REVIEW OF THE ST. LOUIS BOILER TRIALS

BY

DWIGHT T. RANDALL, B.S., 1897

THESIS

FOR THE DEGREE OF MECHANICAL ENGINEER

IN THE
GRADUATE SCHOOL
OF THE
UNIVERSITY OF ILLINOIS
PRESENTED JUNE, 1905

UNIVERSITY OF ILLINOIS

May 26, 1905 190

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

DWIGHT T RANDALL

ENTITLED REVIEW OF THE St. LOUIS BOILER TRIALS

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

OF Mechanical Engineer

L. P. Breckenridge

HEAD OF DEPARTMENT OF Mechanical Engineering

153

O U T L I N E

THE COAL TESTING PLANT

Description

THE BOILER DIVISION

1. The Organization
2. Object of Boiler Trials
3. Description of Steam Plant
4. Description of Boilers and Apparatus
5. Methods of Conducting the Tests
6. Methods of Calculating Results
7. Results Presented on Cross-Section Paper
8. Comparison of Results with Tests Made by the
   Mechanical Engineering Department
   University of Illinois
9. Conclusions

COAL TESTS WITH TWO 210 HORSE POWER HEINE BOILERS AND PLAIN GRATES

Made at the United States Geological Survey Coal Testing Plant under the direction of Professor L. P. Breckenridge.

St. Louis, Missouri, 1904.

THE COAL TESTING PLANT

In connection with the plans for the exhibits of mines and mining machinery, Mr. Joseph A. Holmes, Chief of the Department of Mines and Metallurgy of the Louisiana Purchase Exposition, and Mr. Edward W. Parker, Statistician of the United States Geological Survey, together conceived the idea of making practical tests of the coals of the United States as one of the working exhibits in the "Mining Gulch."

They first secured from Congress thirty thousand dollars to carry on this work, but finding it inadequate they asked for as much more, which was granted. The appropriation was so worded that no money was available for the purchase of equipment or coal or for freight on either. This made it necessary that the entire equipment be arranged for as a working exhibit. Great credit is due the above named gentlemen for the continuous and successful efforts they made to induce the manufacturers and railroad to furnish and transport the machinery and other necessary equipment without cost to the Government. The appropriation was available only for buildings, erection of machinery, operating expenses, miscellaneous supplies, and for salaries of men conducting the experiments. Owing to the time required to arrange for all of the necessary apparatus and the difficulty in getting transportation promptly, it was nearly the middle of September before the plant as a whole was ready for operation.

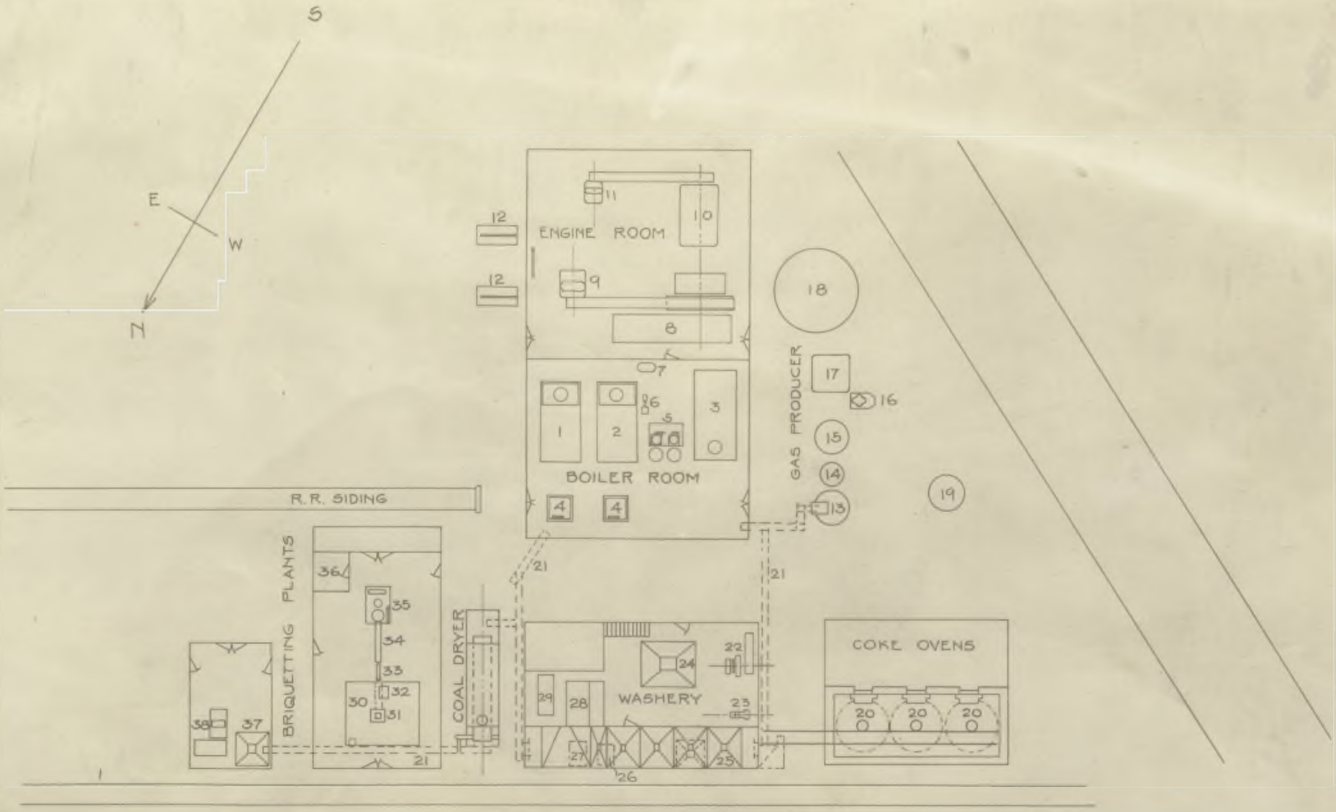
The plant consisted of the following departments:

1. A coal washery and distributing plant.
2. A coking plant of three beehive ovens.
3. A coal drier.
4. Two briquetting plants.
5. A gas producer plant with gas-engine.
6. A steam boiler and engine plant.
7. A chemistry department for analysis of coals.
8. A field force to obtain samples of coal.

In order that the coal tested should represent the mine correctly, the field force under the direction of Mr. M. A. Campbell visited each mine, obtained mine samples which were sent by mail to the Chemistry Department, and also supervised the loading of the coal shipped to the plant for tests.

On reaching the Coal Testing Plant the cars were unloaded, the coal being passed through a crusher, from which it was elevated

(2a) No. 1.



1 HEINE BOILER NO. 1
2 " " " 2
3 FROST BOILER
4 COAL WEIGHING SCALES
5 WATER " "
6 FEED PUMP
7 FEED WATER HEATER
8 ALLIS-CHALMERS CORLISS ENGINE
9 BULLOCK D. C. GENERATOR
10 WESTINGHOUSE GAS ENGINE
11 " D. C. GENERATOR
12 WATER RHEOSTATS
13 R.D. WOOD & CO. GAS PRODUCER
14 " " " ECONOMIZER
15 " " " SCRUBBER
16 " " " TAR EXTRACTOR
17 " " " PURIFIER
18 " " " GAS HOLDER
19 FORTER GAS PRODUCER
20
20 COKE OVENS
21 CONVEYORS
22 STEAM ENGINE
23 CENTRIFUGAL PUMP
24 SLUDGE TANK
25 HOPPERS
26 ROLLER CRUSHER
27 WILLIAMS MILL
28 LINK-BELT JIG
29 CENTURY JIG
30 MIXER
31 HOPPER
32 PITCH CRACKER
33 ELEVATING FAN
34 ELEVATOR
35 WM. JOHNSON & SONS BRIQUETTING MACHINE
36 OFFICE
37 HOPPER & STORAGE
38 CHISHOLM, BOYD & WHITE " "

UNITED STATES
GEOLOGICAL SURVEY
FUEL TESTING PLANT
BOILER DIVISION
ST. LOUIS, MO. SEP. 1904

1

and distributed by machinery. A card was made out describing the coal and a copy was furnished to each division receiving a portion of the coal. A receipted card was returned by the division receiving the coal to the person having in charge the distribution of the coals. This seemed to effectually prevent mistakes regarding the identity of the coals. As the cars were unloaded a small portion of the coal was taken at regular intervals for a "car sample" to be sent to the chemical laboratory. Samples from the coals delivered to the several divisions were also sent to the chemical laboratory so that not less than four samples of the coal were sent for analysis.

The Chemistry Department was under the direction of Professor N. W. Lord of Ohio University. The work was done by his assistant, Mr. E. E. Somermier and three chemists, all from Ohio University.

All chemical results, except the analysis of flue gases, were furnished by the Chemistry Department.

THE BOILER DIVISION

1. Organization

Early in the spring of 1904 Professor L. P. Breckenridge of the University of Illinois was asked to consider the position of Director of the Boiler Test Division of the United States Geological Survey Coal Tests, to be conducted at the plant in the "Mining Gulch" at St. Louis, and to arrange to meet the Committee appointed by the Director of the Survey, consisting of Mr. Edward W. Parker, Mr. Joseph A. Holmes, and Mr. M. A. Campbell. At this meeting it was agreed that Professor Breckenridge would take charge of the Boiler Division. Owing to the short time and the number of coals to be tested, it was decided to be impossible to make five or six tests on each coal, as was recommended by Professor Breckenridge, and that only one test would be possible in many cases. It was plainly stated to the Committee that one test only might be misleading in its results and that other conditions might give better results. This was fully understood by the Committee, and they decided to proceed on this basis without expecting the results of the tests to be strictly comparable as regards the fuel values of the coals. It was agreed by all concerned that even one test with complete data for each coal would be a valuable collection of information, not then available.

Shortly after this meeting a Boiler Test Force was organized as follows:

Director

Professor L. P. Breckenridge

Assistant Director

D. T. Randall

Boiler Room Observers

J. J. Harman

H. B. Dirks

Henry Kreisinger

Computers

R. H. Kuss

R. W. Rutt

Chemist for Flue Gases, etc.

C. H. McClure

These men reported at St. Louis about the middle of July and were engaged in arranging apparatus, making sketches and drawings of the boilers and settings, and similar work up to the time the tests began. On September 7 three of the men returned to their work at the University of Illinois, and they were succeeded by other men, making changes in the organization as follows:

Boiler Room Observers

Henry Kreisinger

R. H. Post

H. W. Weeks

Computers

R. W. Rutt

C. H. Green

One fireman fired for nearly all the tests. He was a middle-aged man named Henry Arens, who had been employed by the Koken Iron Works of St. Louis. He was not better than the average fireman, except that he was a reliable and trustworthy one. A few extra tests were fired by William Cameron, who was employed as fireman for the auxiliary plants which were supplied with steam from the horizontal return tubular boiler.

2. Object of the Boiler Trials

It was desired to determine the fuel value of the coals, when burned under a Heine water-tube boiler, with plain grates, hand fired, and to note the action of the coals on the grate, the amount of clinkers formed, the amount of free ash falling through the grates, and the labor required to handle the fire successfully. These results have been put in convenient form on regular data sheets, as recommended by the American Society of Mechanical Engineers.

3. Description of the Steam Plant

A building was erected to be used as a boiler and engine room. It was 94 feet by 54 feet floor area and was inexpensive in construction, having a wooden framework covered with sheet steel siding and a composition roof.

The boiler room was 54 feet by about 43 feet in floor area. It was equipped with two Heine water-tube boilers of 210 Horse Power each, and one H. R. T. boiler of 100 Horse Power capacity, each having separate stacks and independent brick settings.

