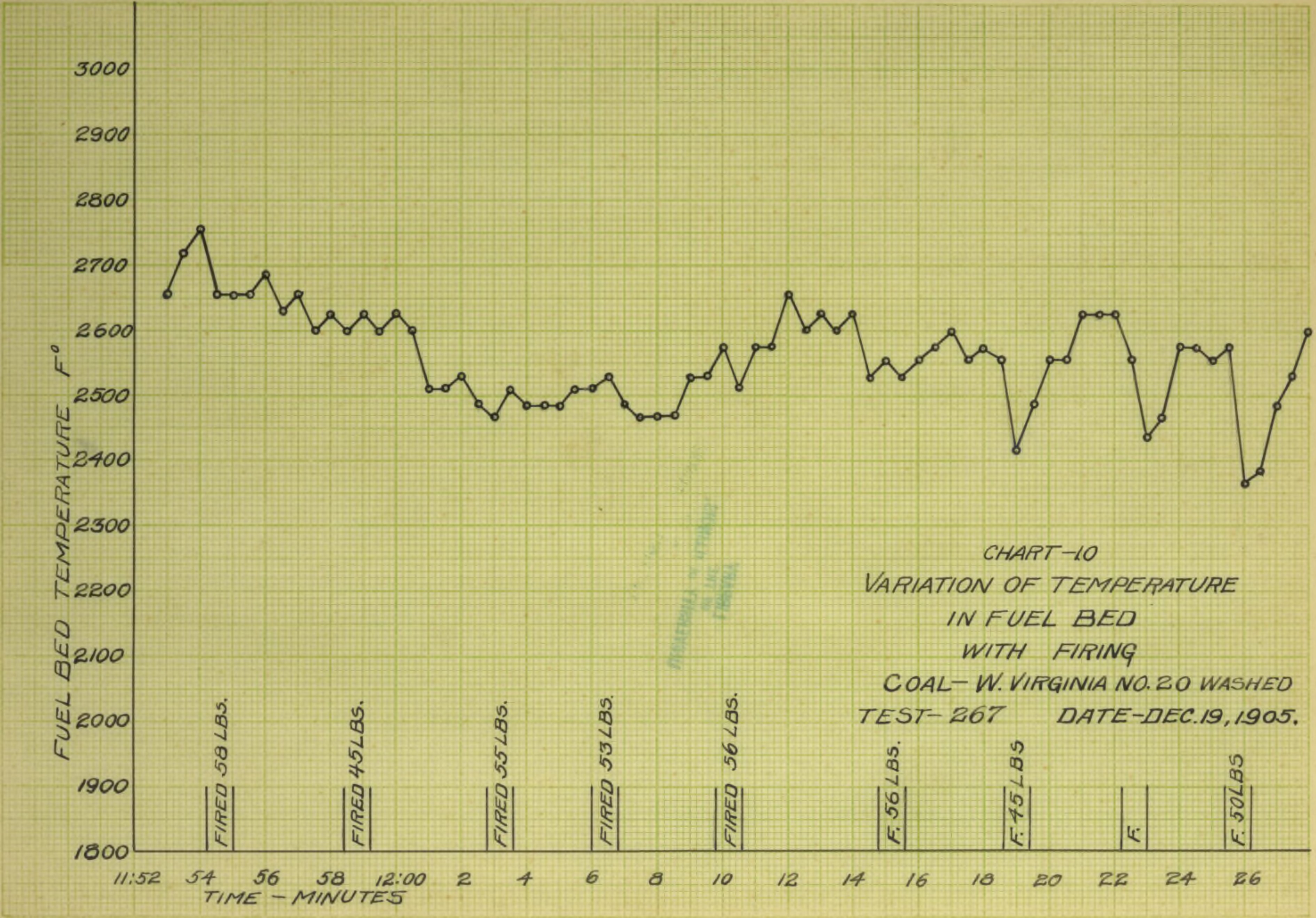
EUGENE DIETZGEN CO., CHICAGO.

EUGENE DIETZGEN CO., CHICAGO.



CHART–9.
VARIATION OF TEMPERATURE
IN COMBUSTION CHAMBER
WITH FIRING
COAL – VIRGINIA #2. WASHED
TEST – 260   DATE – DEC. 11, 1905.

EUGENE DIETZGEN CO. CHICAGO.



CHART–10
VARIATION OF TEMPERATURE
IN FUEL BED
WITH FIRING
COAL– W. VIRGINIA NO. 20 WASHED
TEST– 267 DATE–DEC. 19, 1905.

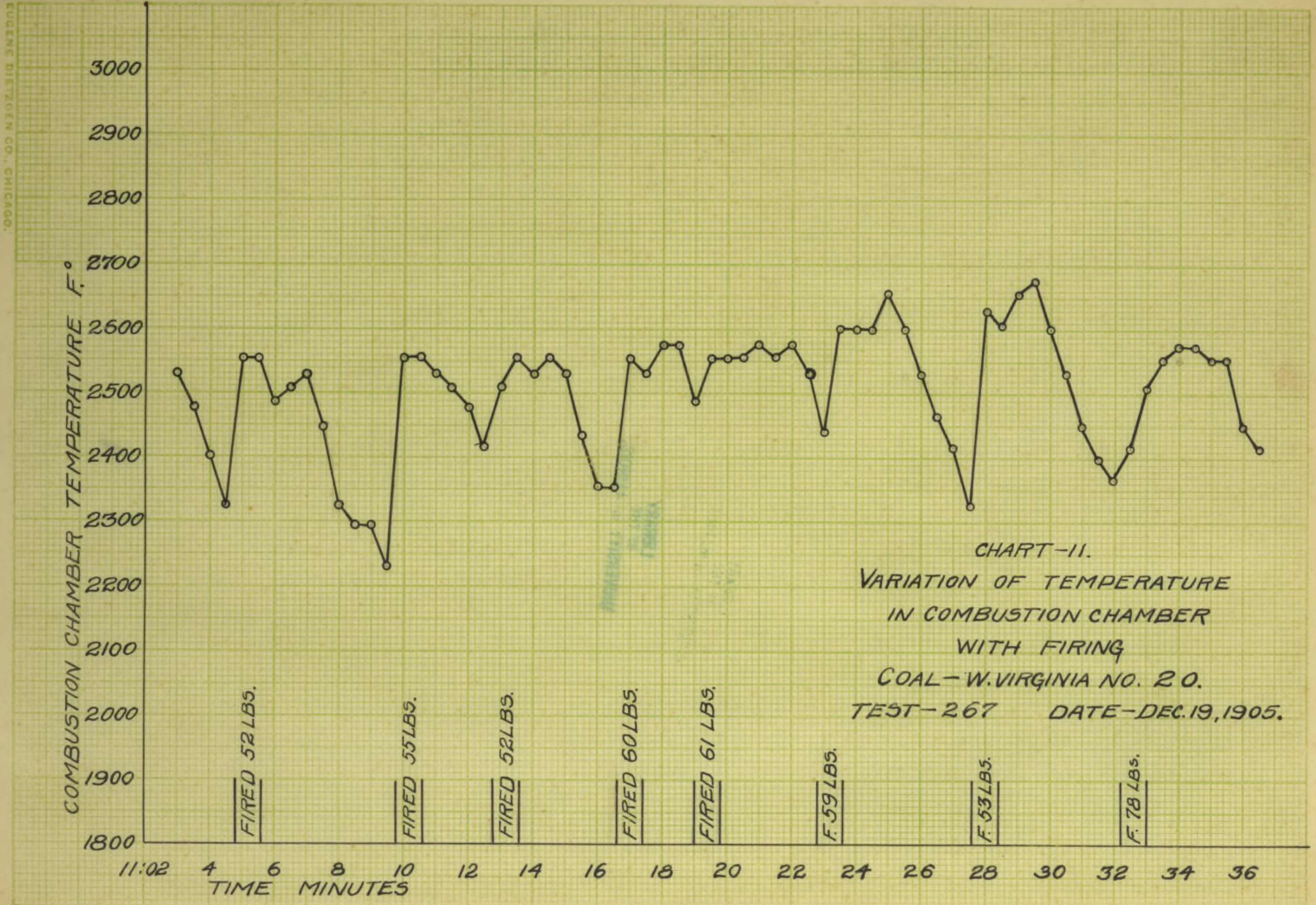


CHART-11.

VARIATION OF TEMPERATURE
IN COMBUSTION CHAMBER
WITH FIRING

COAL-W. VIRGINIA NO. 20.

TEST-267 DATE-DEC. 19, 1905.

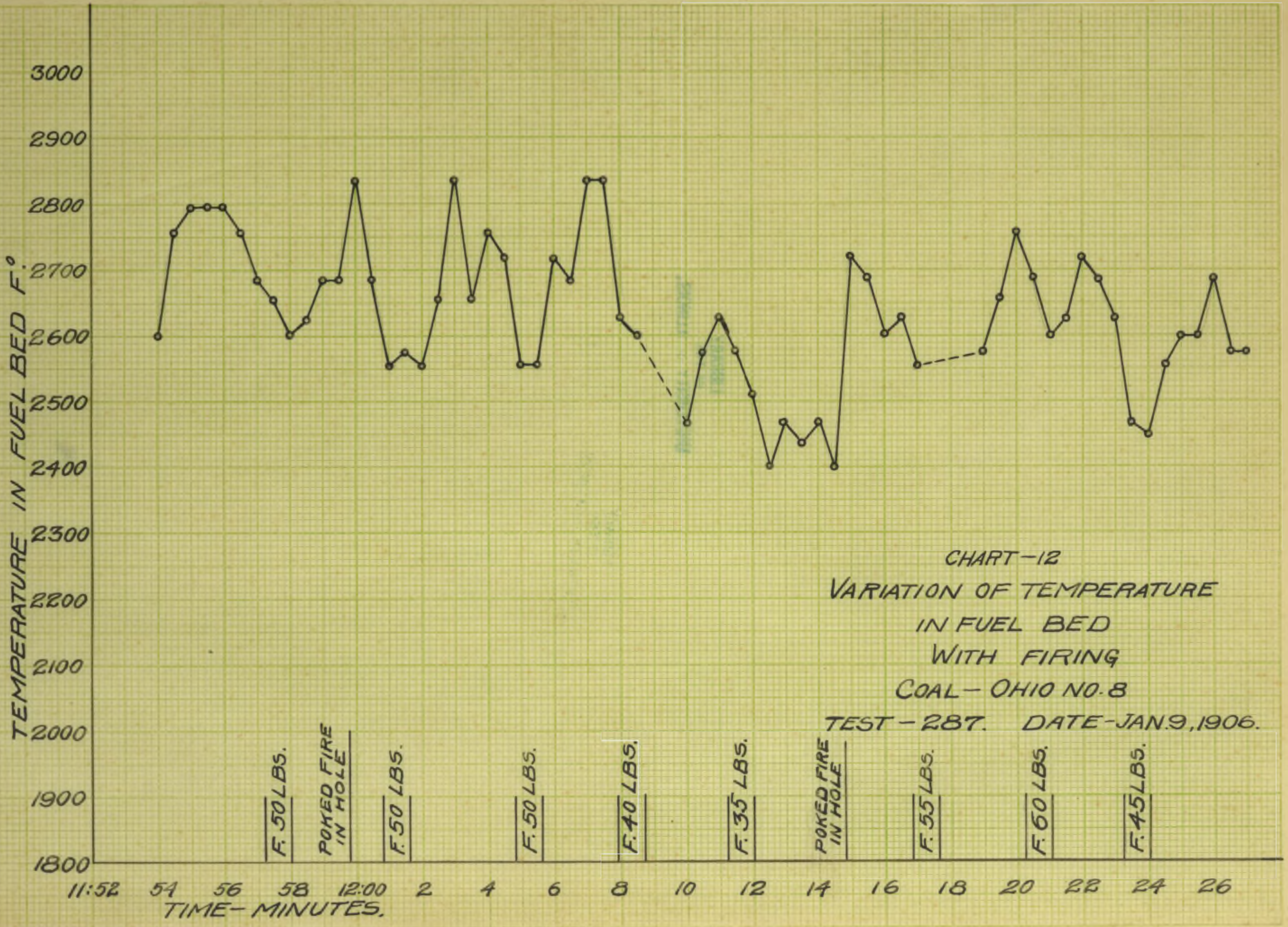


CHART-12

VARIATION OF TEMPERATURE
IN FUEL BED
WITH FIRING

COAL-OHIO NO. 8

TEST-287. DATE-JAN. 9, 1906.

EUGENE DIETZGEN CO., CHICAGO.

