TESTS ON UNIVERSITY OF ILLINOIS BOILER PLANT WITH TWO GRADES OF COAL

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

Guy Lyman Morrill and Thomas Leo Robinson

ENTITLED Tests on University of Illinois Boiler Plant with Two Grades of Coal

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

DEGREE OF Bachelor of Science in Mechanical Engineering.

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TESTS ON UNIVERSITY OF ILLINOIS BOILER PLANT WITH TWO GRADES OF COAL.

I. INTRODUCTION.

Object. The primary object of these tests was to determine the economic results and the efficiency of the two boilers when operated as a unit with each of the two grades of coal.

Number of Tests. Four ten-hour steaming tests were made. During three of these tests screenings were used and during the other test pea coal was used.

Conditions of Test. In general the methods as indicated by the American Society of Mechanical Engineers were followed. During the test no effort was made to maintain exact uniformity of all conditions. It was endeavored however to maintain good fire conditions at all times.

The boilers carried their usual load which consisted of the heating and power load of the University. Because of this condition, the load on different dates varied considerably. On cooler days and during the school week the load was comparatively heavy, falling off on Saturday and Sunday and in warmer weather.

An analysis of the flue gas was made every twenty minutes and the results reported to the Superintendent of the plant. If it were necessary, he changed the draft or grate speed thus altering conditions so as to give the maximum CO_2 consistent with the maintenance of good fire conditions.

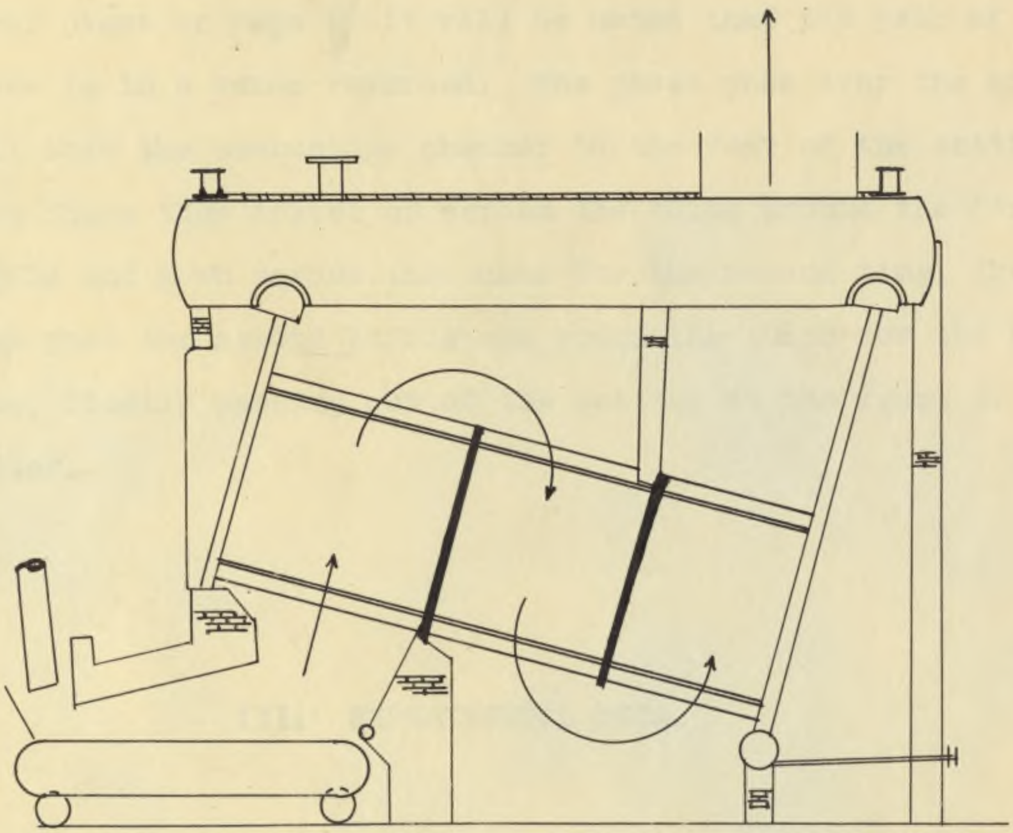
Fuel. In tests No. 2, 3 and 4, 1-1/4-in. screenings from the Electric mine at Danville, Illinois, were used while in test No. 6 Springfield pea from Springfield, Illinois, was used. In making a comparison between the two fuels, either test No. 2, 3 or 4 can be compared with No. 6 since the essential conditions under which all data and results were obtained were uniform. On page 24 will be found proximate and ultimate analyses of the coals used during the tests.

II. The Boiler Plant. The battery of two boilers upon which the tests were run constitute the beginning of the future power plant of the University of Illinois. The Power Plant adjoins the Mechanical Engineering Laboratory on the North, is just South of the Illinois Traction System's right of way and faces Matthews avenue, Urbana, Illinois, on the East. This location gives easy access to railroad facilities. The Illinois Traction System enters the Eastern, Central and Southern Illinois coal fields and also serves as a belt line to the principal coal roads traversing the State.

The plant consists of two Babcock and Wilcox boilers rated at 508 H.P. each and designed for a working pressure of 155 lb. The boilers are fired with Green travelling chain grates.

The baffling in these two boilers differs somewhat from the usual Babcock and Wilcox setting. In the regular setting of Babcock and Wilcox boilers the path of the gases is as shown in Fig. I. The gases from the furnace are taken directly up across the tubes over the first baffle and down

Fig. I.