There were also the following: A Stilwell Bierce heater, boiler feed-pump, and a complete outfit for boiler testing, which will be described later. The Heine boilers were used for the tests and as a rule only one was under steam. The steam from these boilers was furnished to an Allis-Chalmers Corliss engine, 22" x 42" in size, run non-condensing, and driving a Bullock generator of 200 K. W. capacity, having a voltage of 240 when run at 550 R. P. M. The current was distributed at the switchboard, to the motors in the briquette plant, the washery, and to the mine railroad. The remaining current was absorbed by a water rheostat located just outside the engine room and regulated by the switchboard attendant, to give the required load to the engine. The H. R. T. boiler furnished steam to the washery engine and to several exhibits, a valve in the steam header being closed to separate the steam from that generated in the Heine boilers. This was done after a few tests had been run and the load had proven too variable to handle easily on the test boiler. Owing to the variation in the motor and railway loads, it was found difficult to hold a steady steam pressure on the test boiler even after the water rheostat was in operation, which was not until September 25. Later on in November a 3-inch pipe was connected to the header and provided with two valves, one of which was used to regulate the flow of steam into the atmosphere. This valve being under the control of the fireman, it was possible to keep a much more uniform pressure than had been done by the switchboard attendant.

4. Description of the Apparatus

(a) The boilers were exactly alike in construction, settings, stacks, etc., and the following applies to both:

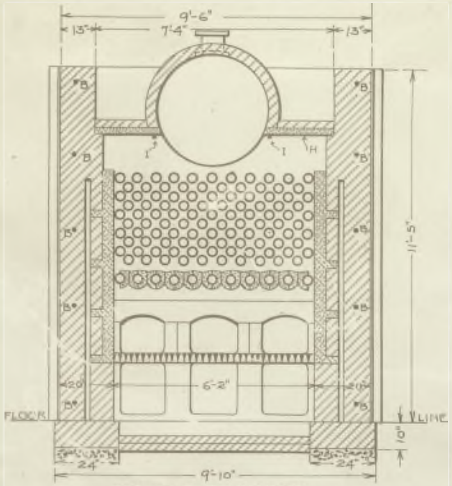
Table of Dimensions of Boilers

Make of Boiler	Heine Water-Tube Boiler
Length of Drum	21' - 7"
Inside Diameter of Drum	42"
Number of Tubes	116
Internal Diameter of Tubes	3.26"
Outside Diameter of Tubes	3.5
Length of Tubes Exposed	17' - 10.5"
Width of Furnace, feet	6.16
Length of Furnace, feet	6.58
Mean Height of Furnace, inches	26.
Kind of Grate Bars	Plain
Dimension of Air Spaces	0.5" x 17.5"
Ratio of Grate Area to Air Spaces	40 to 17
Area of Grate Surface, square feet	40.55
Ash-Pit Below Grate Surface, inches	25.
Height of Stack above the Grate, feet	113.25
Length of Flue Connecting to Stack	None
Diameter of the Stack, inches	37.5
Area of the Stack, square inches	1104.
Area of Draft Passage Over Bridge Wall, square inches	888.
Area at Lower Entrance to Tubes, square inches	1070
Area between Tubes, square inches	1612

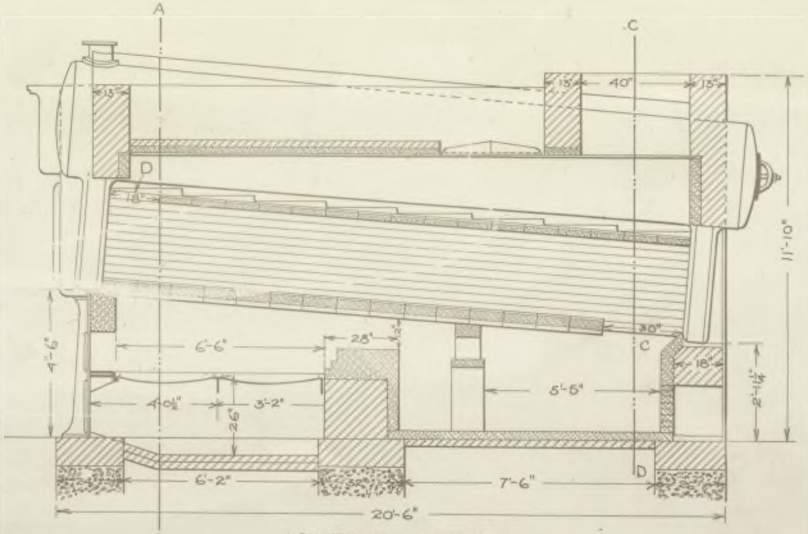
Area Leaving Tubes, square inches	640
Water Heating Surface in Tubes, square feet	1897
Water Heating Surface, Water-Legs, square feet	91
Water Heating Surface, Shell	43
Total Water Heating Surface, square feet	2031
Total Water Space, cubic feet	287
Steam Space, cubic feet	73
Ratio of Heating to Grate Surface	50.1 to 1
Ratio of Smallest Draft Area to Grate Area	1 to 9.1

When the water stood at 3" in the gage-glass #1 Boiler contained 16890 pounds and #2 Boiler contained 16775 pounds of water at 60° F. Each inch of water in Boiler #1 as shown by the glass was equal to 352 pounds, and on Boiler #2, to 343 pounds. These figures were determined by calibrating the boilers with cold water at about 60° F., noting the height of water in the gage-glass as the water was drawn from the blow-off and weighed. The boilers were provided with mud-drums and deflecting plates.

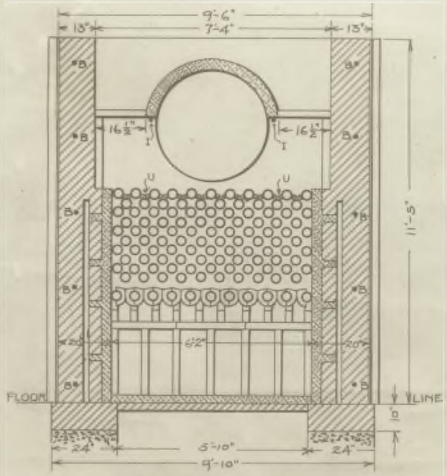
(b) The furnaces were of fire-brick walls and special tile covering the lower row of tubes of the boiler. These tile prevented the contact of the hot gases with the iron surfaces until they had reached the rear of the combustion chamber. The boiler walls were 20 inches thick with a 2-inch air space. The bridge wall was built to within 11 inches of the tile covering the lower row of tubes. A combustion arch was located about two feet back from the bridge wall, for the purpose of aiding in the combustion of the gases. These walls burned and melted down gradually, and



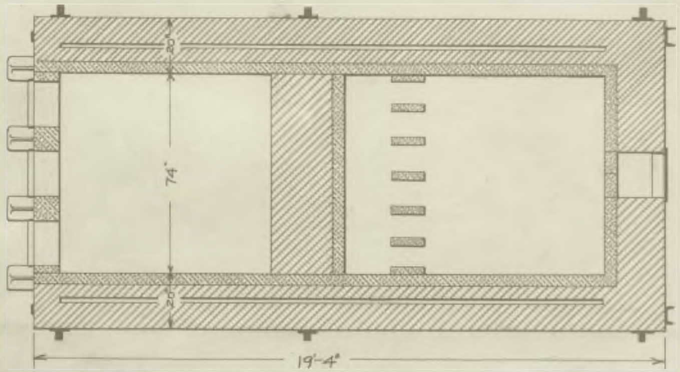
SECTION A-B — FORWARD



LONGITUDINAL SECTION



SECTION C-D — FORWARD



PLAN

SETTING FOR HEINE BOILERS

RATED AT 210 B. H. P. EACH

UNITED STATES
GEOLOGICAL SURVEY
FUEL TESTING PLANT
BOILER DIVISION
ST. LOUIS, MO. SEP. 1904

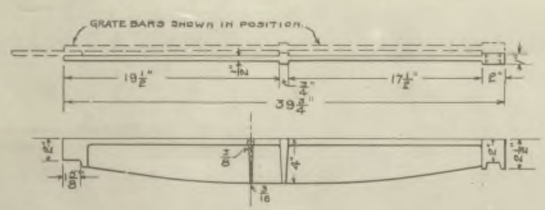
4

(9a)
No. 2.

it was not thought advisable on account of the short time remaining for tests, to rebuild them. The lower row of tiles reached to within 30 inches of the rear water-leg, except during a few tests at first when the distance was 42 inches. The upper row of tiles was of the ordinary type used by the Heine Company, and extended to within 18 inches of the front water-leg, except during a few tests, after which both the passages were reduced in order to cause the gases to reach the tube surface not in the direct line of the openings. The changes in dimensions will be noted on the data sheets of the United States Geological Survey reports.

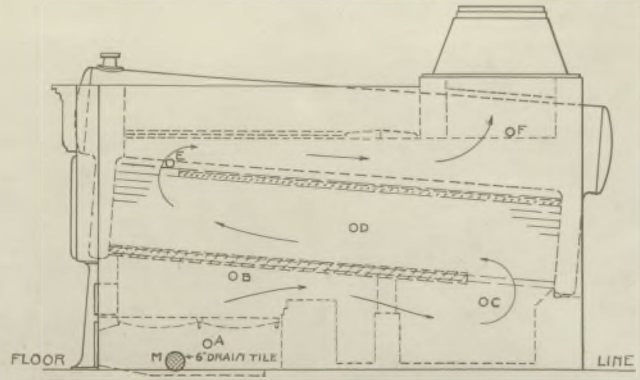
In order that the temperatures and pressures at each important passage might be obtained, several 2-inch pipes, 24 inches long, provided with caps, were set in the side walls when they were being laid by the masons. They were located as shown at A, B, C, D, E, F, in Drawing No. 3. By removing the cap from the pipes an instrument could be easily inserted into the gas passage. After the boilers were completely bricked in, careful measurements were taken of all areas of passages and other dimensions, and the results are given in the above table and Drawing No. 2. The grates were plain single bars as shown in Drawing No. 3. They were one half inch wide and so constructed as to give an air space of one half inch. The grate surface was 74 inches wide by 66 inches long, giving an area of 40.55 square feet.

So much trouble was experienced due to clinker sticking to the grate bars during the first six tests, that it was decided to put pipes in the ash-pit to admit steam under the grates. This was done in preference to using water in the pit, because it was desir-



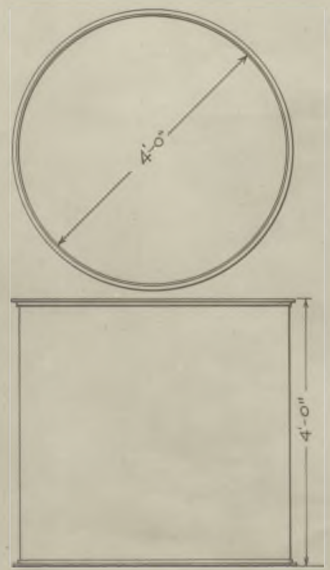
DETAILS OF GRATE BARS.

FIG. 9



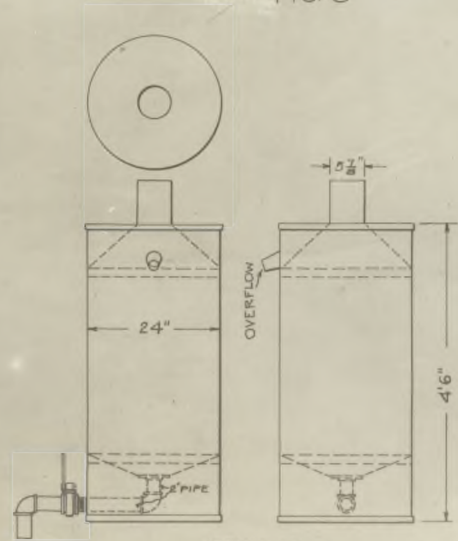
SIDE ELEVATION OF BOILER SETTING SHOWING POSITIONS OF PIPES LEADING INTO CHAMBERS OF WHICH TEMPERATURES AND DRAFT OBSERVATIONS ARE TAKEN.