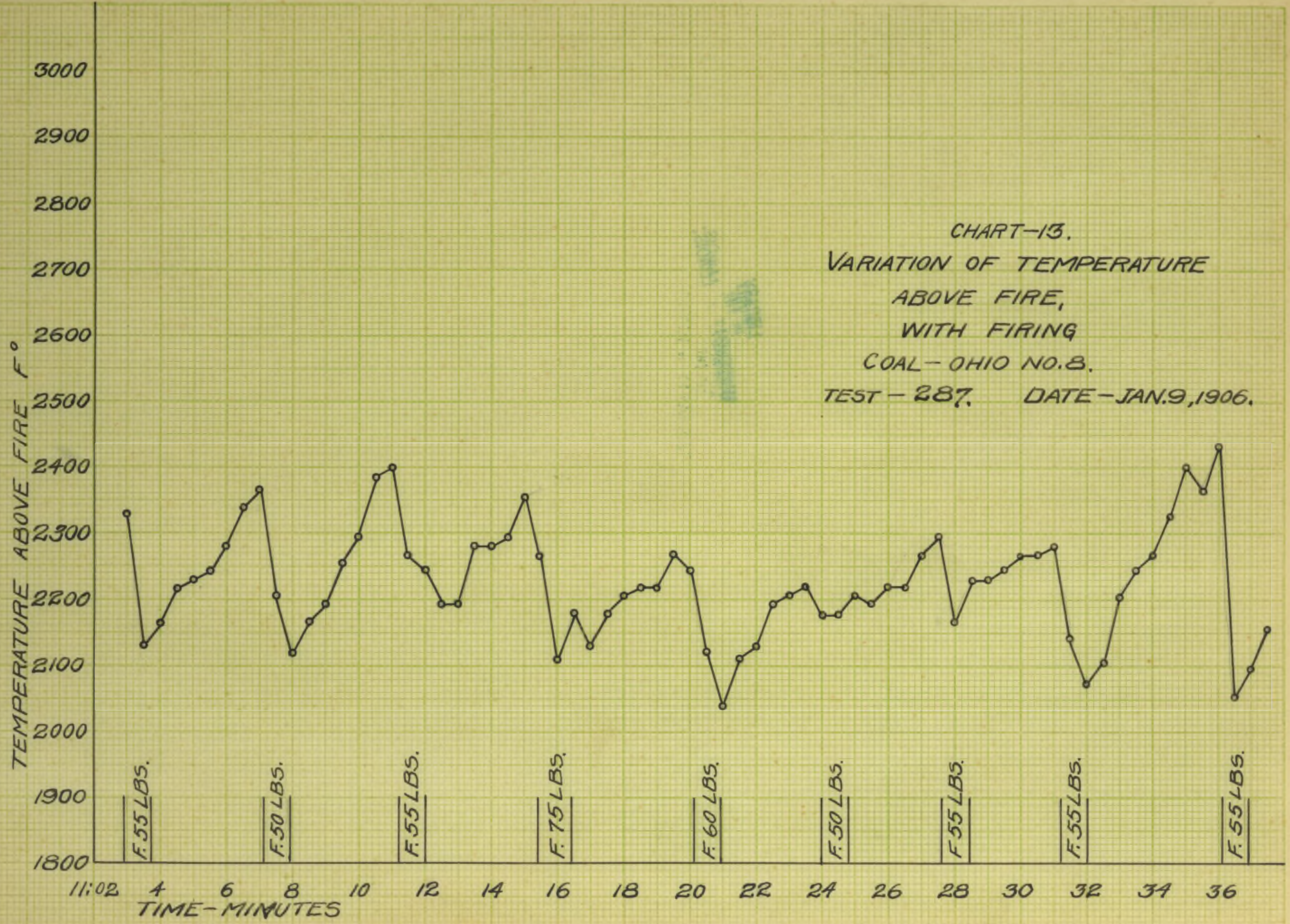
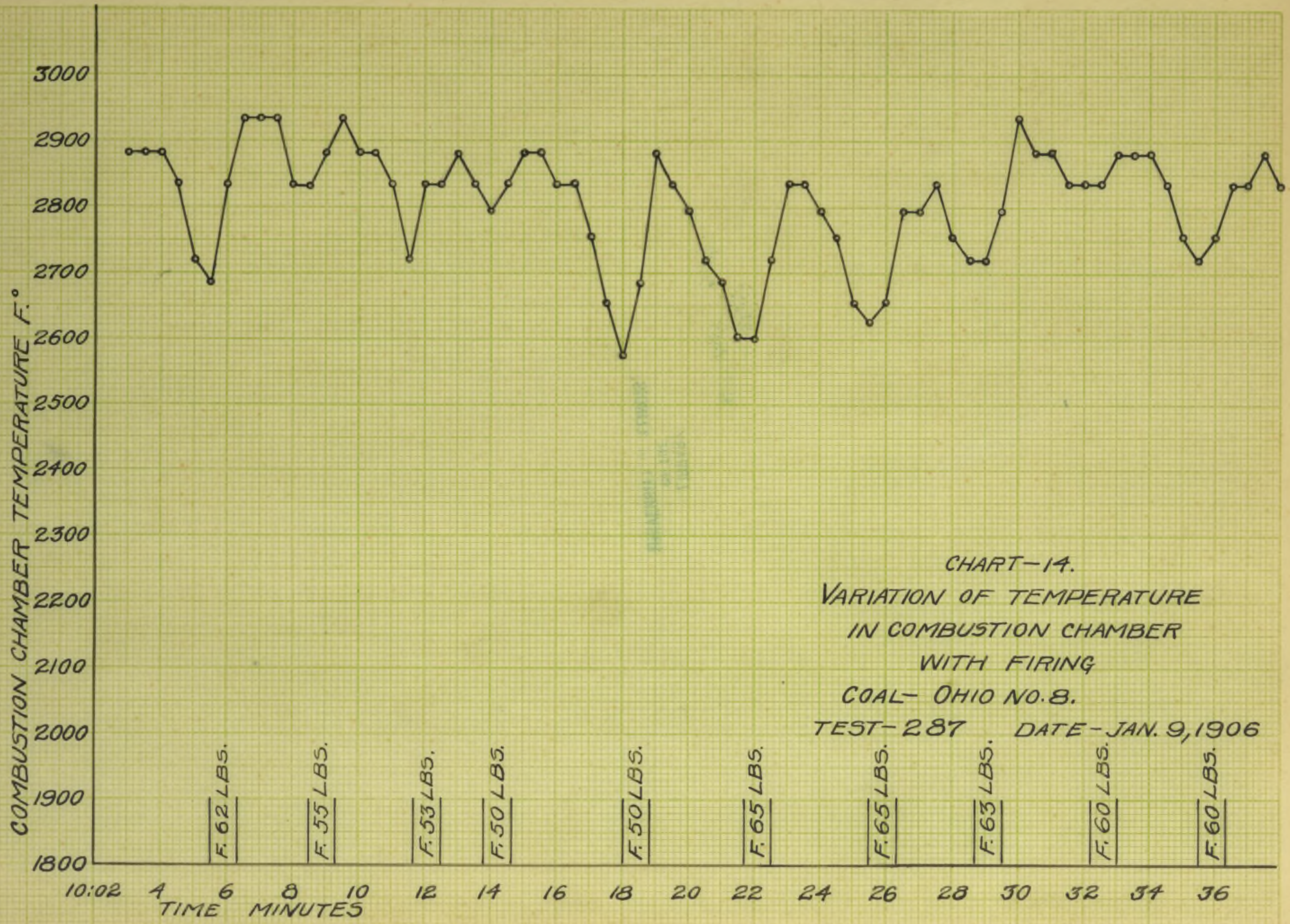


CHART-13.

VARIATION OF TEMPERATURE
ABOVE FIRE,
WITH FIRING
COAL-OHIO NO. 8.
TEST-287. DATE-JAN. 9, 1906.

EUGENE DIETZGEN CO., CHICAGO.

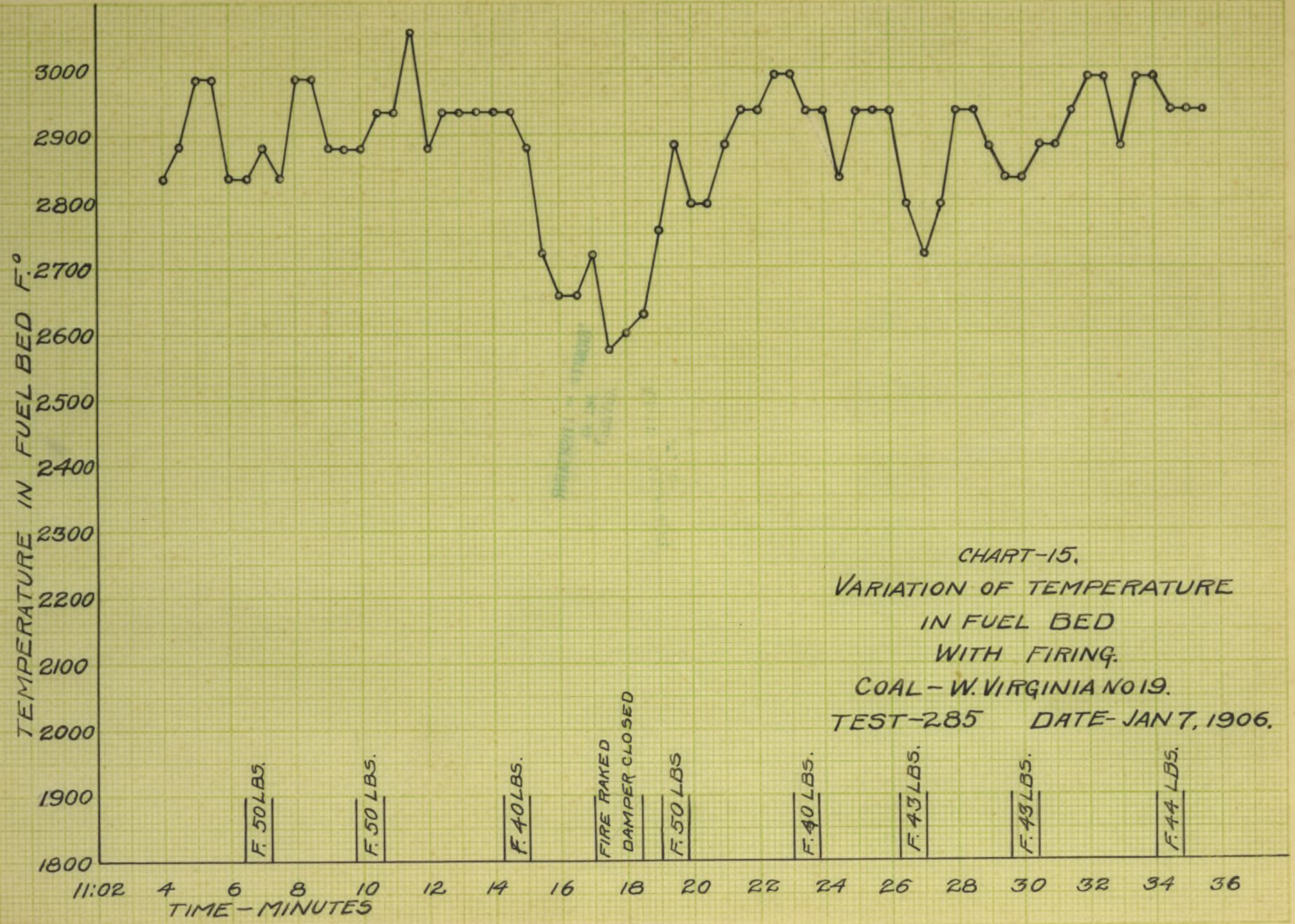
EUGENE DIETZGEN CO., CHICAGO.



CHART—14.

VARIATION OF TEMPERATURE
IN COMBUSTION CHAMBER
WITH FIRING
COAL— OHIO NO. 8.
TEST—287 DATE—JAN. 9, 1906

EUGENE DIETZGEN CO., CHICAGO.



CHART–15.
VARIATION OF TEMPERATURE
IN FUEL BED
WITH FIRING.
COAL – W. VIRGINIA NO 19.
TEST–285 DATE– JAN 7, 1906.

EUGENE DIETZGEN CO., CHICAGO.

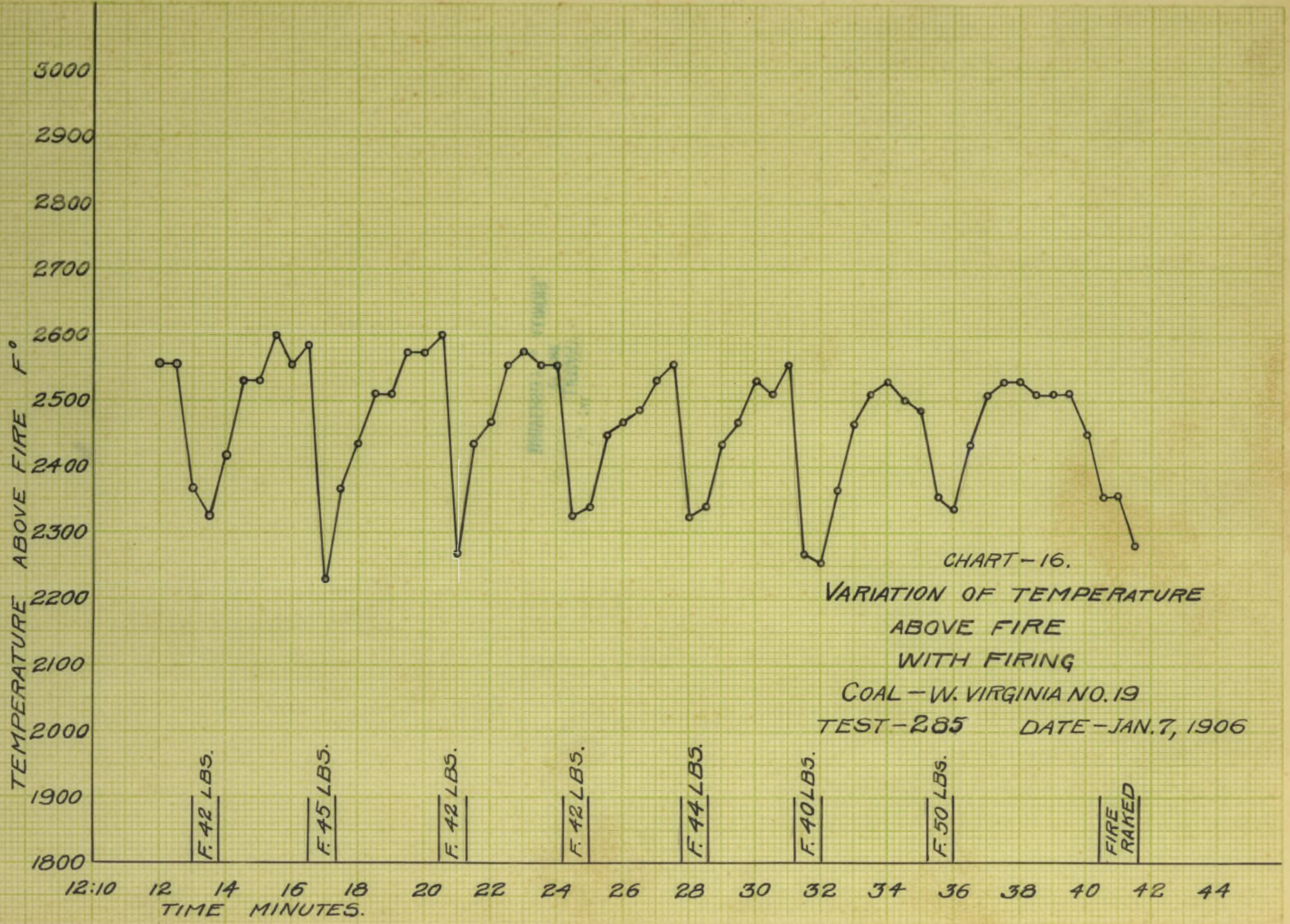


CHART – 16.

VARIATION OF TEMPERATURE
ABOVE FIRE
WITH FIRING
COAL – W. VIRGINIA NO. 19
TEST – 285 DATE – JAN. 7, 1906

EUGENE DIETZGEN CO., CHICAGO.

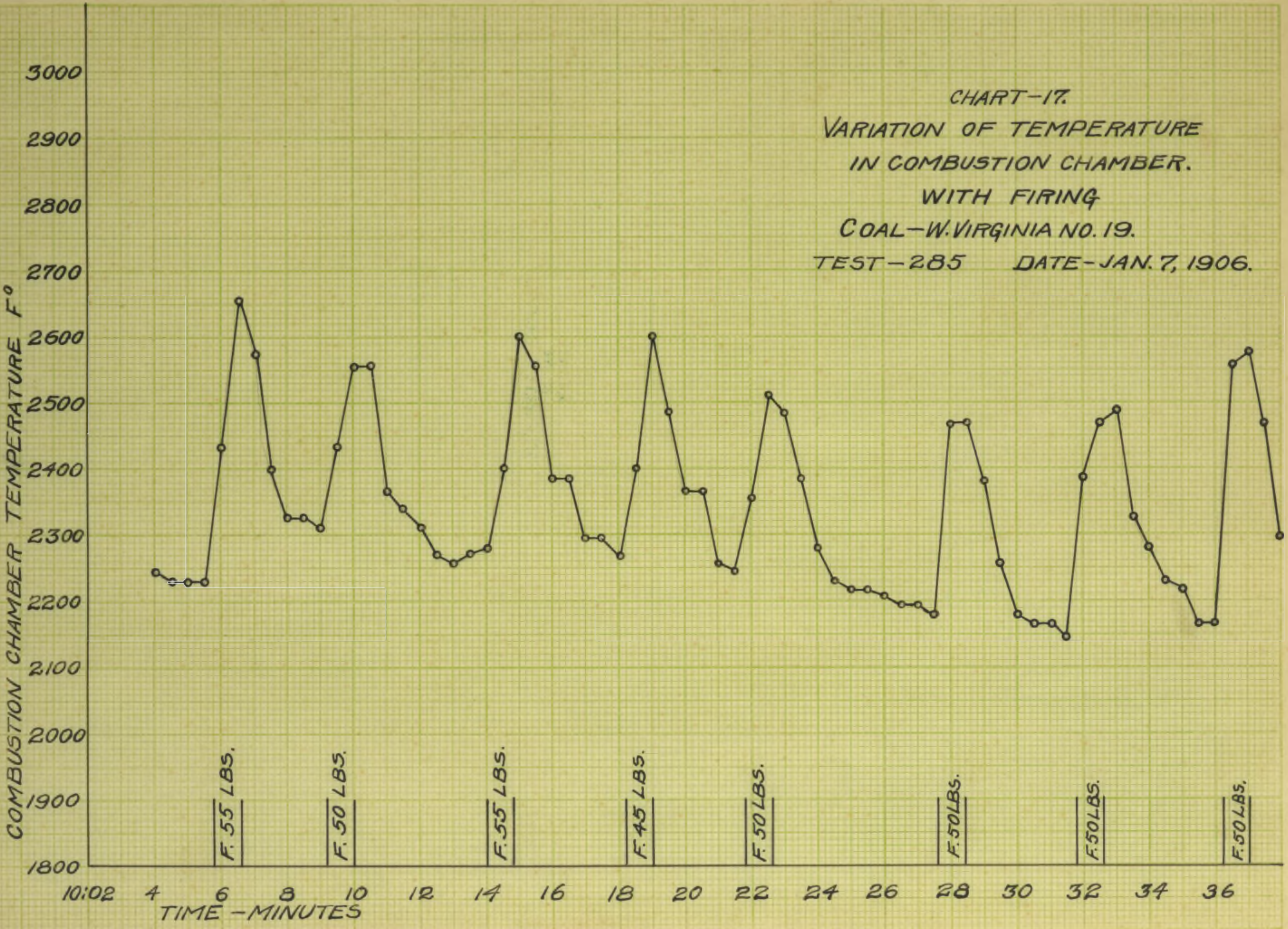


CHART-17.
VARIATION OF TEMPERATURE
IN COMBUSTION CHAMBER.
WITH FIRING
COAL-W. VIRGINIA NO. 19.
TEST-285 DATE-JAN. 7, 1906.

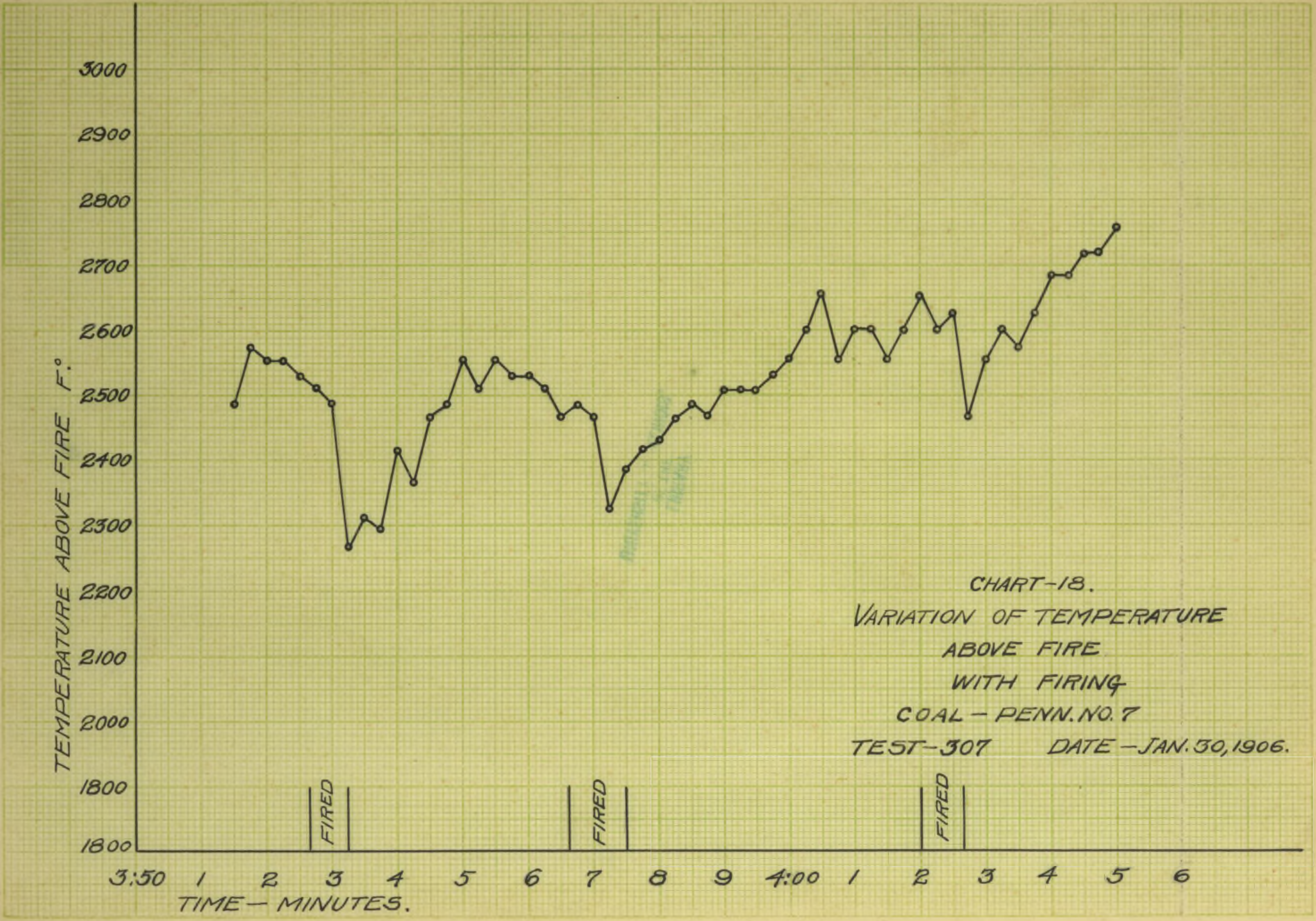


CHART-18.
VARIATION OF TEMPERATURE
ABOVE FIRE
WITH FIRING
COAL — PENN. NO. 7
TEST-307 DATE — JAN. 30, 1906.

EUGENE DIETZGEN CO., CHICAGO.

EUGENE DIETZGEN CO., CHICAGO.

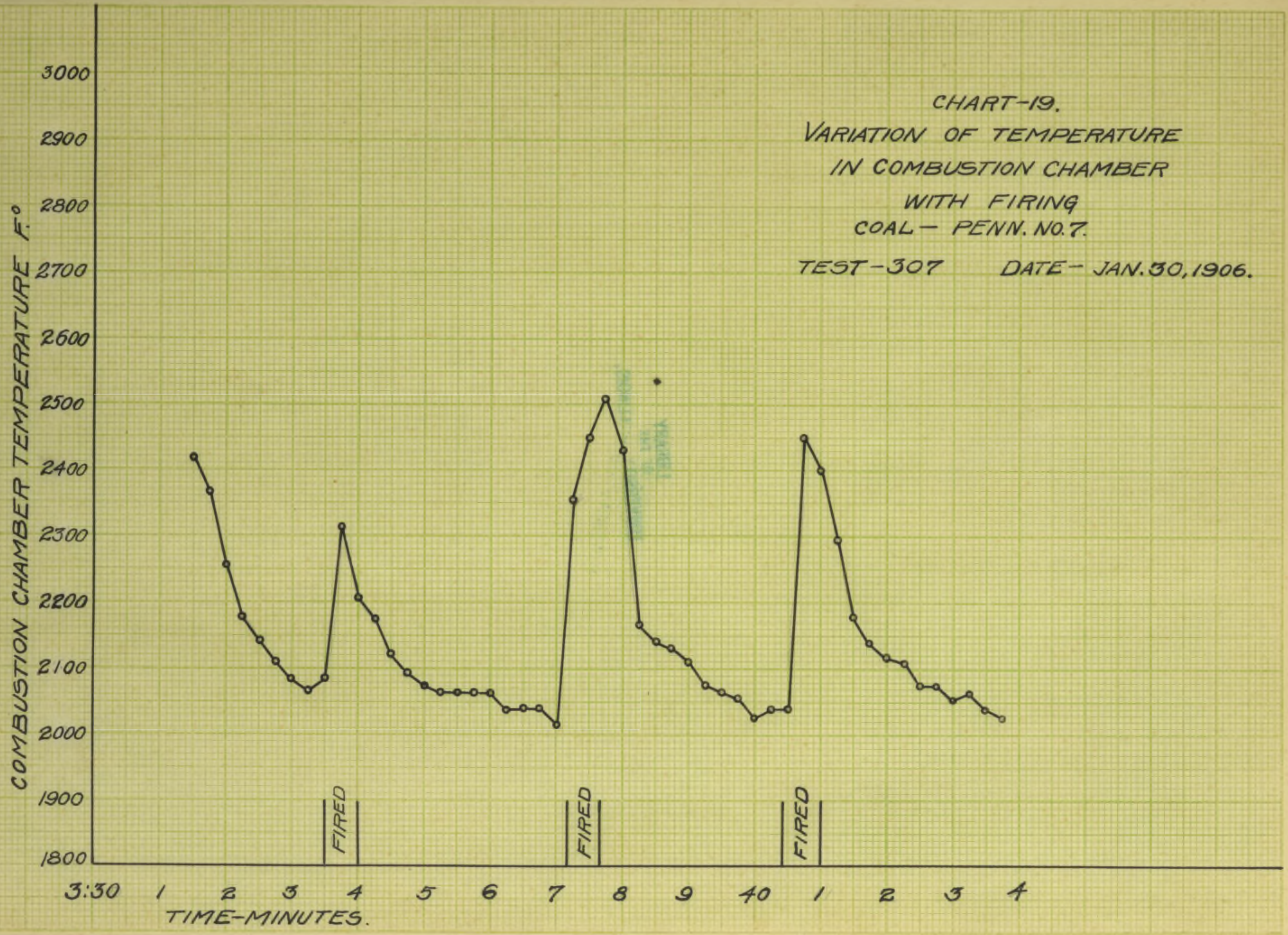


CHART-19.
VARIATION OF TEMPERATURE
IN COMBUSTION CHAMBER
WITH FIRING
COAL— PENN. NO.7.