FIG. 6



DETAILS OF —
GAL IRON WATER STORAGE TANKS.

FIG. 18



DETAILS OF
WATER WEIGHING TANKS.

FIG. 17

UNITED STATES
GEOLOGICAL SURVEY
FUEL TESTING PLANT
BOILER DIVISION
ST. LOUIS, MO. SEP. 1904

6

No. 3

(10 a)

ed to keep the ash dry. As it was some distance to pipe of exhaust steam and live steam could be piped much more easily, live steam was used. It has not been charged to the economy of the coals in any case, because some other method could have been used, which would not be counted an expense. The use of the steam greatly reduced the difficulty due to sulphur in the coal. The pipes are shown in Drawing No. 4.

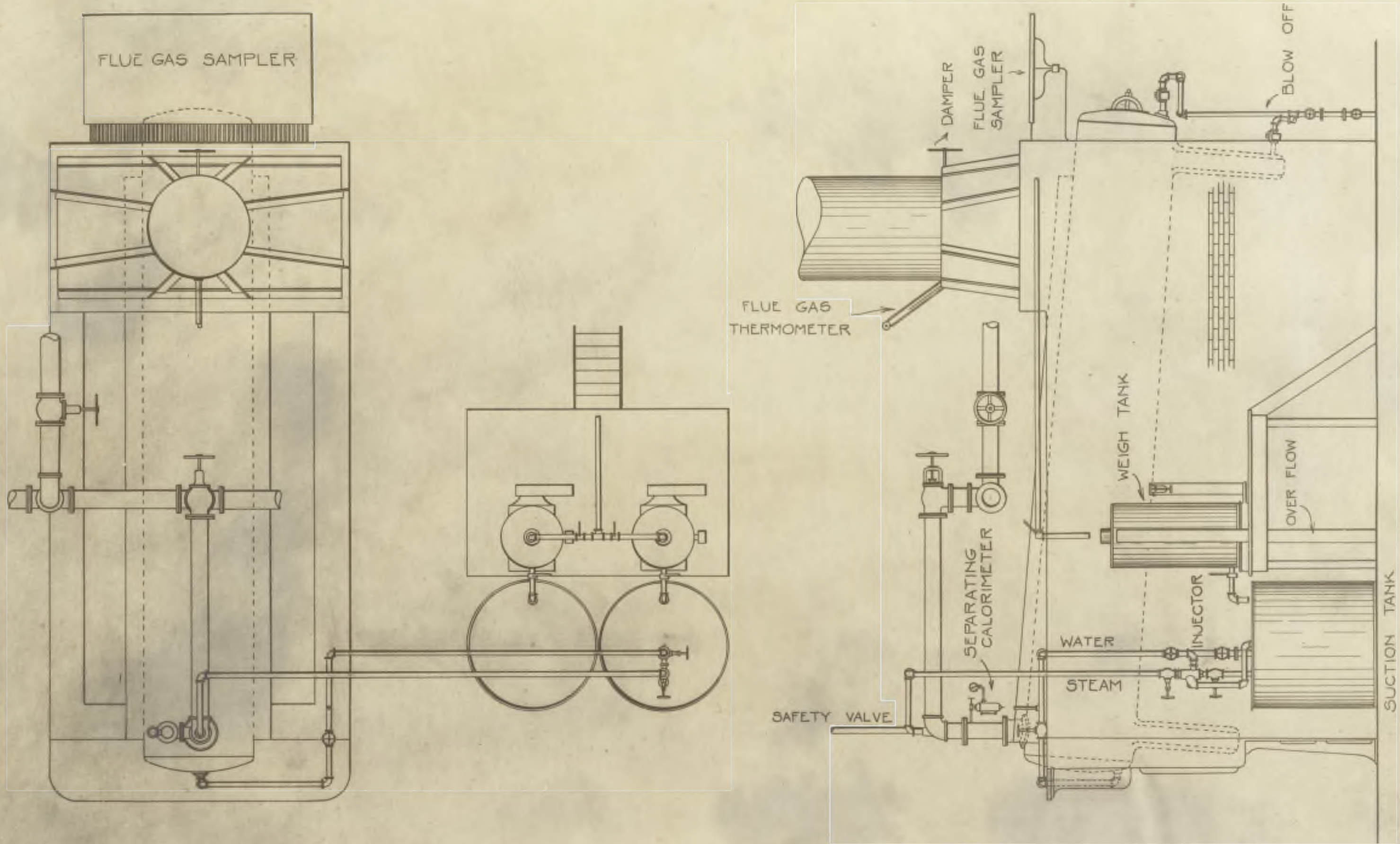
The boilers were also equipped with Hughes smoke preventor consisting of a set of three steam jets above the fire-doors and four damper-like doors below the grates to admit air after firing coal. Both air and steam were cut off automatically, closing slowly and adjusted as to time by the fireman. The automatic attachment was actuated by a chain driven by the hinge of the left-hand fire-door. The steam jets were not used during any of the tests, but the damper doors for admission of air were used in all cases in accordance with the judgment of the man in charge of the fires. The same effect might have been obtained by leaving the fire-doors open slightly for about two minutes, more or less. During the tests some smoke was made as will be seen by referring to the tables of results.

(c) The stacks were of sheet steel 37.5 inches diameter and 113.25 feet above the grates. They rested on suitable hoods directly on the rear walls of the boilers, giving direct draft connections. A hole was made in the base of each stack to insert a pipe for draft measurement, and higher up as shown by drawings was an opening for the flue thermometer. A damper was placed at the top of the hood. Wires were run from the dampers over suitable pulleys to the front wall of the building, within easy reach of the man in charge of the fires. The stacks were properly fastened by guy wires. These stacks were high enough to give the draft necessary for soft coal of nut size, but not for slack or lignites as will be seen from an inspection of the results.

(d) The steam pipes from the boiler to the header are shown in Drawing No. 5. These pipes were covered with a good sectional covering. The steam pipe to the Corliss engine was covered and a separator was placed above the trottle valve. Steam was taken from the boiler through a tee and a short section of 6-inch vertical pipe in which was placed the calorimeter nipple. All steam pipes were inclined away from the boilers.

(e) The injectors first installed were 2-inch Pemberthy, but after making a few trials, they were changed to the 1 1/2-inch size of the same make, which were more easily regulated to suit the capacity of the boiler. Each injector was supplied with steam from the boiler into which it discharged. The 2-inch steam pipes were led from the tops of the vertical pipes out of the boilers. The injectors were placed directly over the feed tank and were suspended by iron hangers. The 2-inch discharge pipes connected directly with the boiler into which they delivered the feed-water, except for a pump connection on each. This pump connection was provided with two valves and between the valves was a short length of pipe with flanges. At the beginning of each test the valves were closed and the length of pipe was removed to prevent a possible loss of

(12a)
No 4.



BOILER SETTING SHOWING PIPES
AND INSTRUMENTS IN POSITION

UNITED STATES
GEOLOGICAL SURVEY
FUEL TESTING PLANT
BOILER DIVISION
ST. LOUIS, MO. SEP. 1904

8

water not accounted for. All pipes leading to and from the injectors were covered with sectional covering to prevent loss by radiation. The blow-off pipes were also arranged with short pieces of pipe, which were easily removed at the beginning of the tests. Any water which leaked by the valves was caught and returned to the feed tanks.

(f) The weighing scales were furnished by the Fairbanks, Morse Company. There were two platform scales of 1000 pounds capacity for weighing water, and two large scales with their platforms set flush with the brick floor of the boiler room for weighing coal and ash. By using a tank of water and a standard 50-pound test weight the scales were calibrated and found correct. They were frequently checked by means of the test weight during the period of the tests.

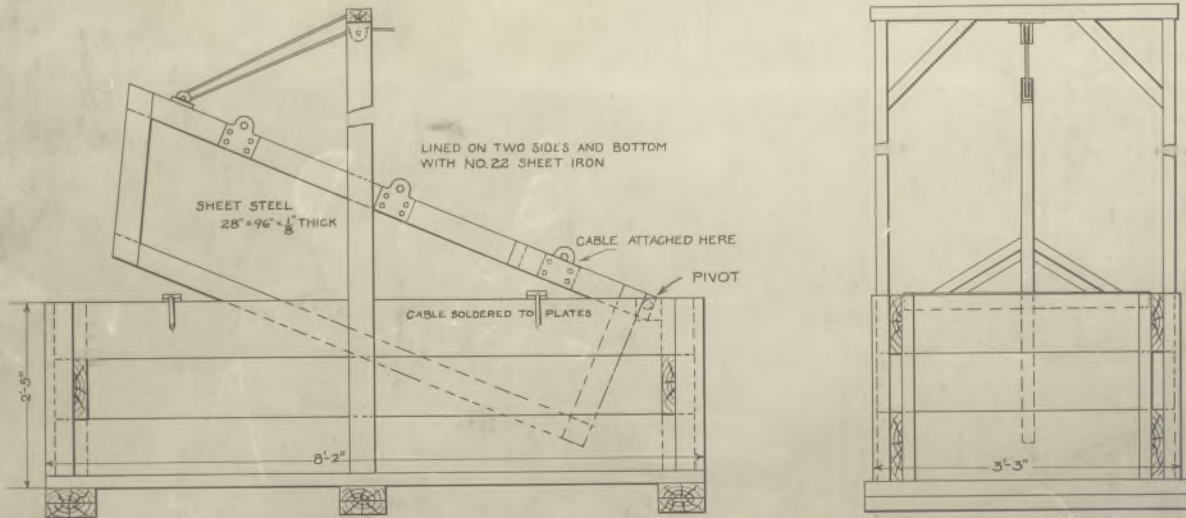
(g) The tanks for weighing water were constructed according to sketches furnished by Professor Breckenridge. See Drawing No. 3. They were provided with "Handy" gate-valves on the 2-inch outlets and water was admitted through a 2-inch pipe also fitted with the same type of valves. On account of the supply pipe being under a pressure of about 70 pounds, the gate-valves worked too hard to be satisfactory. The time required to fill and empty one of the weighing tanks was about three minutes. To get the capacity of the boiler it was only necessary to empty a tank once in six minutes. Only one weighing tank was used for each boiler. Both tanks were adjusted to hold 634 pounds of water at 60° F. Owing to the neck of the tank being a little less than 6 inches diameter, any variation in the height of water above the edge of the overflow, was less than the range of the scales, one sixteenth of an inch being but one ounce in weight. The weighing tanks were placed on scales located on a platform about four feet above the floor, and the water was discharged directly into the feed tanks which were four feet in diameter by four feet high. These tanks were provided with floats which indicated at all times the number of inches of water in the tanks. By calibration it was found that each inch of water was equal to 59 pounds. There was also provided a tank about 24 inches in diameter by 30 inches high for use in calibrating boilers and similar uses. This tank was provided with a 1 1/2-inch outlet pipe with globe-valve. All the above tanks were made of galvanized iron.

(h) The coal charging car was built entirely of steel and the box was 30" x 54" x 13". One side was hinged and arranged to lower for the convenience of the fireman. This car when loaded with 700 pounds of coal was nearly full.

(i) Four sample cans were provided for keeping samples of the coal and ash. They were about 18 inches diameter by 30 inches high and were made of galvanized iron. They were closed by tight fitting covers.

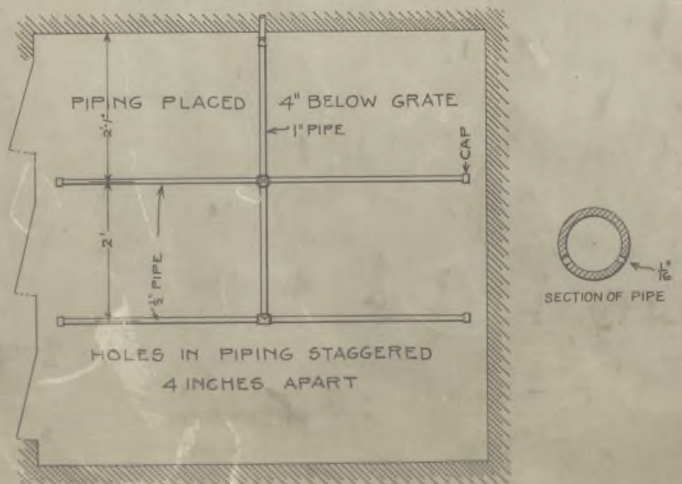
(j) The gas analysis apparatus consisted of two samplers for obtaining the gas, four leveling bottles, and two Orsat apparatus with the necessary pipes, aspirators, etc. To insure a uniform sample of the gas a sampler was constructed for each boiler and installed before the brickwork was finished. This is shown in Draw-

(14a)
No. 5.



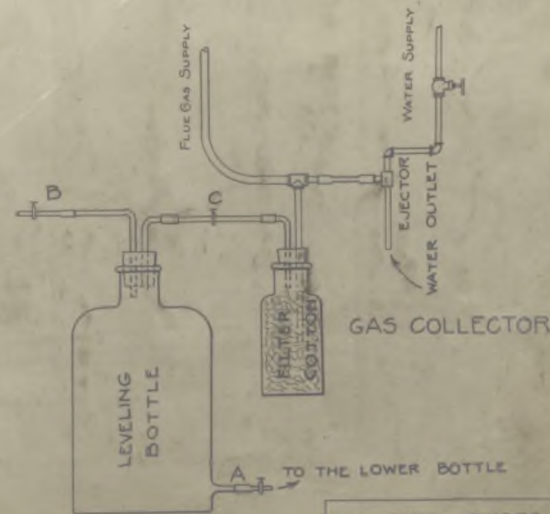
WATER RHEOSTAT

FIG. 13



ARRANGEMENT OF STEAM PIPING UNDER GRATE

FIG. 10

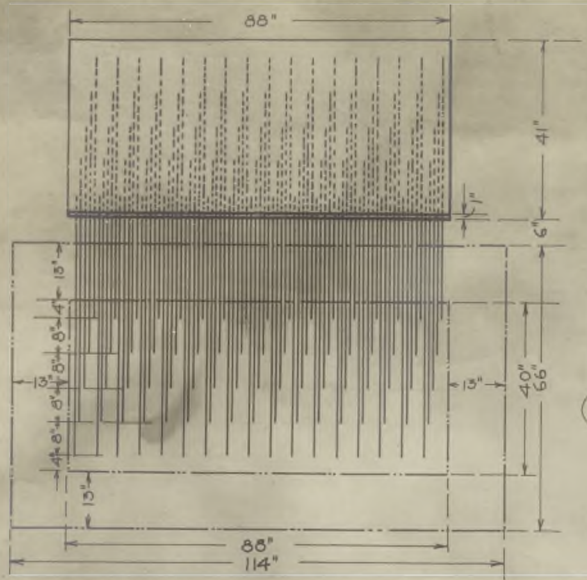


GAS COLLECTOR

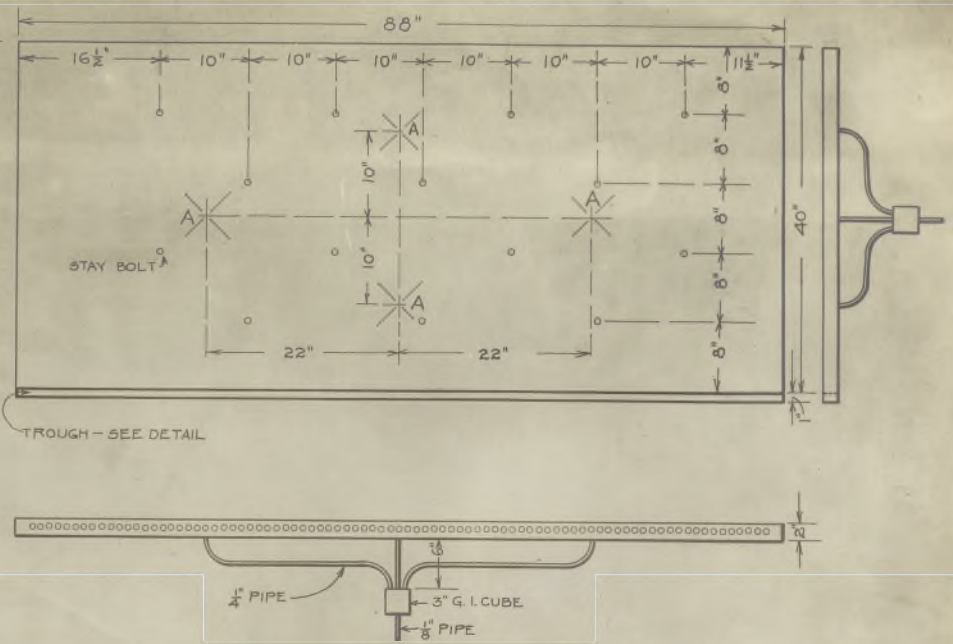
FIG. 24

UNITED STATES
GEOLOGICAL SURVEY
FUEL TESTING PLANT
BOILER DIVISION
ST. LOUIS, MO. SEP. 1904

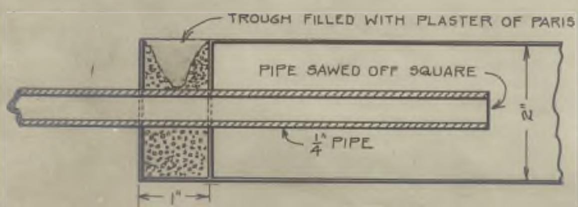
ing No. 6. Each consisted of a thin box of galvanized iron of the same width and length as inside dimensions of the brick smoke flue at the base of the stack hood. From this box 85 pipes one fourth inch in diameter and five feet long,cut from standard gas pipe and having both ends square, led to the flue and were so placed as to give one opening for each 40 square inches of flue area. As shown in the sketch these pipes were not soldered to the box where they passed through it, but the box was provided with a lip forming a small trough through which the pipes passed. These pipes fitted snugly in the holes and the trough was filled around the pipes with plaster of Paris. As an added precaution against a possible leakage of air, a thin layer of pitch was run over the plaster. The chemist in charge assured himself that the apparatus was free from leaks. From the bottom of the sample box four 1/4-inch pipes led to a 3-inch cube of galvanized iron, which served to further mix the gases, and from this cube a short 1/8-inch pipe made connections with a 1/8-inch bent pipe leading to the aspirator. The aspirator was supplied with water under pressure to cause a suction in the gas sampler. This apparatus was essentially the same as is recommended by the American Society of Mechanical Engineers. A glass tee was placed in the suction pipe near the aspirator and samples of the gas passing were drawn from this tee into a bottle by allowing the brine solution with which it was filled, to flow down to another bottle at a lower level, the flow being controlled by pinch-cocks on the tubing. Samples were also taken from a 1/2-inch pipe, seven feet long, which extended across the flue at right angles to the pipes of the sampler. This pipe was plugged at the



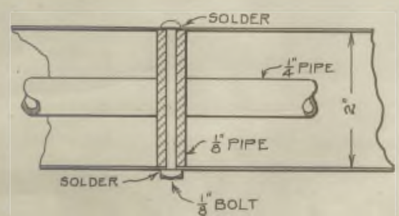
PLAN SHOWING POSITION OF FLUE GAS SAMPLER
AND
PLACING OF 85 - $\frac{1}{4}$" INCH PIPES - 60" LONG
TUBES OF WROUGT IRON - SAWED OFF SQUARE AT BOTH ENDS
AND SPACED ONE INCH CENTER TO CENTER.



GALVANIZED FLUE GAS SAMPLER
MADE OF #20 IRON
PLACES MARKED "A" OUTLET TO 3" CUBE



SECTION THROUGH TROUGH OF FLUE GAS SAMPLER
METHOD OF SEALING OPENINGS
AROUND TUBES ENTERING SAMPLER.



DETAIL OF BOLTS TO PREVENT
COLLAPSE OF SAMPLER.

UNITED STATES
GEOLOGICAL SURVEY
FUEL TESTING PLANT
BOILER DIVISION
ST. LOUIS, MO. SEP 1904

No. 6.

(15a)

11

end and was perforated by drilling 1/16-inch holes six inches apart on one side of the pipe. These holes were placed away from the current to prevent soot filling them. Analyses made from gas obtained through this pipe are marked "Stack Sample." It seemed advisable to take a few samples of gas by this method, because in many cases it is impossible or at least difficult to install the apparatus recommended.

(k) The pressure-gage used was a standard Crosby test gage graduated to single pounds on a 6-inch dial. A Crosby gage testing outfit was provided and the test gage was calibrated frequently. It was always practically correct.

(l) The calorimeters used were Carpenter's throttling and separating. On nearly all of the tests the separating calorimeter was used. In case it was desired to examine the regular one, or when two tests were to be run at the same time, the throttling calorimeter was used. The separating calorimeter with its connections uncovered is shown in Drawing No. 4. This instrument was provided with a gage to determine the flow of steam. This discharge was carefully calibrated and while it showed a slight error, it would not effect the results more than .003 of one per cent and no correction was made, except for changes in the calibration of the gage which was tested frequently, and the results reduced to true pressures by the aid of a calibration curve on cross-section paper.

(m) A number of chemical thermometers and three flue thermometers were furnished by Hohmann and Maurer. These were compared with the standard thermometer at Washington University, and all but one were found to be correct. The only test which could be provided for the flue thermometers was a comparison at about the boiling point of water. When new, they were found to agree, but one of the thermometers after having been in use about one month, was found to be in error 10° and was adjusted accordingly.

(n) The draft gages were furnished by the Appliance Manufacturing Company of Chicago, and were an improved type of Eames differential draft gage, using a 300° test kerosene oil instead of water, in order to overcome the influence of capillarity of the tube. These gages were graduated to .01 of an inch of water. They were compared with a standard U tube containing water under the same suction, and were found correct.

5. Method of Conducting the Tests

The fires were started early in the morning from a banked fire and the pressure was maintained at the usual working pressure. The steam-engine was run under load for at least 45 minutes before starting the tests. When the furnace walls were heated and other conditions were favorable, the fire was allowed to burn low and was raked clean and level. At this time a signal was given to begin the test. The thickness of the fire on the grate was determined by measurement on a fire-hook at several points, and the average recorded. No particular time was set for starting, but the tests were started as soon after 7:30 a. m. as the conditions were thought favorable. The height of water in the gage-glass, the height of water in the feed tank, the steam pressure, and other observations were taken when the signal was given to begin. The injector was not in operation during the starting or closing of the tests.

The tests were run as nearly ten hours as was consistent with correct results. About thirty minutes before the end of the ten hour period, the fire was cleaned and it was then burned to the same depth on the grate as at the start. When in the opinion of the observer in charge, this condition was reached, a signal was given to take the final observation for the test.

It was thought that by using care in obtaining the same condition in the fire, less error would be introduced than if an attempt was made to get the water level and steam pressure the same as at the beginning and then estimating the difference in the depth of the fire. With a hand fired furnace it is difficult to close a test with the same depth of fire, water level, and steam pressure, when the same load on the engine is maintained as at the start. As an error in one pound of coal is equivalent to an error of about seven pounds of water and as it is possible to calibrate the boilers to within a small percentage of error, this method was decided upon. Before starting the series of tests, the boilers were calibrated and records were made on the steam pressure and water level gages during the rise and fall of pressure between 0 and 100 pounds per square inch. These results gave a basis for correction for differences of water level and steam pressure in case they were not the same at the close as at the start. An attempt was made in all cases to close the test with the same load, the same condition of fire, and as nearly as possible the same water level and steam pressure. This was not accomplished in many cases especially during the period before the rheostat was completed.

When the clinker was unusually bad, the pressure often fell while cleaning the fire at the end of the test. This difficulty was due in a measure to the fact that a new coal was tested each day, and in many cases but little information regarding it could be obtained.