TEST-307 DATE— JAN.30,1906.

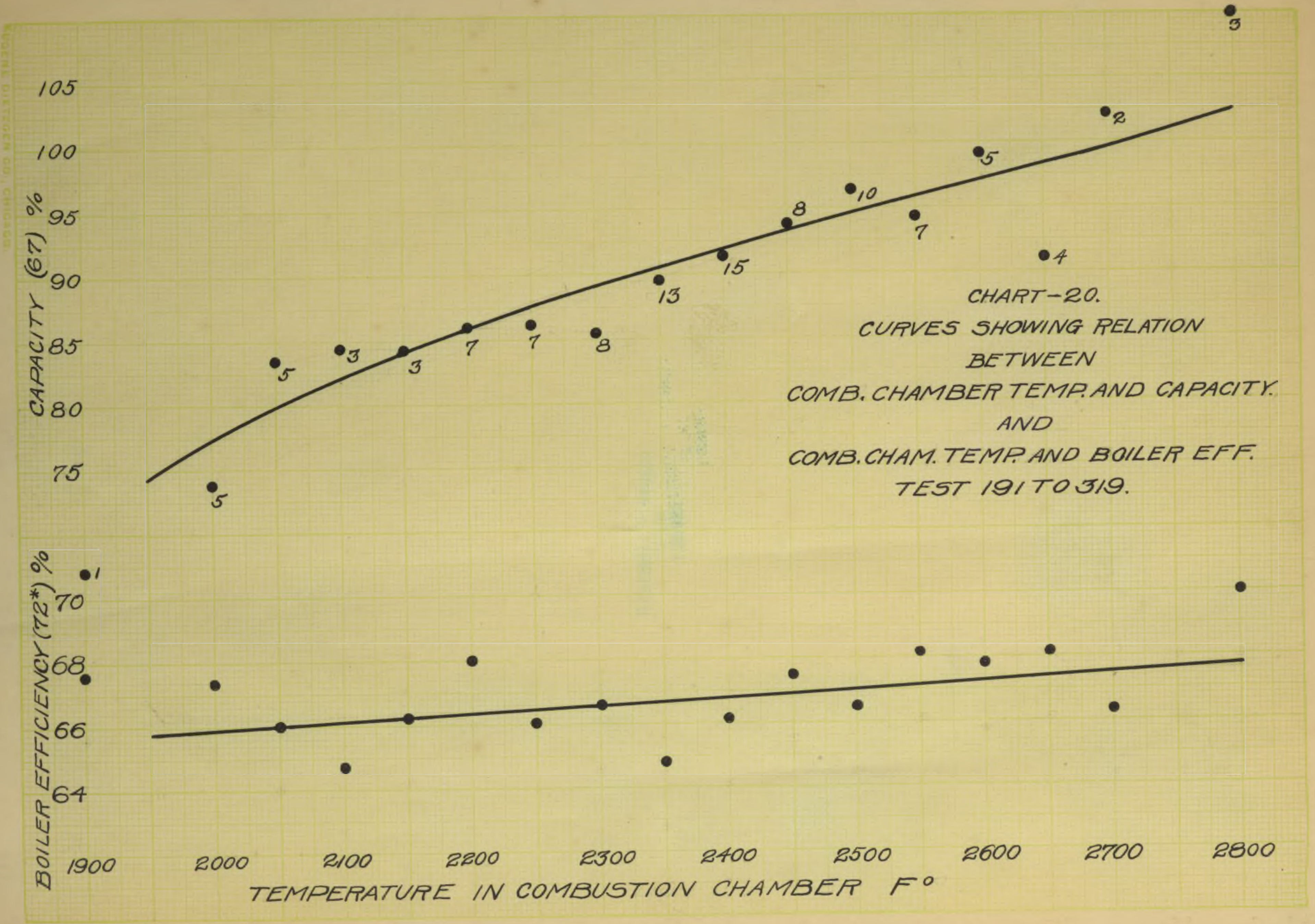


CHART-20.
CURVES SHOWING RELATION BETWEEN COMB. CHAMBER TEMP. AND CAPACITY. AND COMB. CHAM. TEMP. AND BOILER EFF. TEST 191 TO 319.

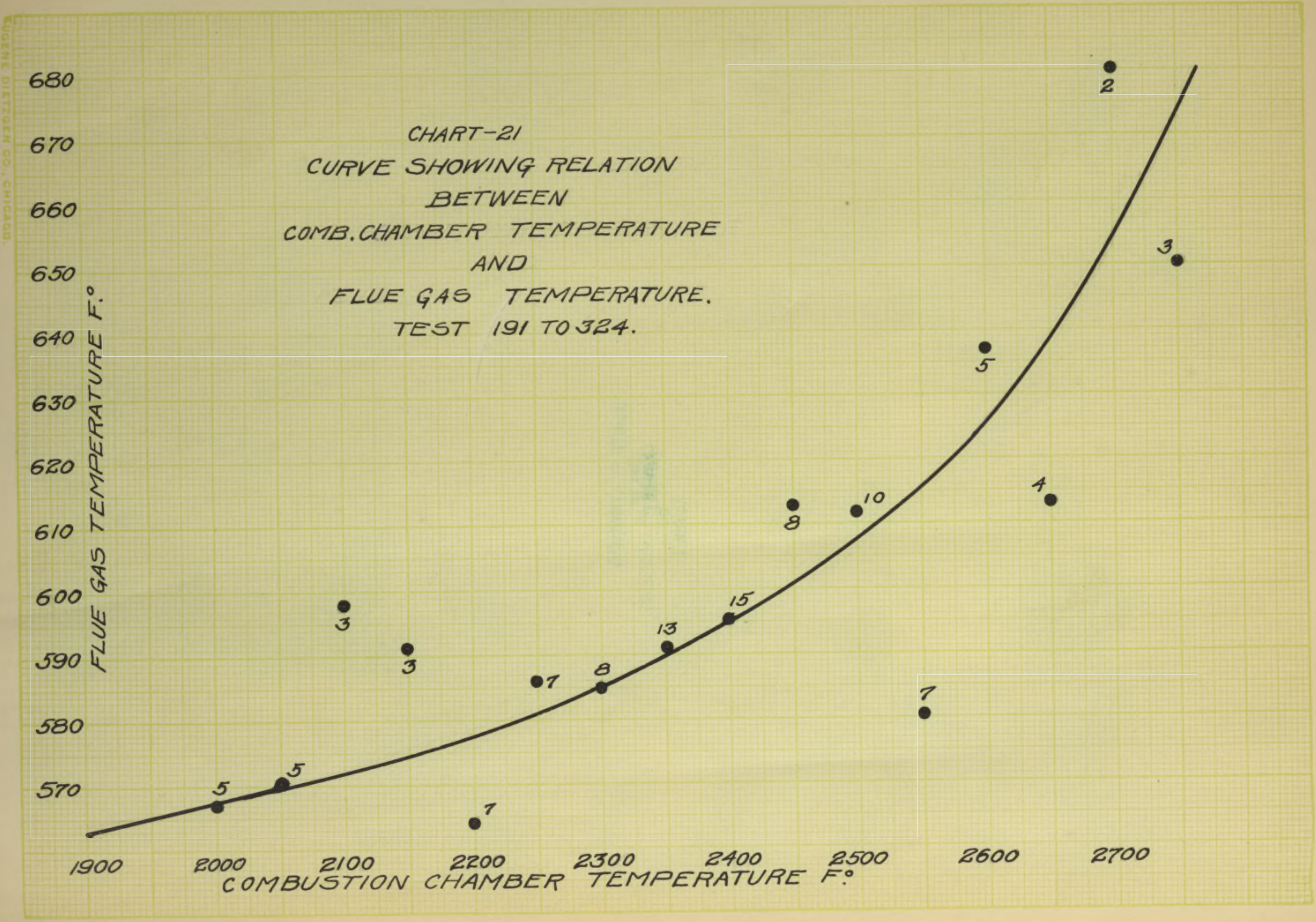
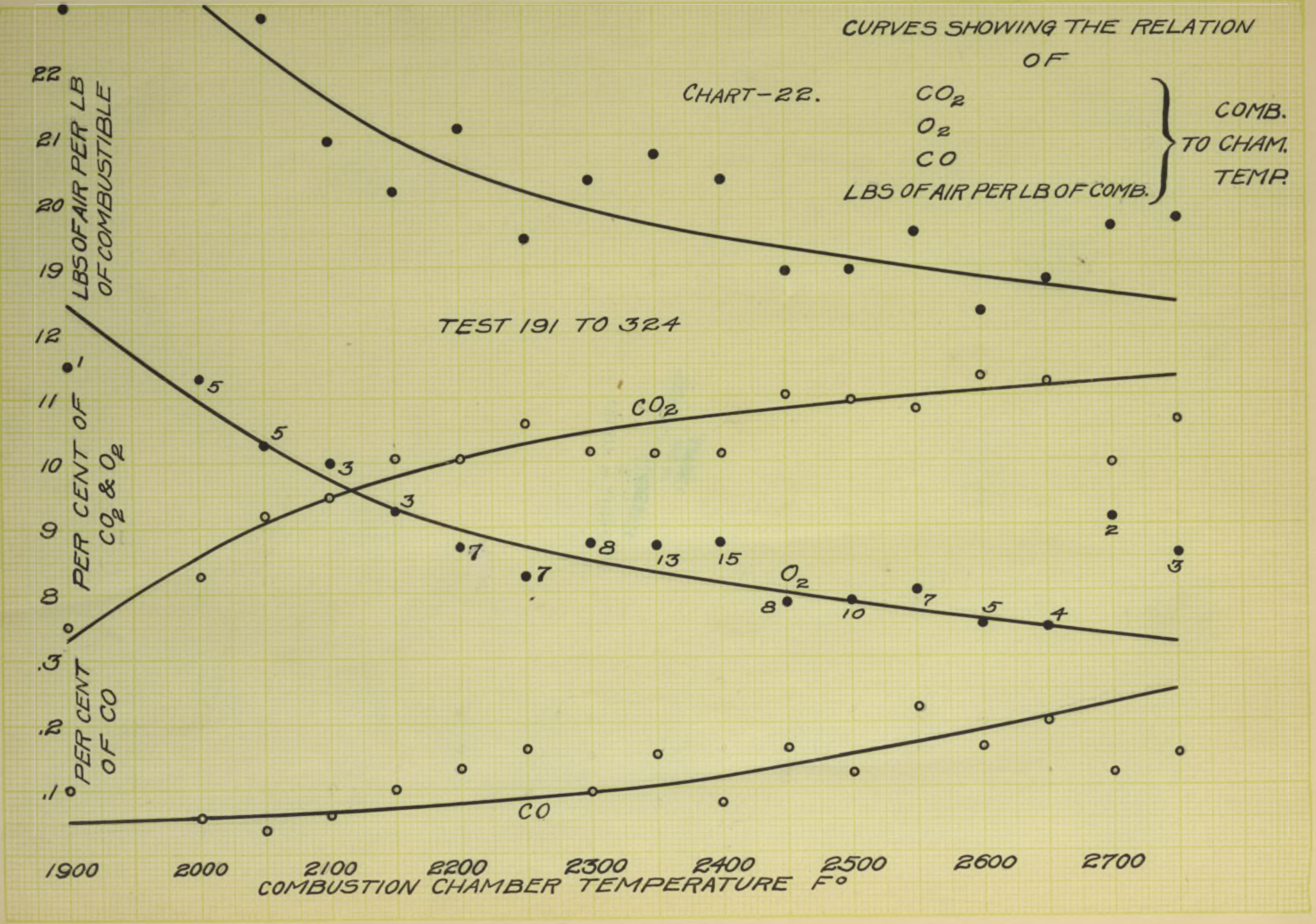


CHART-21
CURVE SHOWING RELATION
BETWEEN
COMB. CHAMBER TEMPERATURE
AND
FLUE GAS TEMPERATURE.
TEST 191 TO 324.