The coal was weighed in portions of 700 pounds in a charging car. The coal and car were weighed after each time of firing until the car was empty. This gave a record of coal fired each time. When the car was empty a signal was given and the height of water in the boiler and in the feed tank were observed and recorded. Mr. Kreisinger was in charge of the observations relating to the coal used and the furnace conditions.

Samples of coal were taken from the charging car each time it was loaded, the samples being put in a can with a tight cover. These samples were turned over to the Chemistry Department once each day for analysis.

When the fires were cleaned no water was put on the ash and clinker, which were allowed to cool before being weighed. The weight of refuse drawn from the door when cleaning was taken separately and recorded as "Clinker and Ash." The ash which fell through the grate bars was weighed at convenient times and recorded as "Free Ash." A sample of each was taken in proportion to their weights, usually about 5 per cent of the total and this was also turned over to the Chemistry Department for analysis.

The water was weighed in the weighing tank once each morning to make sure that it held the usual amount. The succeeding observations were taken by measurement and recorded as the same weight. The weight of water in each tank increased as the weather became cooler, and was recorded as 634 1/4 pounds for a number of tests during November and December. Mr. R. H. Post and Mr. H. W. Weeks weighed and recorded the amount of water used on alternate weeks. The feed-water temperature was obtained by the use of a calibrated thermometer suspended at the middle of the feed tank.

The general observations of temperatures, pressures, calorimeter readings, etc., were taken by an observer alternating with the work of weighing water each week. These observations were taken once in twenty minutes. The height of water in the feed tank and in the boiler gage-glass was recorded at the same time. All log sheets were made in duplicate by the use of carbon paper and one copy was sent to the University of Illinois for safe keeping to avoid possible loss by fire or otherwise.

It was planned to take temperatures in the furnace and a Le Chatlier electrical pyrometer was loaned for the purpose by Charles Englehardt of New York. On using this instrument, which was furnished with a gas pipe covering to protect the porcelain tube, it was found that the steel tube would fuse under the high temperatures and on cooling would adhere to and crack the porcelain tube. The real cause of the breaking was not discovered until two tubes had failed, and as an unprotected tube would be very liable to get broken, it was decided to take no further observations during this series of tests. The Pennsylvania locomotive testing force had great difficulty in keeping unprotected tubes from breaking, and they continued to use the instruments with the wires exposed.

The flue gas was sampled from the start of the test for one hour and then an analysis made and so on for each successive hour. This analysis is assumed to represent the average for the hour. The leveling bottles used for gathering the gas held a solution of salt brine instead of water, which absorbs a large portion of the CO_2 in the gas and also gives it up in case the gas is low in CO_2. An Orsat apparatus was used, being well suited to the conditions, and was considered sufficiently accurate for the purpose. It is probable that the chemical apparatus is more accurate than the usual method of obtaining a sample of gas. Not much difficulty was experienced, except in a few cases, cold draughts of air caused difficulty in obtaining reliable results on account of contraction of the gases. This was caused by unavoidable opening of doors. The soot occasionally clogged the pipes in the sampling apparatus and it was necessary to provide openings in the sample boxes for blowing out the accumulations. The chemist for flue gases was also in charge of the smoke observations. The smoke observations were taken for a period of ten minutes during each hour. A set of Ringlemen's smoke charts was used as standards.

The boilers were cleaned once a week during the first month of the tests, but this was found to be unnecessary and later on they were cleaned but once in two weeks and at no time were they dirty or in bad condition. They were blown off each evening and the outsides of the tubes cleaned with the steam jet blowers. The condition of the boiler being tested was at all times such as to be equally favorable to coals being tested.

6. Method of Calculating Results

All totals for the observations were found by the aid of a Burroughs adding machine which printed the figures for checking with the original. The calculations involving multiplication and division were performed by the aid of a Burkhart computing machine furnished by Keuffel & Esser Company. These machines enabled the two computers, Mr. Rutt and Mr. Green, to each calculate and check a boiler test in about six hours. In all this work the code for boiler testing as published by the American Society of Mechanical Engineers was followed in all particulars. It will be noted that the efficiency of the boiler is expressed in two values, one of which is based on combustible, as shown by the actual weight of the ash determined by weighing, but not including such ash as is carried over the bridge wall, etc., and the other value based on the chemical analysis, which is assumed to be the true value. It was desired to make tests on the same boiler on consecutive days and it was not practicable to recover the ash carried over the bridge wall and into the flues. The heat balance is based upon the chemical results.

Complete results of these tests may be found in the United

States Geological Survey Report on the Coal Tests Made at St. Louis, 1904.

7. Graphic Result Sheets

It will be seen by reference to Charts No. 7-13 that in nearly all cases the refuse by weight exceeded the ash by chemistry as it should on account of the carbon in the ash. Some coals produce an ash which is light, and with a strong draught a portion of it is carried over the bridge wall and in these tests such ash was not recovered. This chart is of value in showing what variation may be expected when the coal is sampled in an approved manner. It will also serve as a basis of comparison in cases when the coal has not been analyzed. It is without doubt difficult to obtain a small sample which exactly represents the coal used during a test, especially with western coals. Analyses taken from the same car-load on different days frequently vary as much as two per cent in the important items.

A study of the composition of the coals and the results obtained at St. Louis is given in Charts No. 11 to 13 inclusive. These need but little if any comment. The general tendency of the curves showing the averages follows the accepted theories. The individual tests, however, are in many cases greatly at variance with the theory, due probably to unfavorable conditions in the furnace.

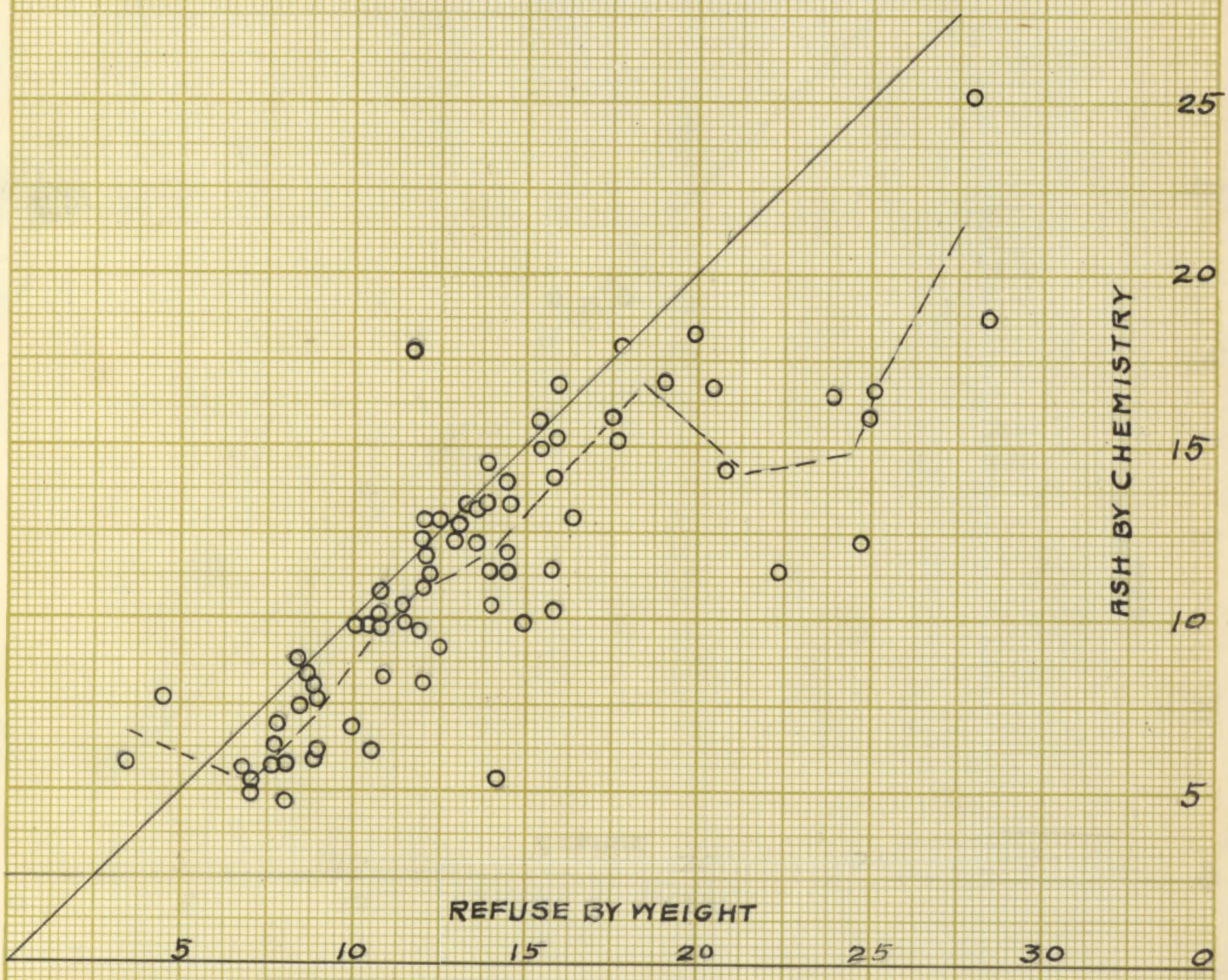
In Chart No. 14 is a special study of the coals of Illinois and near-by states. These curves do not indicate a definite relation between the B. T. U., CO_2 smoke and the efficiency of the boiler as has been assumed by many. It is shown, however, that in

1904.

U.S.G.S. COAL TESTS.

No. 7.

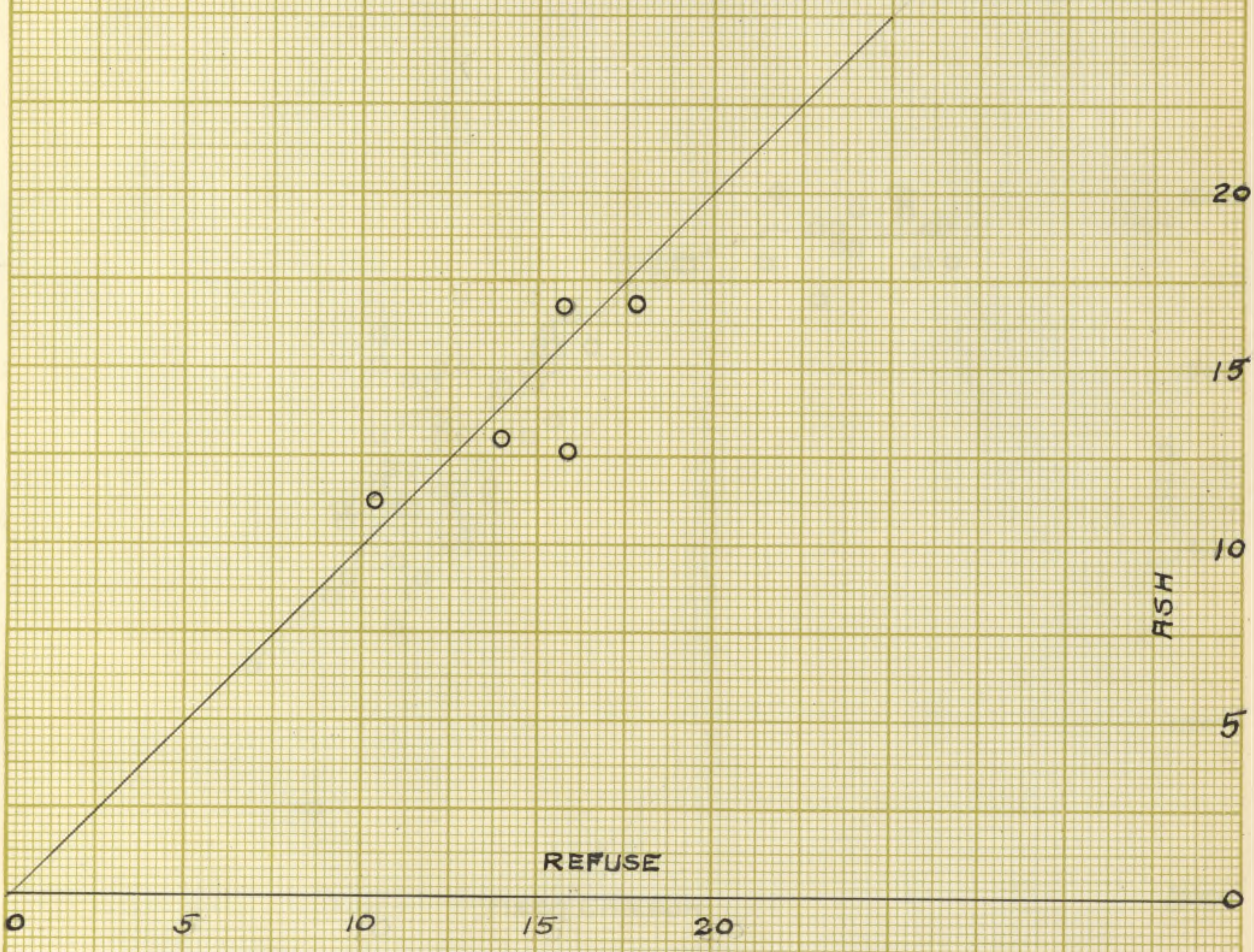
RELATION OF REFUSE BY WEIGHT TO ASH BY CHEMICAL ANALYSIS.