EUGENE DIETZGEN CO., CHICAGO.



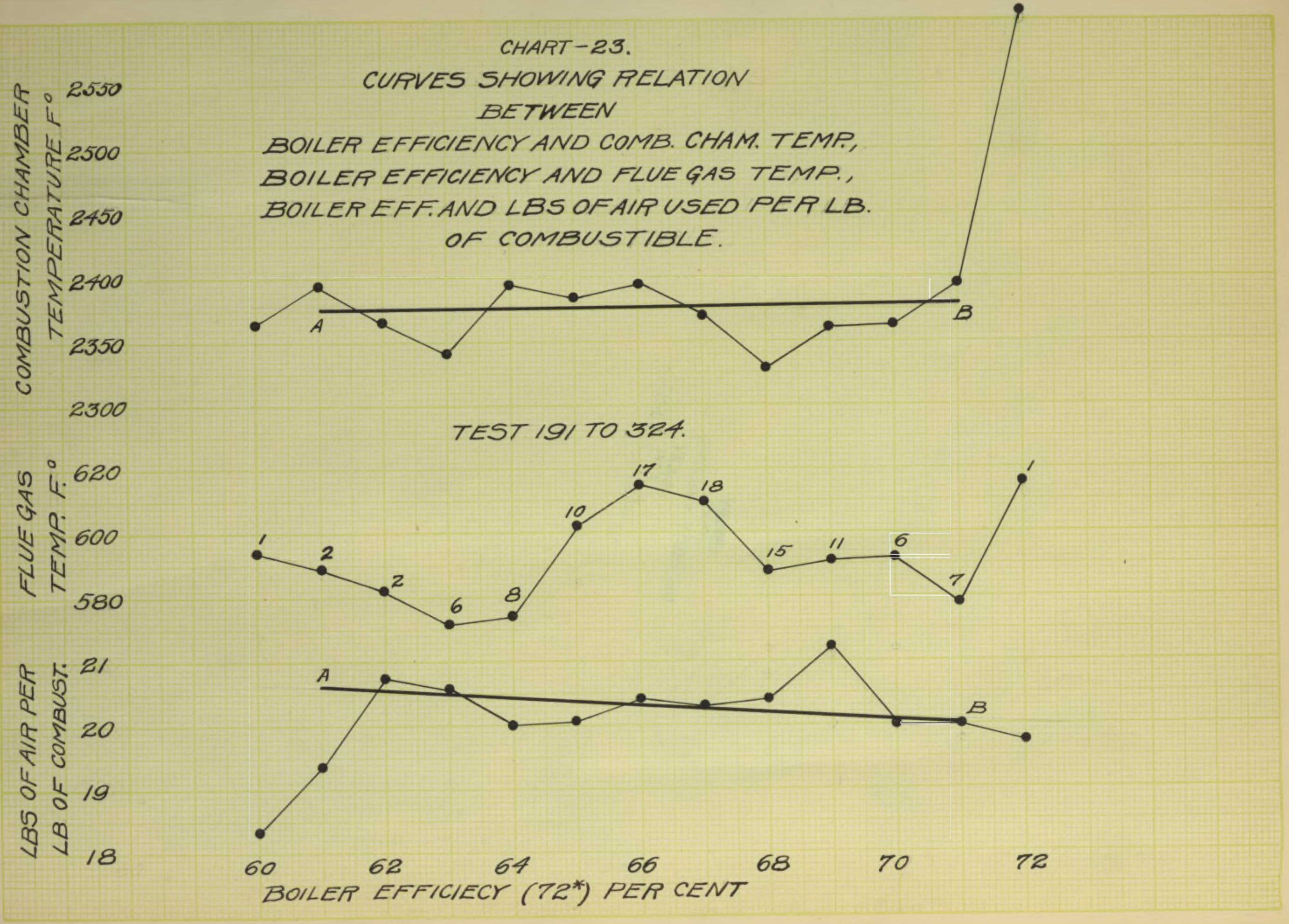
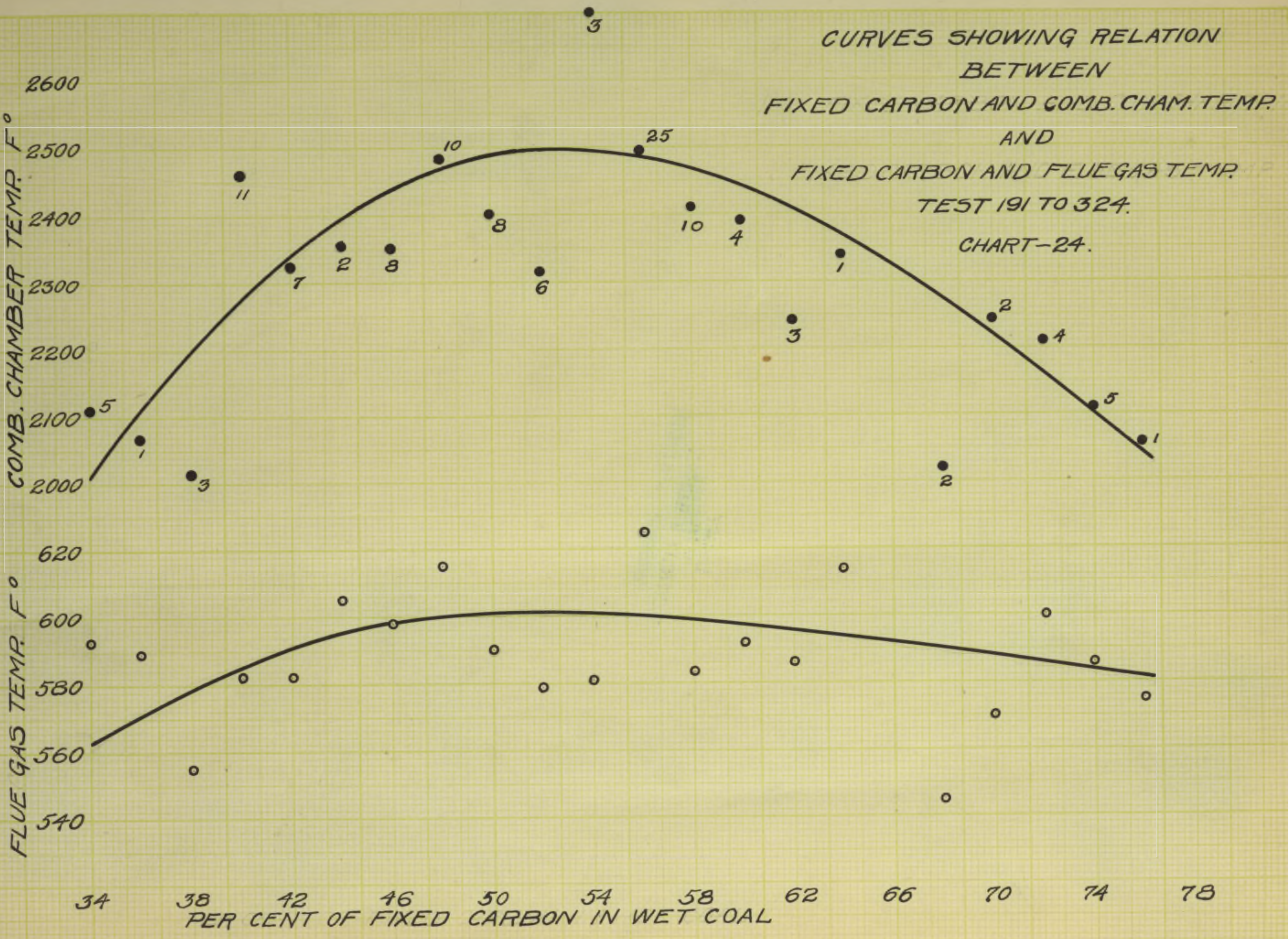


CHART – 23.
CURVES SHOWING RELATION
BETWEEN
BOILER EFFICIENCY AND COMB. CHAM. TEMP.,
BOILER EFFICIENCY AND FLUE GAS TEMP.,
BOILER EFF. AND LBS OF AIR USED PER LB.
OF COMBUSTIBLE.

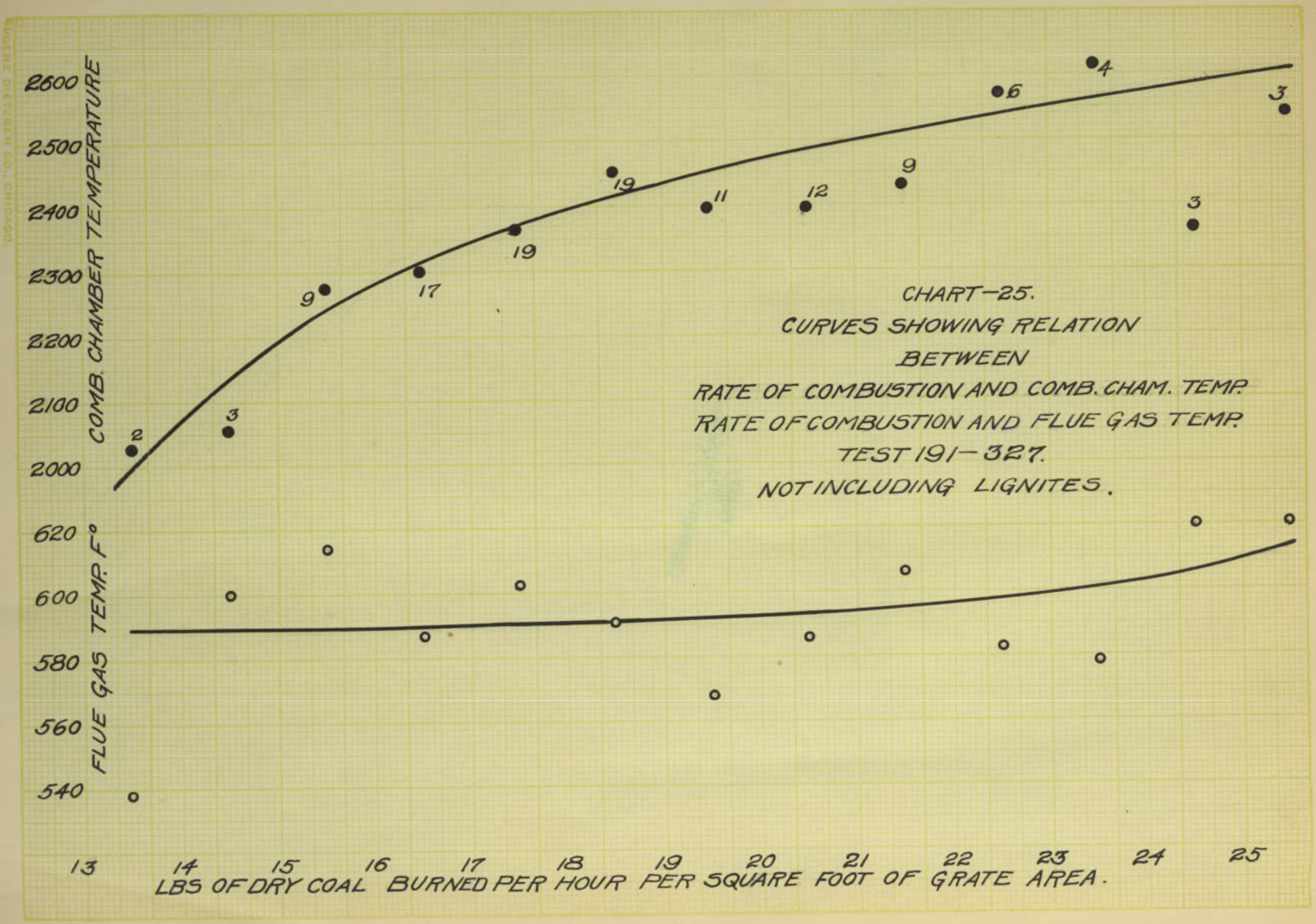
TEST 191 TO 324.

EUGENE DIETZGEN CO., CHICAGO.

EUGENE DIETZGEN CO., CHICAGO.



CURVES SHOWING RELATION
BETWEEN
FIXED CARBON AND COMB. CHAM. TEMP.
AND
FIXED CARBON AND FLUE GAS TEMP.
TEST 191 TO 324.
CHART–24.


CHART—25.
CURVES SHOWING RELATION
BETWEEN
RATE OF COMBUSTION AND COMB. CHAM. TEMP.
RATE OF COMBUSTION AND FLUE GAS TEMP.
TEST 191—327.
NOT INCLUDING LIGNITES.

EUGENE DIETZGEN CO., CHICAGO.