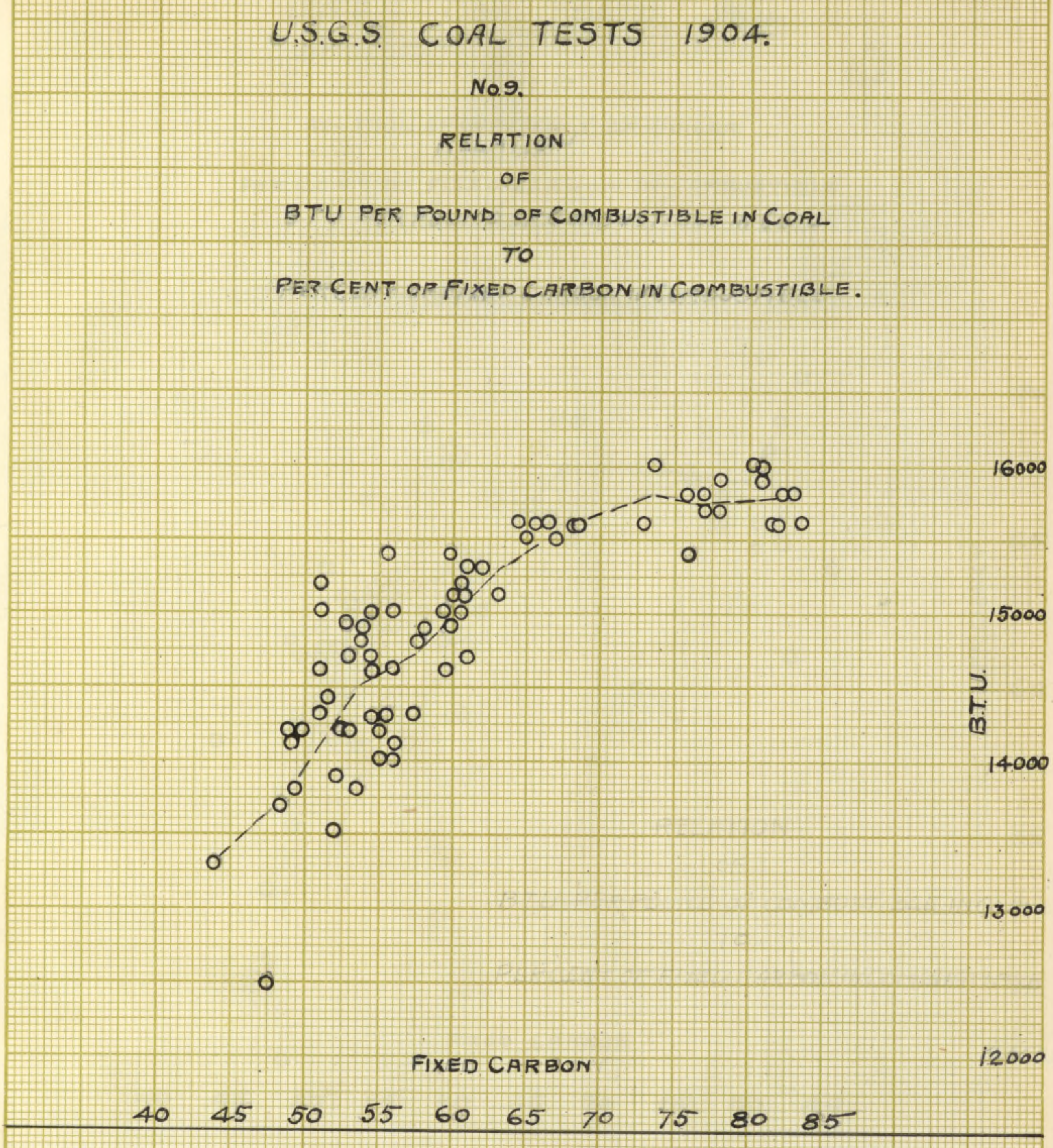


U.S.G.S COAL TESTS WITH ILLINOIS COALS.

No 8.

RELATION OF REFUSE BY WEIGHT TO ASH BY CHEMICAL ANALYSIS.

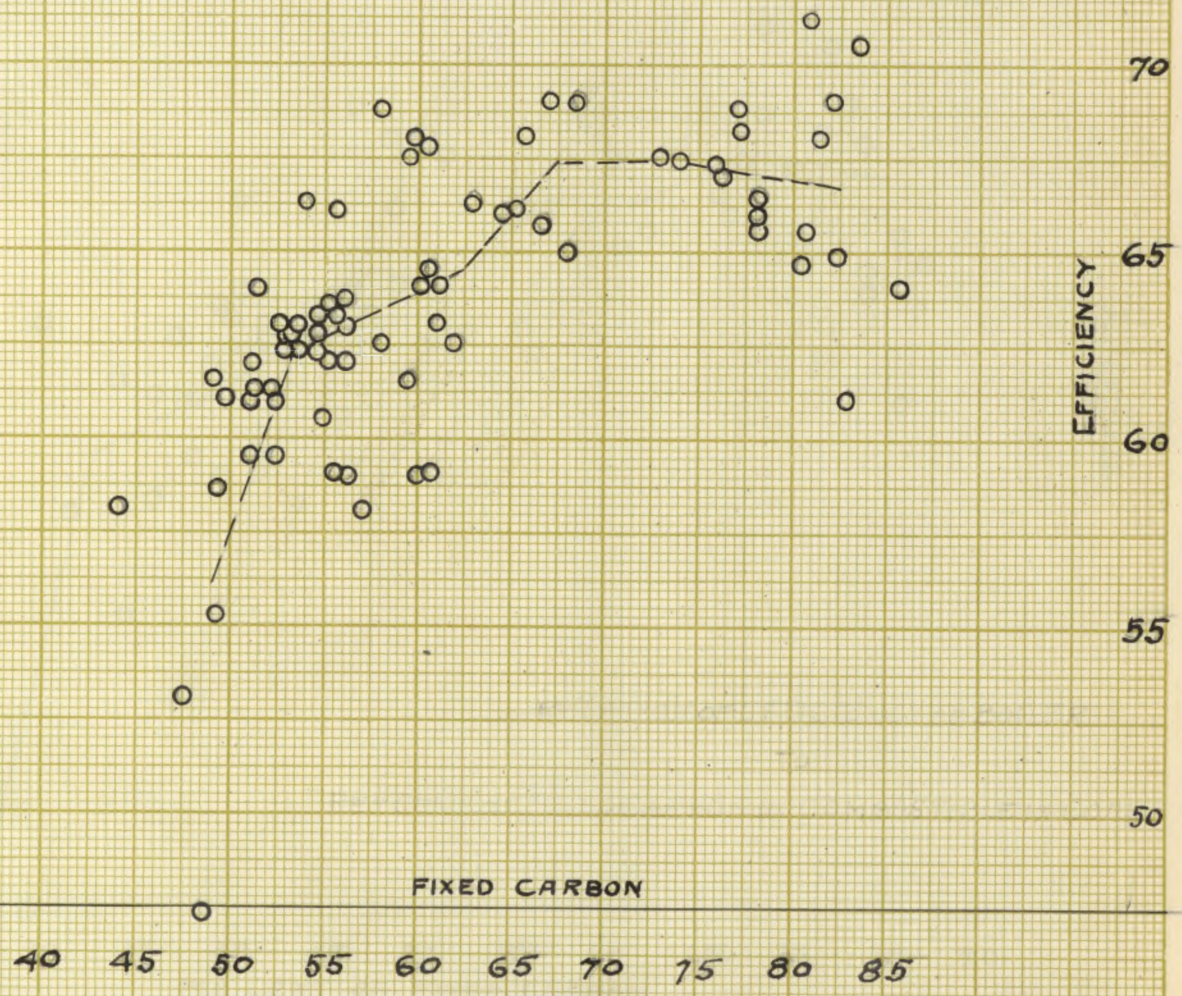


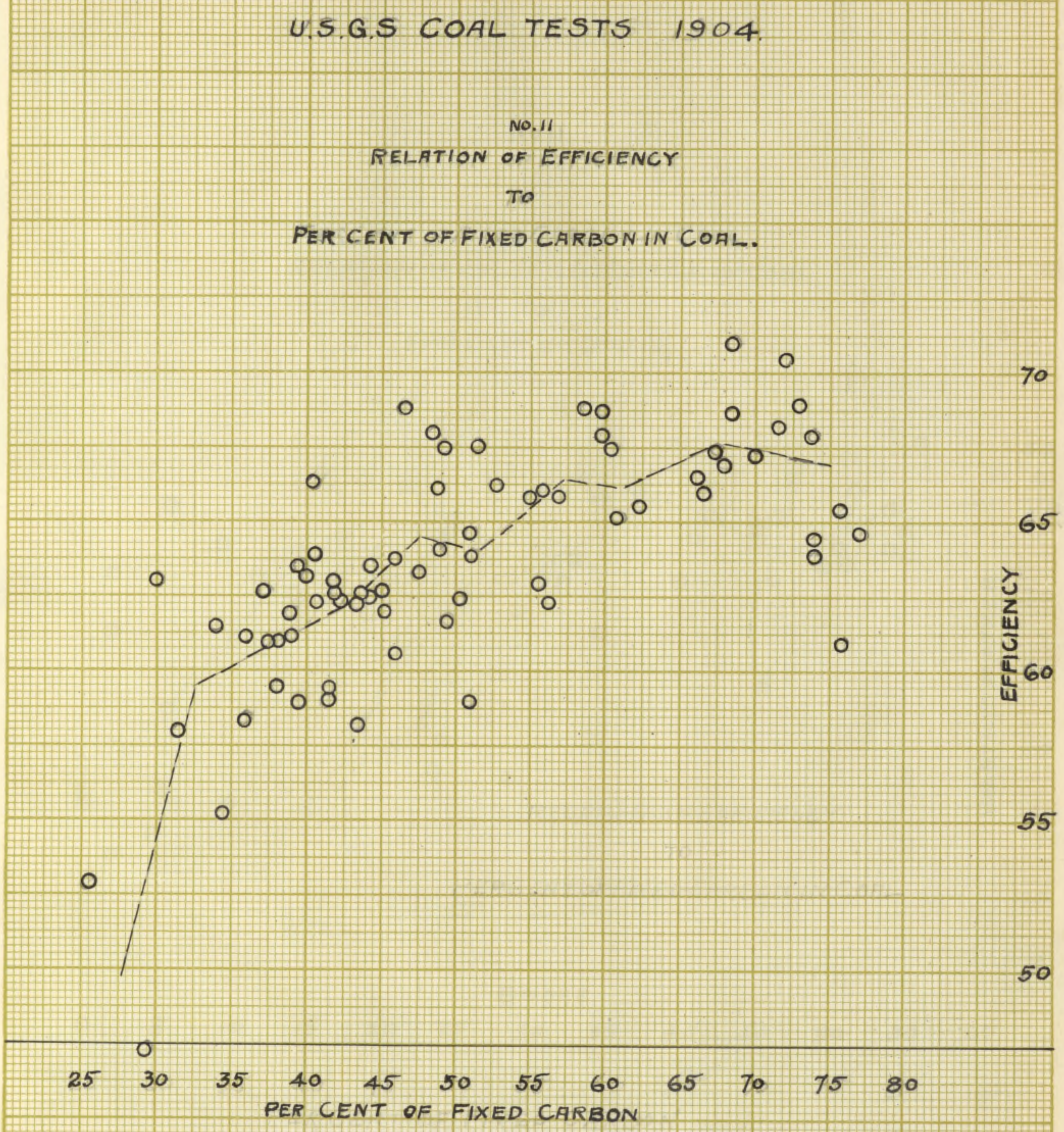

U.S.G.S. COAL TESTS 1904.
No. 9.
RELATION
OF
BTU PER POUND OF COMBUSTIBLE IN COAL
TO
PER CENT OF FIXED CARBON IN COMBUSTIBLE.
16000
15000
B.T.U.
14000
13000
12000
FIXED CARBON
40
45
50
55
60
65
70
75
80
85

U.S.G.S. COAL TESTS 1904.