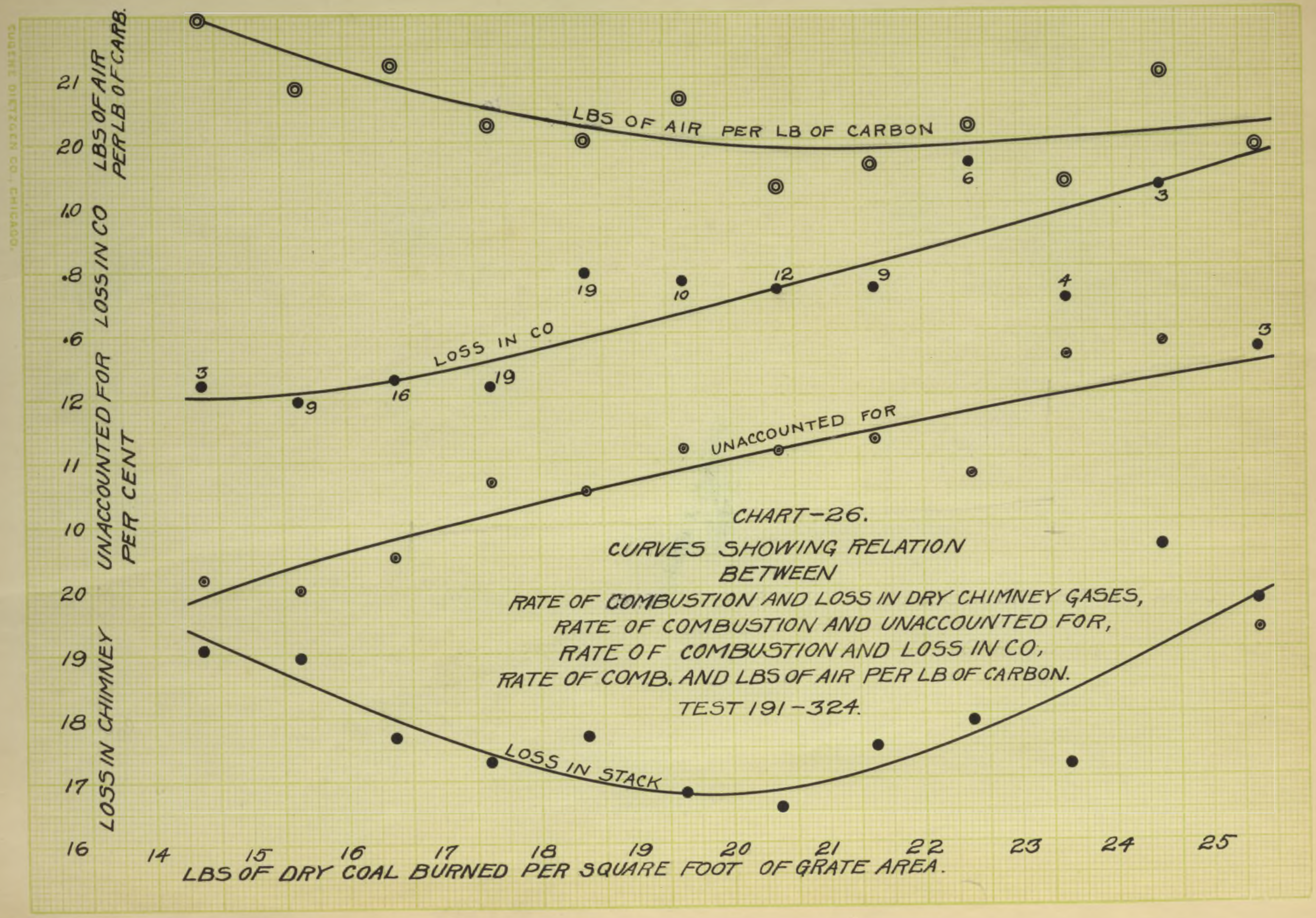
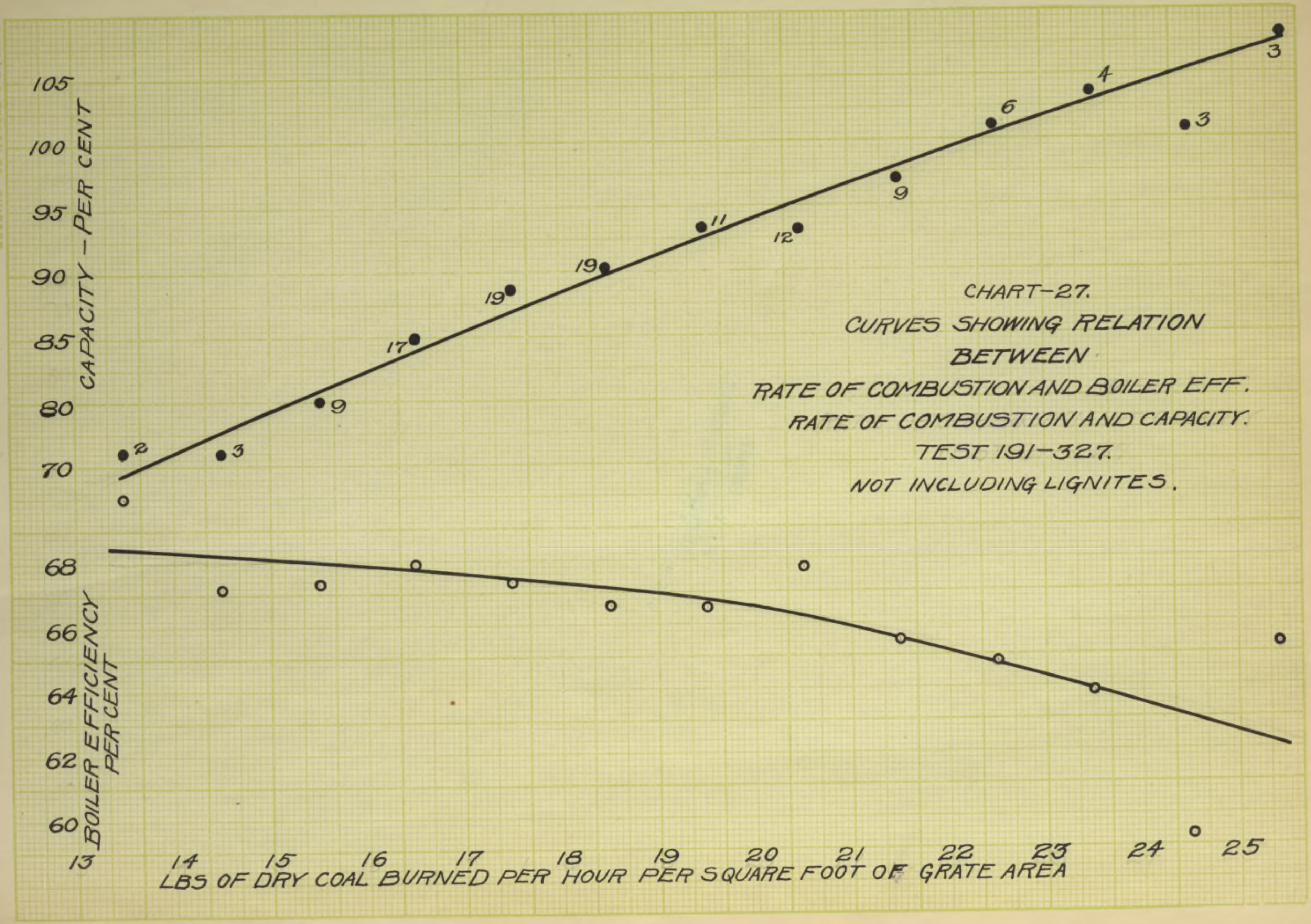


CHART-26.

CURVES SHOWING RELATION BETWEEN
RATE OF COMBUSTION AND LOSS IN DRY CHIMNEY GASES,
RATE OF COMBUSTION AND UNACCOUNTED FOR,
RATE OF COMBUSTION AND LOSS IN CO,
RATE OF COMB. AND LBS OF AIR PER LB OF CARBON.

TEST 191-324.

EUGENE DIETZGEN CO., CHICAGO.



CHART–27.
CURVES SHOWING RELATION
BETWEEN
RATE OF COMBUSTION AND BOILER EFF.
RATE OF COMBUSTION AND CAPACITY.
TEST 191–327.
NOT INCLUDING LIGNITES.

EUGENE DIETZGEN CO., CHICAGO.

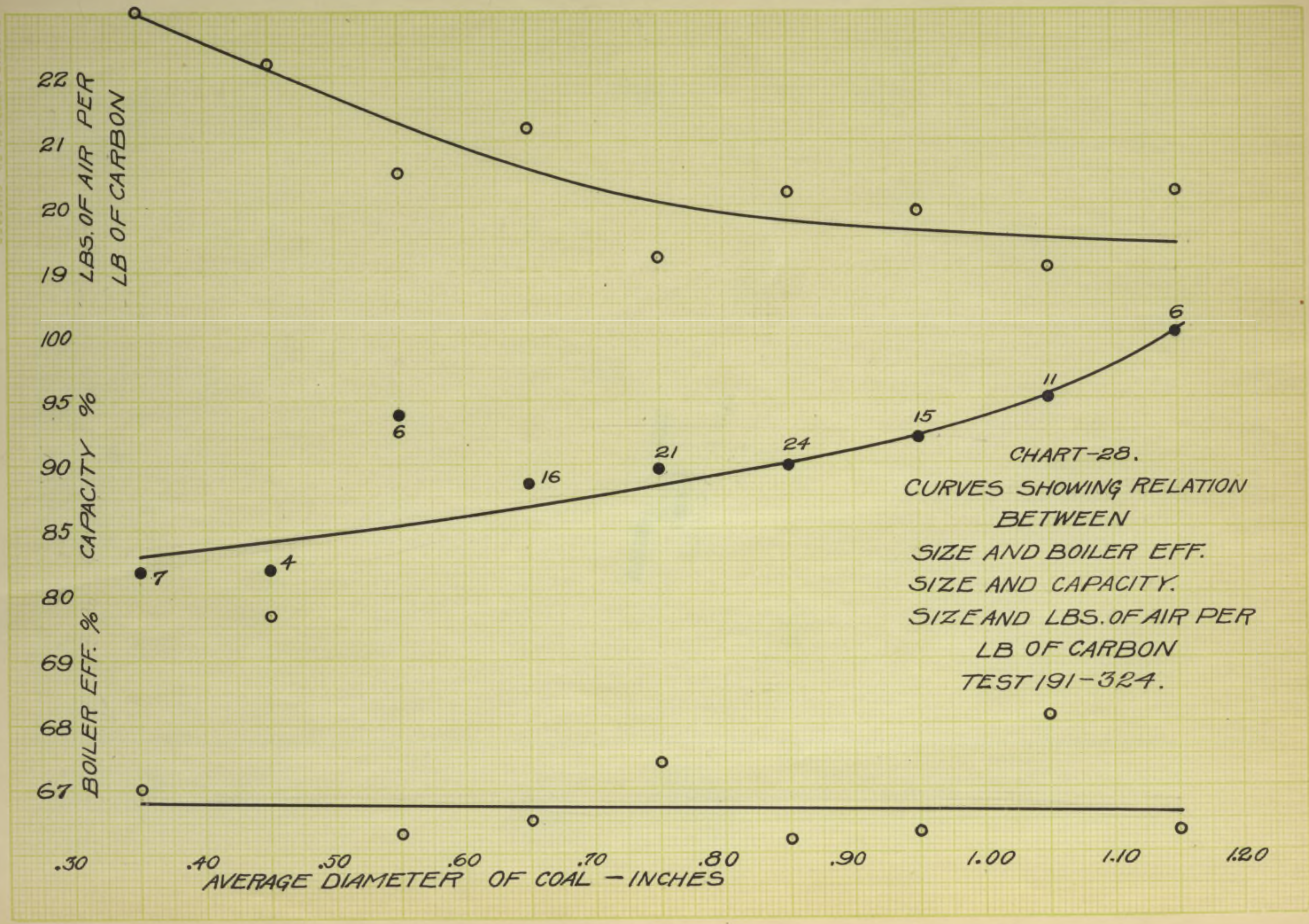


CHART-28.
CURVES SHOWING RELATION
BETWEEN
SIZE AND BOILER EFF.
SIZE AND CAPACITY.
SIZE AND LBS. OF AIR PER
LB OF CARBON
TEST 191–324.

EUGENE DIETZGEN CO. CHICAGO.

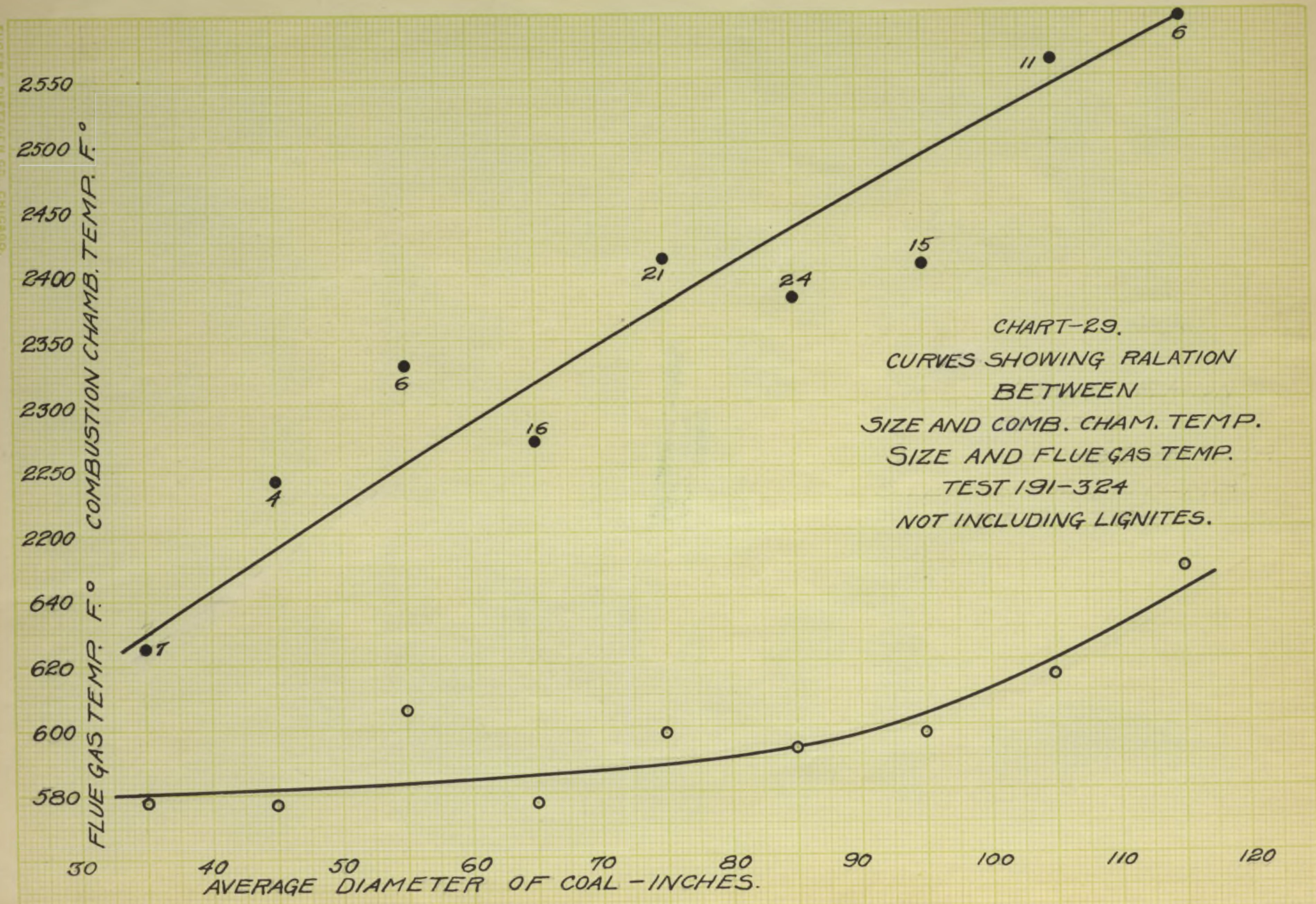
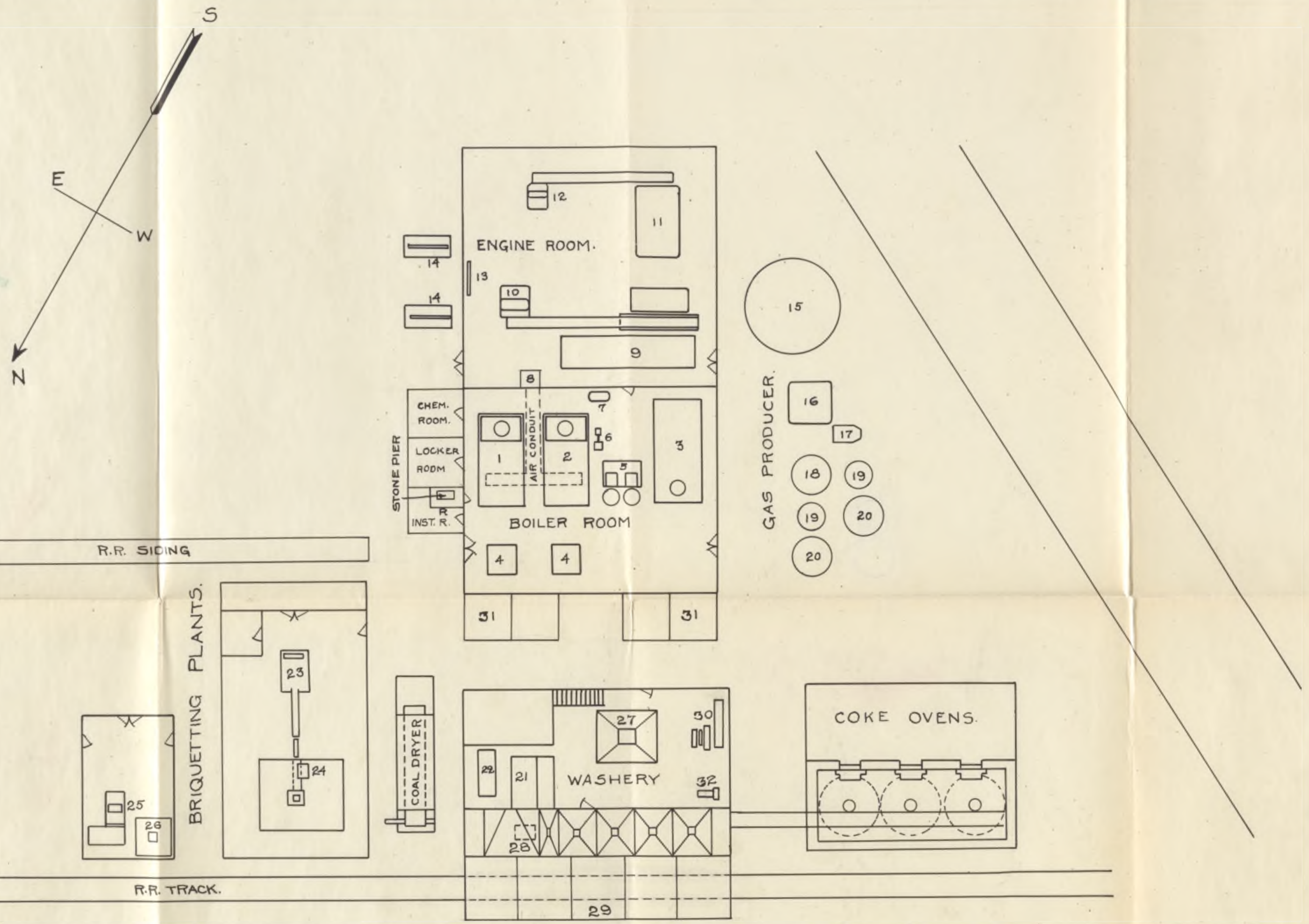


CHART-29.
CURVES SHOWING RALATION
BETWEEN
SIZE AND COMB. CHAM. TEMP.
SIZE AND FLUE GAS TEMP.
TEST 191-324
NOT INCLUDING LIGNITES.

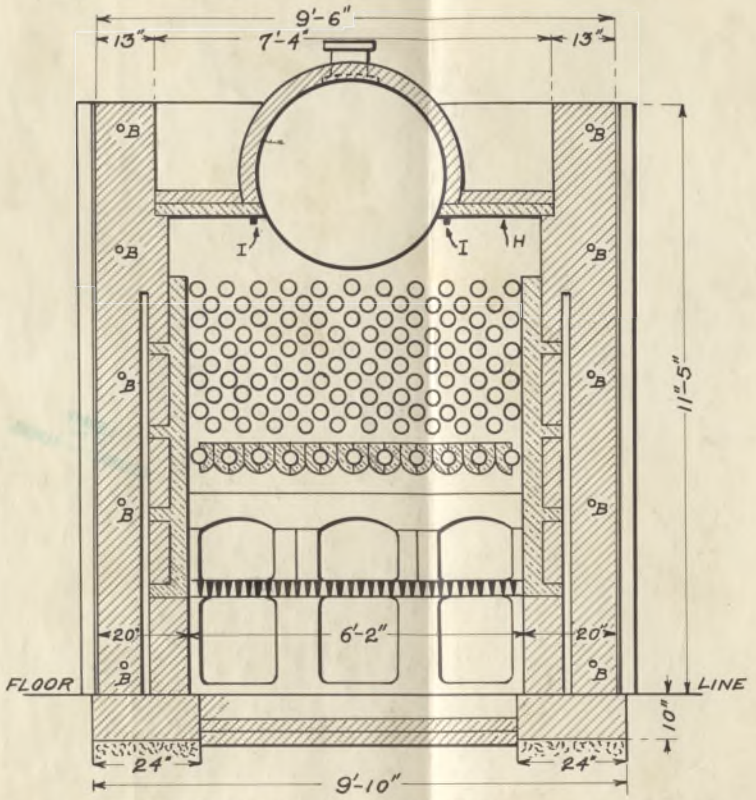


1 HEINE BOILER NO. 1
2 " " " 2
3 FROST BOILER
4 COAL WEIGHING SCALES
5 WATER " "
6 FEED PUMP
7 FEED WATER HEATER
8 ENGINE AND BLOWER FOR FORCED DRAFT
9 ALLIS-CHALMERS CORLISS ENGINE
10 BULLOCK D.C. GENERATOR
11 WESTINGHOUSE GAS ENGINE.
12 " D.C. GENERATOR
13 SWITCH BOARD
14 WATER RHEOSTATS
15 R.D. WOOD & CO. GAS HOLDER
16 " " " PURIFIER
17 R.D. WOOD & CO. TAR EXTRACTOR
18 " " " SCRUBBER
19 " " " ECONOMIZERS
20 " " " GAS PRODUCERS.
21 LINK BELT JIG
22 CENTURY JIG
23 WM. JOHNSON & SONS BRIQUETTING MACHINE
24 PITCH CRACKER
25 CHISHOLM, BOYD & WHITE BRIQ. MACHINE
26 HOPPER & STORAGE
27 SLUDGE TANK
28 ROLLER CRUSHER
29 STORAGE BINS.
30 STEAM ENGINE
31 COAL BINS
32 CENTRIFUGAL PUMP.

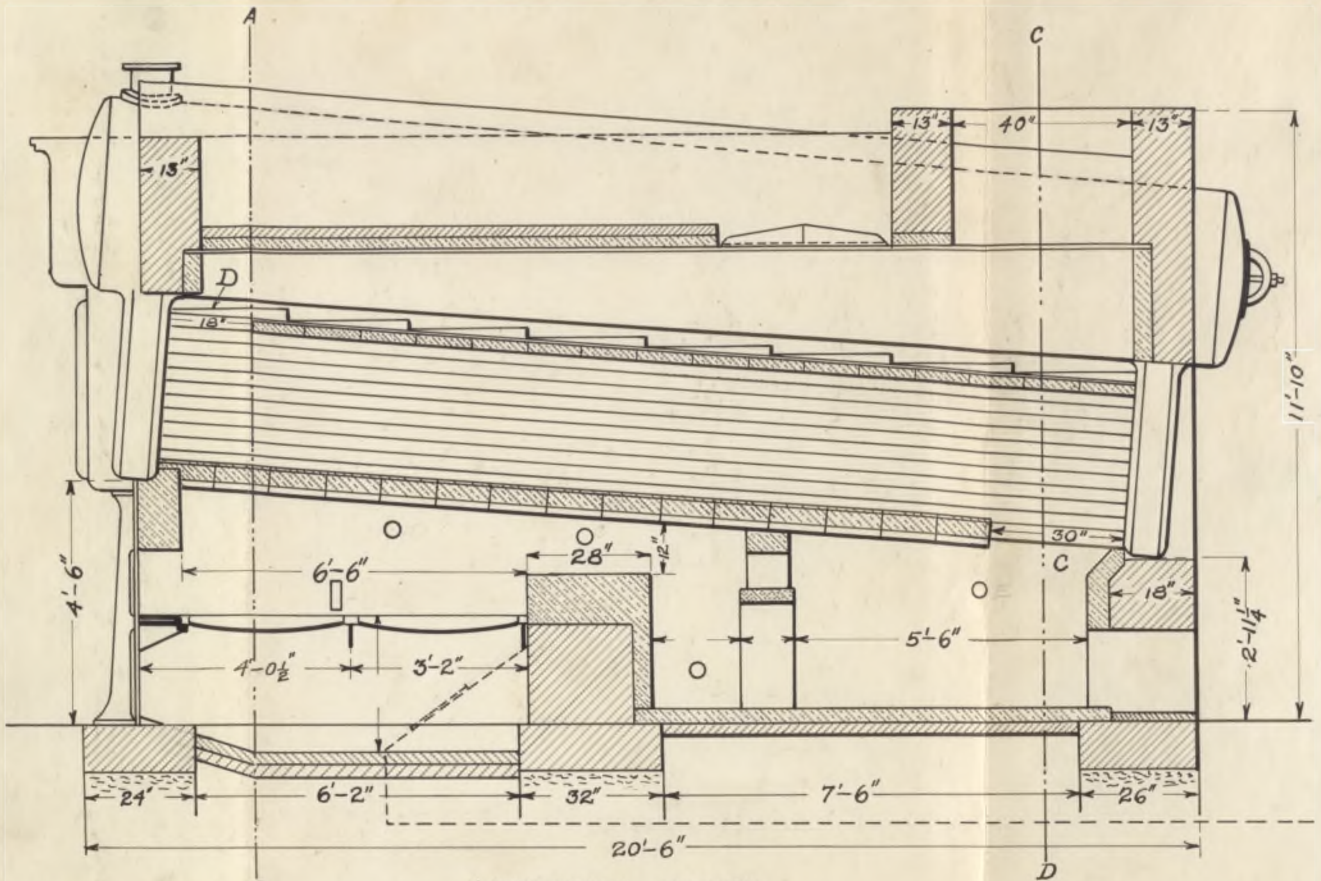
GENERAL PLAN OF COAL TESTING PLANT.