NO. 10.

RELATION OF EFFICIENCY OF BOILER TO PER CENT OF FIXED CARBON IN COMBUSTIBLE IN THE COAL.




U.S.G.S COAL TESTS 1904.
NO. 11
RELATION OF EFFICIENCY
TO
PER CENT OF FIXED CARBON IN COAL.
70
65
60
55
50
EFFICIENCY
25
30
35
40
45
50
55
60
65
70
75
80
PER CENT OF FIXED CARBON

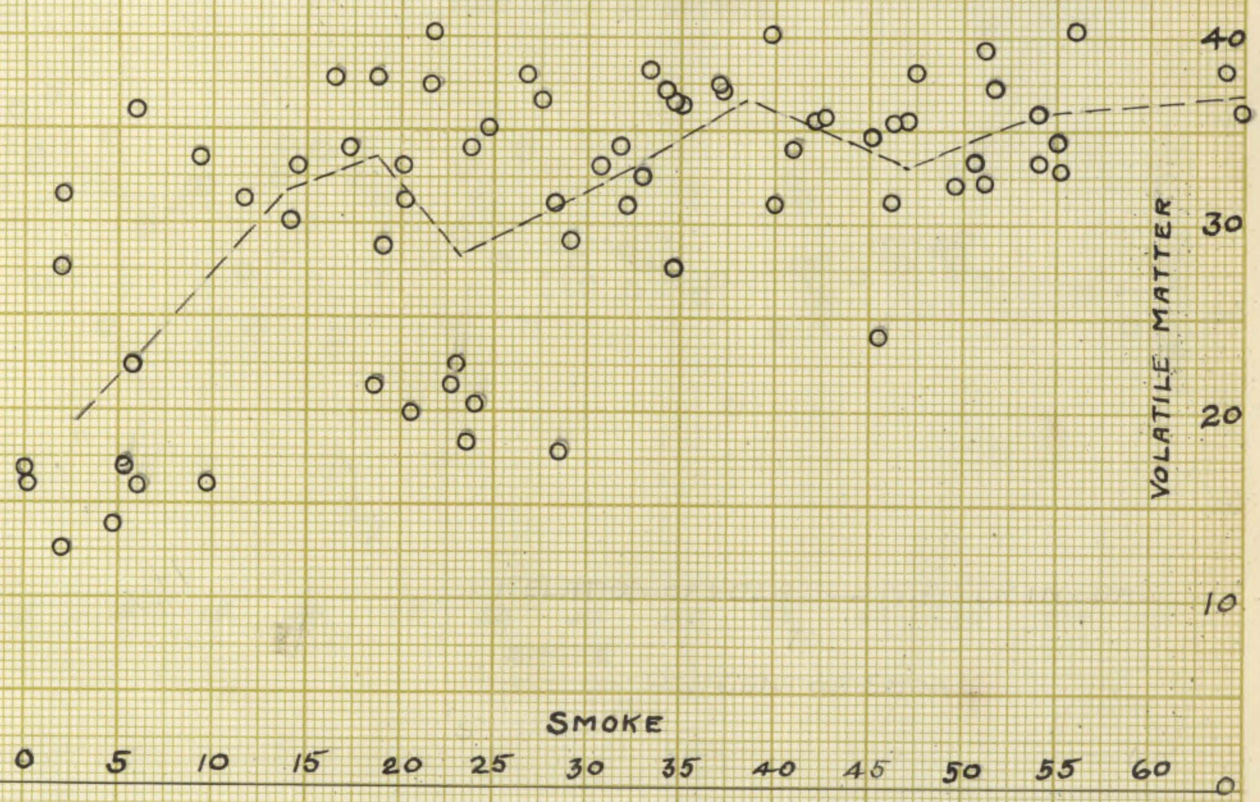
U.S.G.S. COAL TESTS 1904

NO. 12

RELATION OF VOLATILE MATTER IN COAL

TO

PER CENT OF SMOKE.



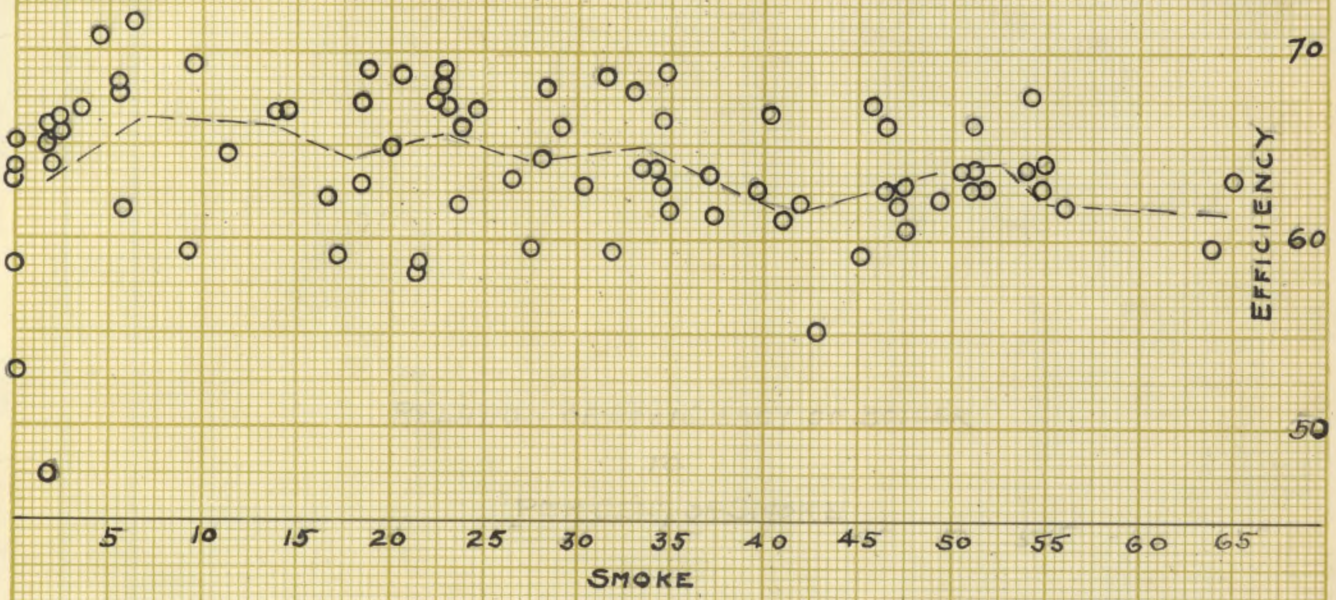
USGS COAL TESTS 1904.

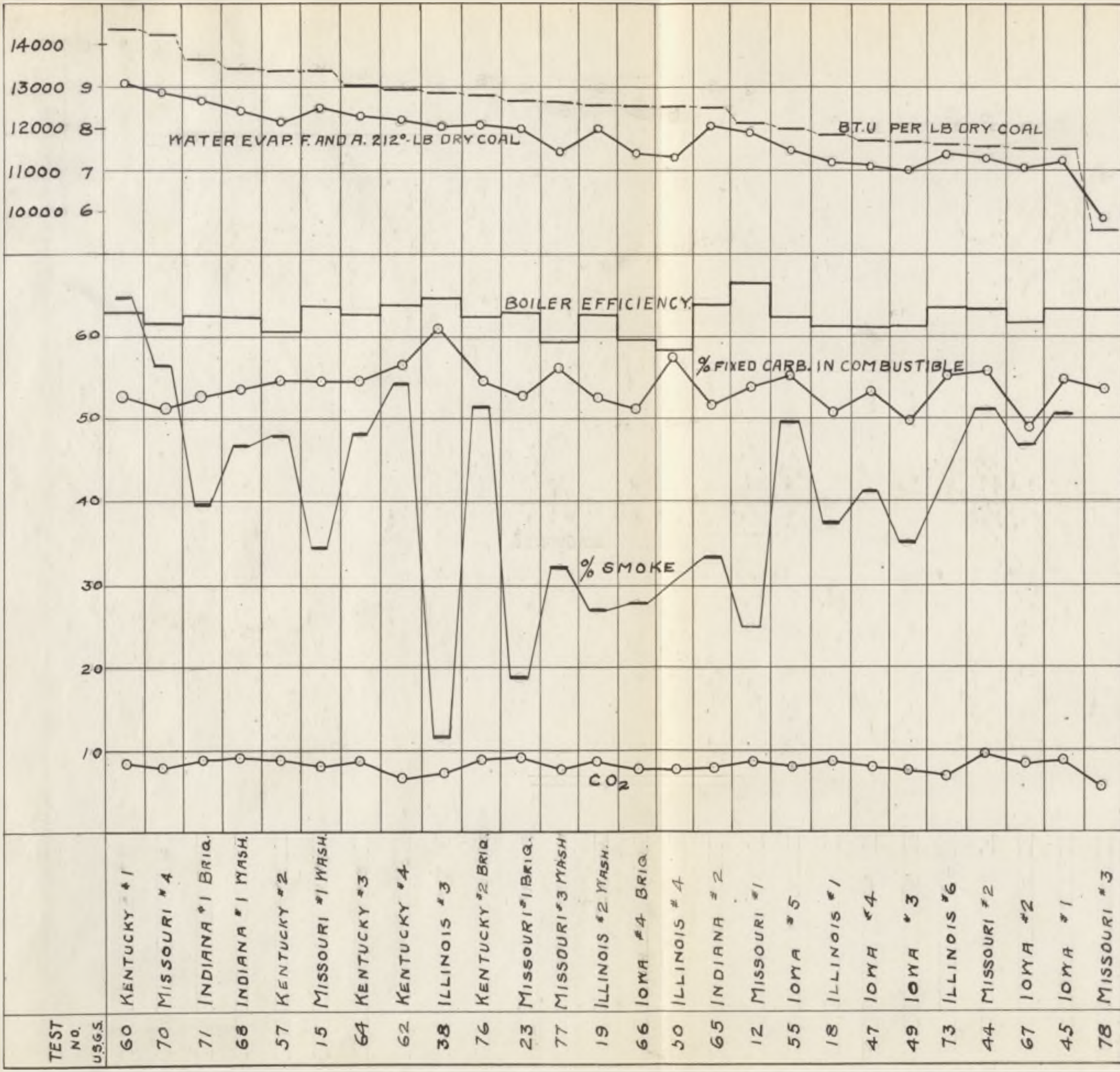
NO 13

RELATION OF EFFICIENCY OF BOILER

TO

PER CENT OF SMOKE.





CURVES SHOWING RESULTS OF TESTS ON COALS OF ILLINOIS AND NEIGHBORING STATES general the coal having the higher number of B. T. U. will evaporate the greater number of pounds of water from and at 212° F. There are some exceptions to this due no doubt to unfavorable conditions. These tests are not conclusive, because only one test was made on each coal and it is evident that differences similar to those pointed out might result from several tests on the same coal under different conditions.

8. Comparison of St. Louis Results with the Results of Tests Made by the Mechanical Engineering Department of the University of Illinois

Up to the present time about 200 boiler tests have been made with Illinois coal by classes under the direction of instructors in the Mechanical Engineering Department and by seniors doing thesis work. These tests have been recorded and are on file in the University Library or in the office of the Mechanical Laboratory.

Table No. 1 is given to show some of the leading results in recorded tests on Illinois coals. In many cases a number of tests have been averaged if the same coal and the same or similar boilers and furnaces were used. The numbers given in the last column refer to tests so numbered and on file in the laboratory office. The results for Illinois coals and those of neighboring states have also been plotted on cross-section paper, showing the effects of conditions and composition of the coals.

It will be noticed that except for the relation between the B. T. U. and the number of pounds of water evaporated, there

BOILER TESTS WITH ILLINOIS COALS COMPILED BY THE M. E. DEPT. UNIV. OF ILL.

1905.

*MOISTURE BY DRYING ABOVE BOILER

IDENTIFICATION OF BOILER AND GRATE	LOCATION OF BOILER	DATE OF TEST	KIND OF COAL	DURATION OF TEST HOURS	GRATE SURFACE SQUARE FEET	WATER HEATING SURFACE SQUARE FEET	RATIO OF WATER HEATING SURFACE TO GRATE SURFACE	STEAM PRESSURE GAGE: LBS PER SQ IN	DRAFT BETWEEN BOILER AND DAMPER - IN. OF WATER	TEMPERATURE OF FEED WATER DEGREES FAH.	TEMPERATURE OF ESCAPING GASES DEGREES FAH	MOISTURE IN COAL PER CENT	ASH AND REFUSE IN DRY COAL PER CENT	DRY COAL PER SQ. FT. OF GRATE SURFACE PER HR. LBS	MOISTURE IN STEAM PER CENT	CO_2 IN DRY FLUE GASES PER CENT	B.T.U. PER LB OF DRY COAL BY OXYGEN CALORIMETER	PROXIMATE ANALYSIS OF COAL PERCENTAGES OF: FIXED CARBON	VOLATILE MATTER	MOISTURE	ASH	HORSE POWER DEVELOPED IN BOILER	BUILDERS RATED HORSE POWER PER CENT OF	ECONOMIC RESULTS: EQUIV. EVAP. FROM AND AT 212° PER LB. OF COAL AS FIRED	EQUIV. EVAP. FROM AND AT 212° PER LB. COMBUSTIBLE	EQUIV. EVAP. FROM AND AT 212° PER LB OF DRY COAL	AVERAGE OF	NUMBERS OF TESTS AVERAGED
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
HEINE SAFETY W.T. PLAIN GRATE	U.S.G.S. PLANT ST. LOUIS MO.	1904 Oct. 3.	BELLEVILLE NUT	9.93	40.5	2031	50.1	83.7	.40	74.4	564	9.69	17.70	24.90	.446	8.50	11855	38.21	36.91	9.69	15.19	211.4	100.7	6.51	8.76	7.21	1 TEST	USGS - 18
HEINE SAFETY W.T. PLAIN GRATE	U.S.G.S PLANT ST. LOUIS MO.	1904 OCT. 4	BELLEVILLE SLACK-WASHED	9.97	40.5	2031	50.1	86.6	.42	74.3	554	10.45	10.40	22.36	.418	8.40	12569	41.72	37.77	10.45	10.06	210.2	100.1	7.16	8.92	8.00	1 TEST	USGS - 19
HEINE SAFETY PLAIN GRATE	U.S.G.S PLANT ST LOUIS MO.	1904 OCT 26.	MARION NUT	10.13	40.5	2031	50.1	84.4	.58	58.6	637	8.51	15.70	21.23	.796	7.10	12857	48.75	31.19	8.51	11.55	200.6	95.5	7.35	9.53	8.04	1 TEST	USGS - 38
HEINE SAFETY W.T. PLAIN GRATE	U.S.G.S. PLANT ST. LOUIS MO.	1904 NOV 9	TROY NUT	10.02	40.5	2031	50.1	83.0	.52	57.0	570	12.58	13.82	23.13	.698	7.40	12459	43.63	32.44	12.58	11.35	197.8	94.20	6.36	8.44	7.27	1 TEST	USGS - 50
HEINE SAFETY W.T. PLAIN GRATE	U.S.G.S. PLANT ST. LOUIS MO.	1904 DEC. 6	COFFEEN NUT.	9.92	40.5	2031	50.1	97.2	.69	44.1	624	13.19	15.45	22.34	.580	6.73	11594	39.62	32.31	13.19	14.88	194.3	92.54	6.43	8.75	7.40	1 TEST	USGS - 73
H.R. TUBULAR PLAIN GRATE	UNIV. OF ILL. HEAT. PLANT	1895	BLOOMINGTON LUMP	10.56	18.75	533	28.4	64.1	.24	52.4	622	3.80	12.22	16.90			12443	43.50	43.90	3.80	8.80	43.6	109.0	6.23	7.94	6.48	16 TESTS	8 TO 23 INCLUSIVE
H. R. TUBULAR PLAIN GRATE	UNIV. OF ILL. PLANT.	1895 1896	DUQUOIN LUMP	8.50	19.16	609	31.8	65.1	.22	60.8	520	8.05	8.38	10.36			12675	47.83	36.73	8.05	7.39	40.1	100.2	5.44	6.80	5.92	7 TESTS	28-40-41-42 27-43-49
BABCOCK & WILCOX PLAIN GRATE	CHAMPAIGN ELECT. LIGHT Co	1901.	DUQUOIN PEA	12.0	51.0	2264	44.4	108.5	.70	48.0	420	5.00	16.50	17.00	2.00			39.99	38.94	3.15	17.92	118.0	59.0	4.73	5.75	4.98	2 TESTS	155 - 157
BABCOCK & WILCOX PLAIN GRATE	UNIV. OF ILL. PLANT	1895 1896 1897	ODIN LUMP	8.71	51.0	2450	48.0	67.8	.33	50.9	478	7.25	16.13	20.5			12722	45.51	37.27	7.25	9.97	176.0	80.0	5.34	6.95	5.76	9 TESTS	112 TO 114 116 TO 121 INC.
NATIONAL W.T. MURPHY STOKER	UNIV OF ILL PLANT	1898 1899 1900	ODIN PEA	8.00	60.7	2539	41.8	93.2	.45	53.8	515	*3.30	18.36	20.1	2.60			43.39	36.88	6.76	12.97	217.0	86.8	5.84	7.47	6.04	5 TESTS	132 133 134 181 182
NATIONAL W.T. MURPHY STOKER	UNIV OF ILL. PLANT	1899.	JUNCTION PEA	7.25	60.7	2539	41.8	108.1	.58	49.1	481	*5.2	10.07	18.44	2.74			43.52	37.04	9.11	10.33	198.0	79.2	5.95	6.99	6.28	4 TESTS	135 145 146 147
BABCOCK & WILCOX PLAIN GRATE	CHAMPAIGN ELECT LT. Co.	1894	PANA SLACK	10.0	55.3	2340	42.4	90.5	.22	59.6	494	9.02		14.10			10783	39.35	35.45	8.55	16.65	111.0	53.6	4.54	6.42	4.99	4 TESTS	122 123 125 126
BABCOCK & WILCOX PLAIN GRATE	CHAMPAIGN ELECT LT. Co.	1894	PANA NUT & SLACK	10.23	46.8	2264	48.3	93.6	.24	60.1	499	*2.90	20.70	17.70	2.25							104.0	53.1	5.16	6.41	5.32	3 TESTS	124 127 129
BABCOCK & WILCOX PLAIN GRATE	UNIV OF ILL PLANT	1901	SPRINGFIELD PEA	8.19	28.0	1486	53.1	105.	.61	63.0	462	*3.68	17.0	26.0	2.80							111.0	74.0	4.05	5.10	4.20	2 TESTS	158 159
BABCOCK & WILCOX CHAIN GRATE	UNIV OF ILL. PLANT	1901	SPRINGFIELD PEA	8.00	28.0	1486	53.1	103	.64	57.5	523	8.95	20.4	30.9	3.28							176.0	117.3	5.58	7.71	6.13	2 TESTS	160 161
BABCOCK & WILCOX RONEY STOKER	UNIV OF ILL PLANT	1904	NEW KENTUCKY WASHED	12.0	104.0	4706	46.0	117.8	.68	57.8	624	11.03	15.8	26.5	1.9		12364	53.26	31.12	5.00	10.62	621.0	132.0	6.90	9.21	7.75	1 TEST	179
BABCOCK & WILCOX CHAIN GRATE	UNIV OF ILL PLANT	1904	NEW KENTUCKY WASHED	20.0	28.0	1486	53.1	120.1	.54	62.0	534	10.38	15.7	34.5	1.67	3.7	13156	53.32	33.10	2.94	10.64	210.0	140.2	6.71	8.89	7.49	1 TEST	180
BABCOCK & WILCOX CHAIN GRATE	UNIV OF ILL PLANT	1903 1904	RIVERTON PEA	8.0	28.0	1486	53.1	115.0	.64	68.4	482	16.50	21.6	26.4	3.00		11682	43.20	36.96	3.38	16.46	137.0	91.3	5.39	8.15	6.46	15 TESTS	164 TO 178 INC.
BABCOCK & WILCOX RONEY STOKER	UNIV OF ILL PLANT	1904	RIVERTON PEA	24	104	4706	46.0	119.4	.50	60.6	559	8.23	20.8	24.2	1.21	2.1	9975	33.98	36.27	8.23	21.52	463	98.5	5.88	8.06	6.43	1 TEST	
H.R.T. BOILER ROCKING GRATES	URBANA E.L.H.& P.Co.	1905	CATLIN 1¼" SCREENINGS.	22.	66	2912	44.1	99.	64	129.5	395.5	15.02	22.55	17.19	2.28	2.75	12368	43.40	29.62	7.41	19.57	201	82.7	5.20	7.95	6.12	2 TESTS	

seems to be but little relation between the conditions and the results. The efficiency for instance does not seem to be influenced by the amount of smoke produced or by the per cent of fixed carbon in the combustible, as shown by the results of these tests.

9. Conclusions

(a) On account of the variations in the chemical composition of the coals tested and the fact that but one test on each sample was usually possible, the results are not strictly comparable for the true fuel value of the coals tested at St. Louis.

(b) The tests, however, are valuable for the reason that they give reliable data on all the details of each test, and after a little study the value of each coal may be estimated very closely by one familiar with boiler practice.

(c) The table of results of tests on Illinois coals shows that the evaporation was higher on the St. Louis tests than is usual at this University or in the neighboring cities.

(d) The sheets of curves show the variation in the composition of the coals. The curves are for this reason valuable only for indicating the averages and the general tendencies due to conditions and the variations in the coals.

(e) The results of tests on Illinois and other western coals do not conform to the theory regarding the relations between the composition of the coals, gas analysis, smoke, and the efficiency of the boiler. This is probably due to the fact that only one test was made with each coal and that in many cases the conditions were not favorable.

(f) All of the above points to the desirability of making a series of tests on each coal.