U.S. GEOLOGICAL SURVEY
ST. LOUIS, MO.

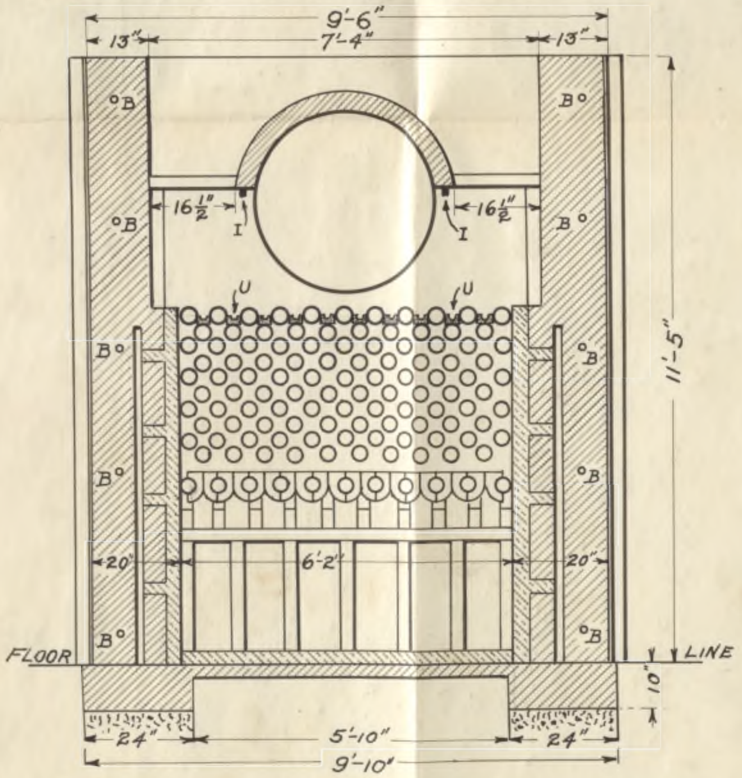
PL. 1.



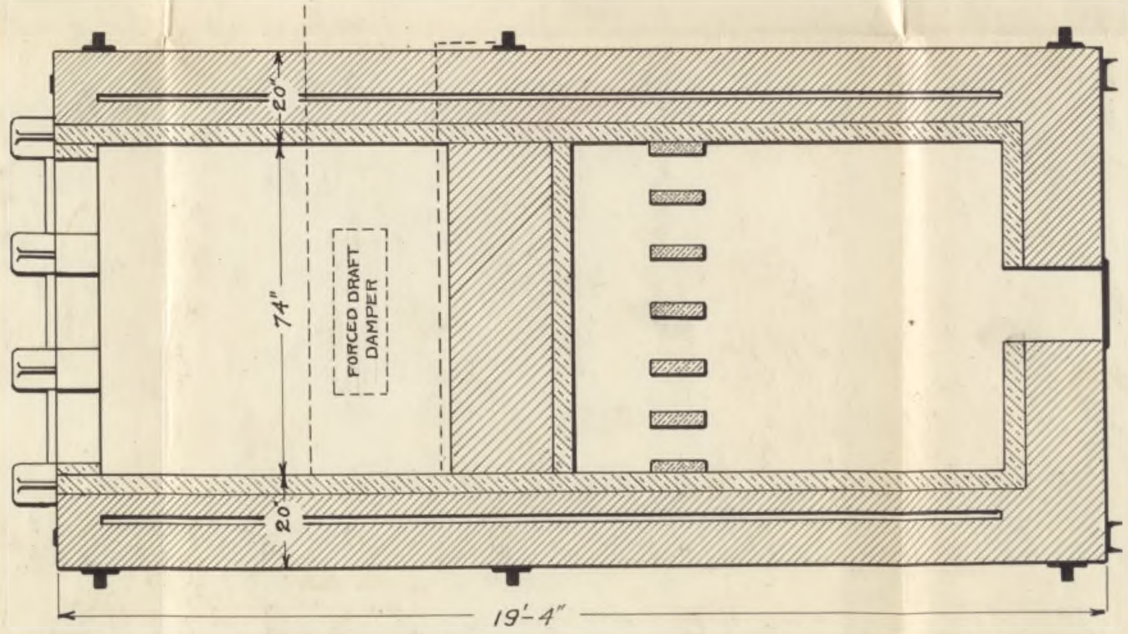
SECTION A-B FORWARD.



LONGITUDINAL SECTION



SECTION C-D FORWARD

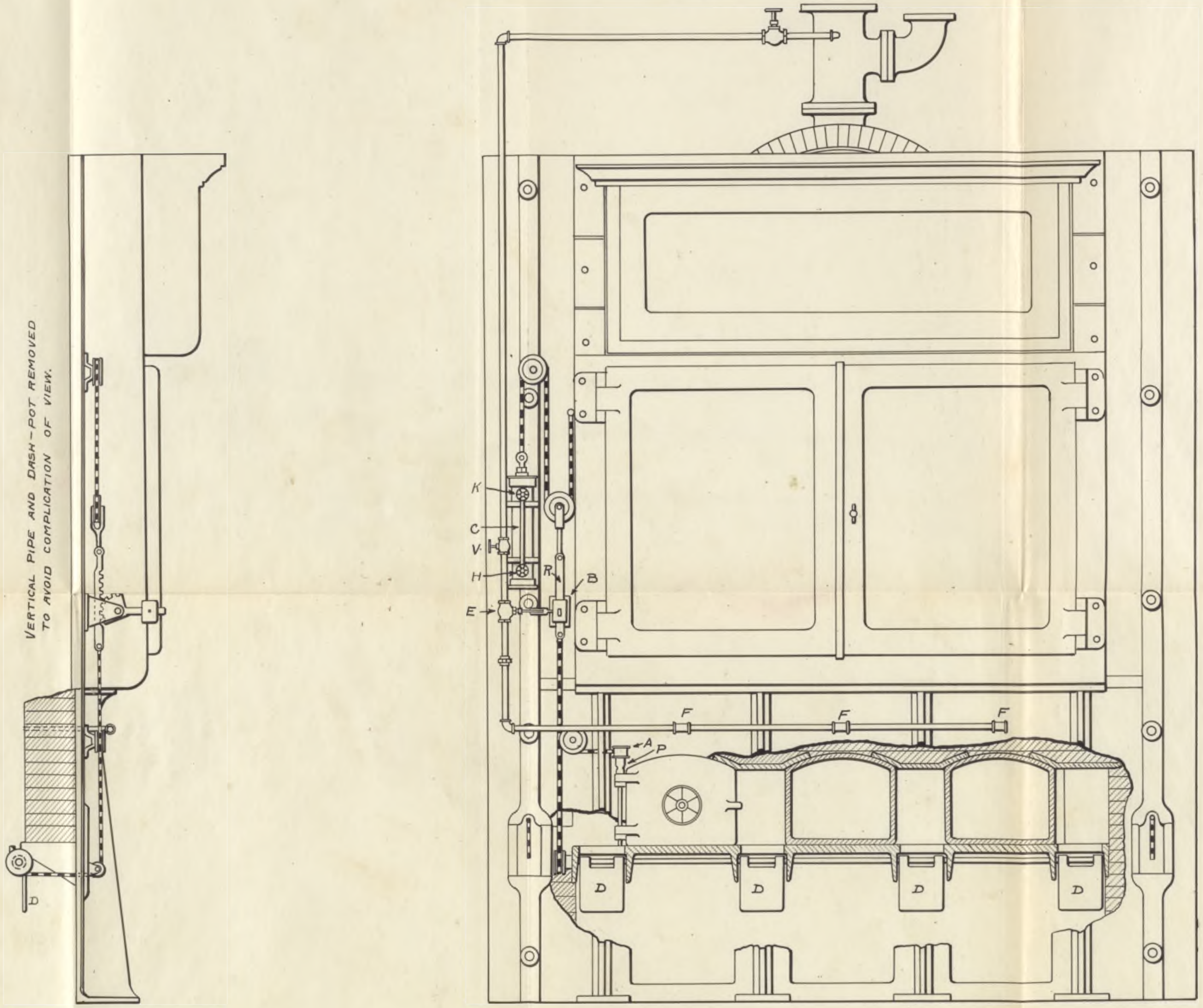


PLAN

SETTING FOR 210 H.P. HEINE BOILER.

U.S.G.S. COAL TESTING PLANT.
ST. LOUIS, MO.

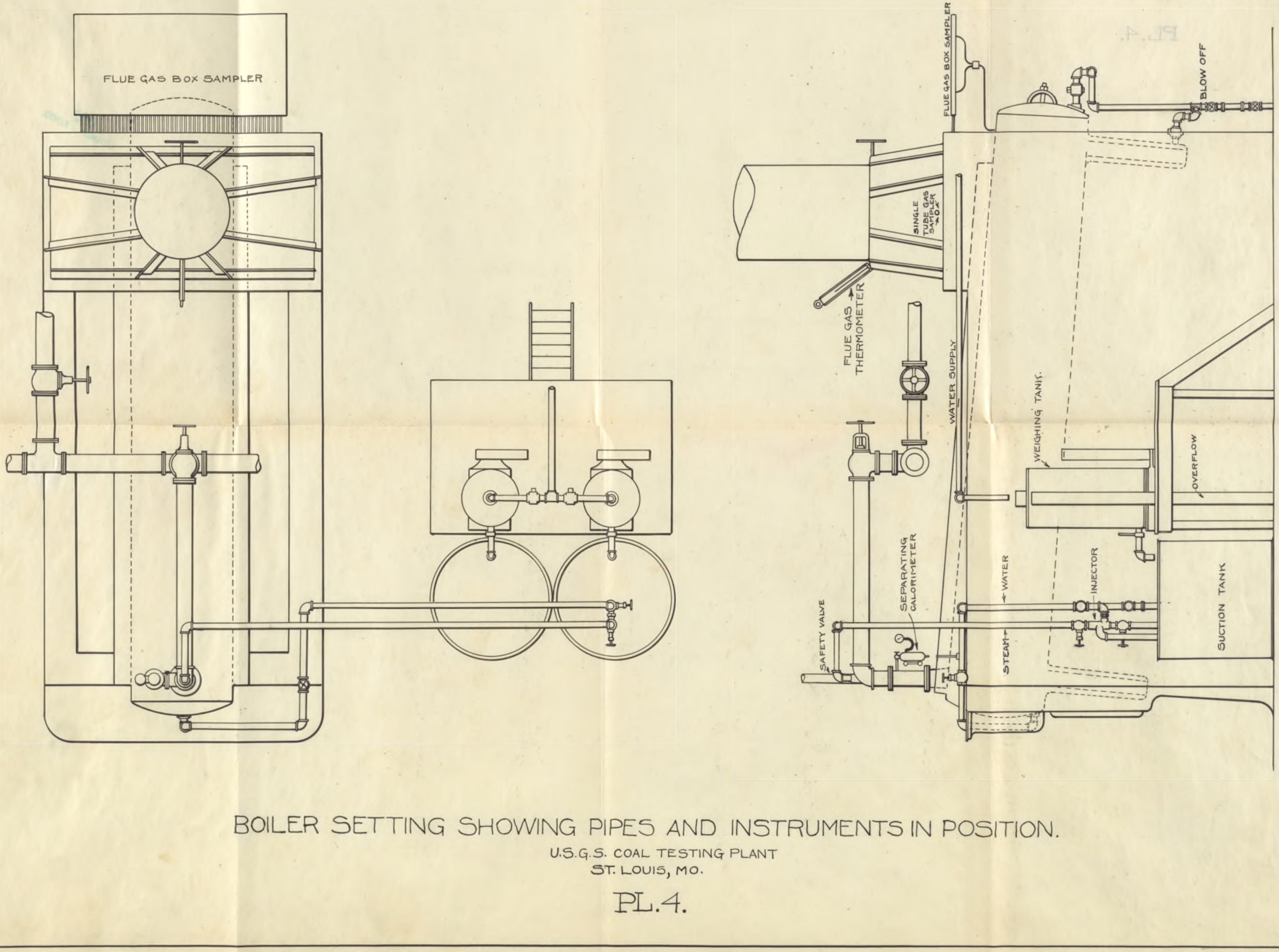
PL. 2.



THE HUGHES AUTOMATIC SMOKE PREVENTOR.

U.S.G.S. COAL TESTING PLANT
ST. LOUIS, MO.

PL. 3.



BOILER SETTING SHOWING PIPES AND INSTRUMENTS IN POSITION.

U.S.G.S. COAL TESTING PLANT
ST. LOUIS, MO.

PL. 4.