Standard B.+W. Boiler Setting

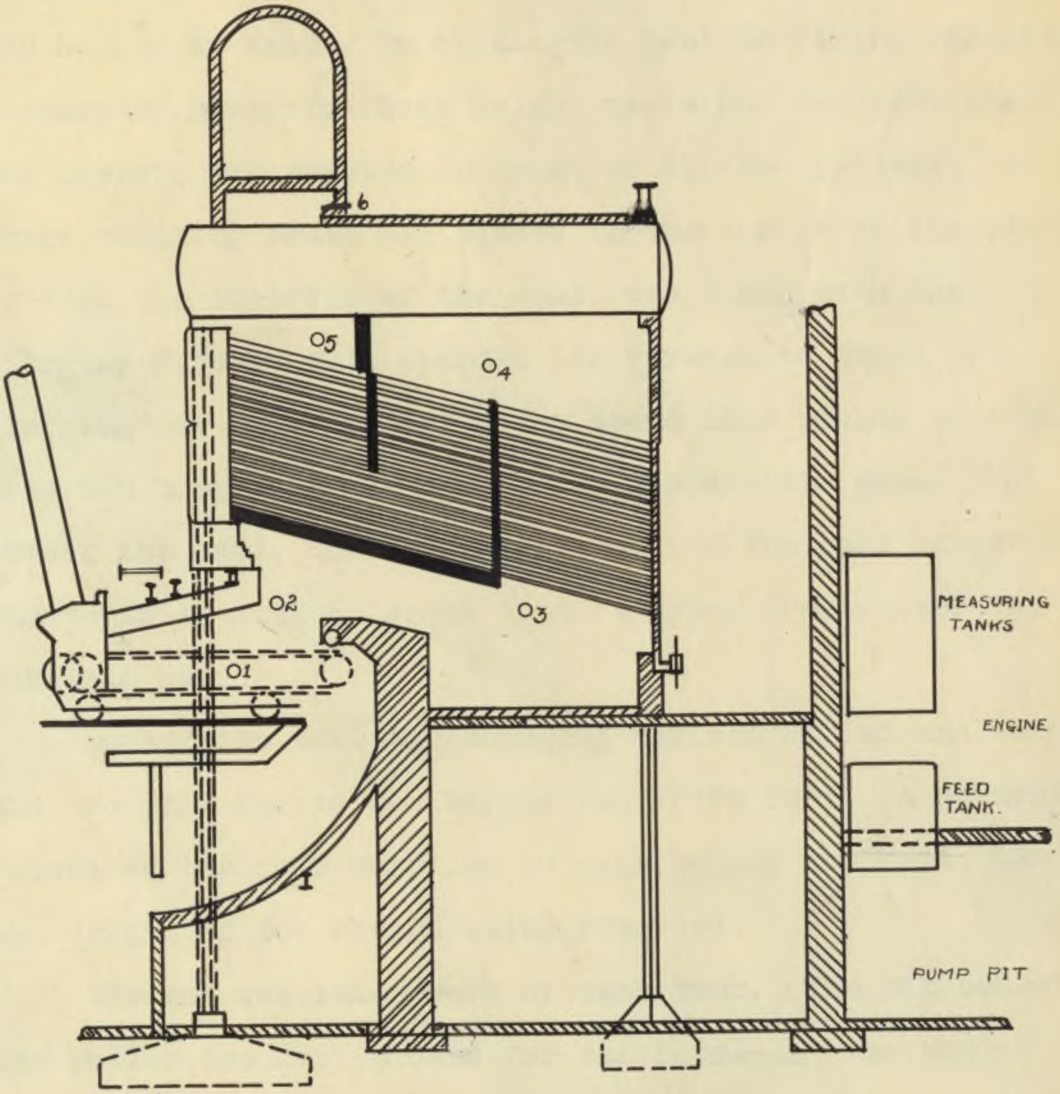
across the tubes for the second time. Then they pass up around the second baffle, up across the tubes for the third time and out of the setting at the rear of the boiler.

By referring to Fig. II, the drawing of the University power plant on page 9 it will be noted that the path of the gases is in a sense reversed. The gases pass over the bridge wall into the combustion chamber to the rear of the setting. From there they travel up across the tubes around the first baffle and down across the tubes for the second time, then they pass the second baffle and cross the tubes for the third time, finally passing out of the setting at the front of the boiler.

III. EXPERIMENTAL DATA.

For the test such instruments were installed as were necessary to obtain essential accuracy in testing. Because some of the methods used differ from those set forth by the A.S.M.E. code, a description of these methods will be given to assist the reader in giving proper weight to the data and results obtained. When unreliable data is retained which may have caused inaccuracies, attention will be called to it.

Fig. II.



Section thru Power Plant looking East

Weighing Fuel and Ash. Fig. III, page 11 illustrates the apparatus used in handling the coal. The coal was fed to the hopper by hand. To obtain the best of firing facilities a charging platform whose height was about two feet above the hopper, was erected in front of the two boilers. A large weighing scale was placed in the center of the platform so that the platform of the scale was flush with the charging floor. This enabled the firemen to wheel the charging car whose capacity was about 1200 pounds of coal, from one hopper to the other with comparative ease. To obtain the coal, the spout leading from the coal bunker was shortened to such a length that it swung freely over the charging car.

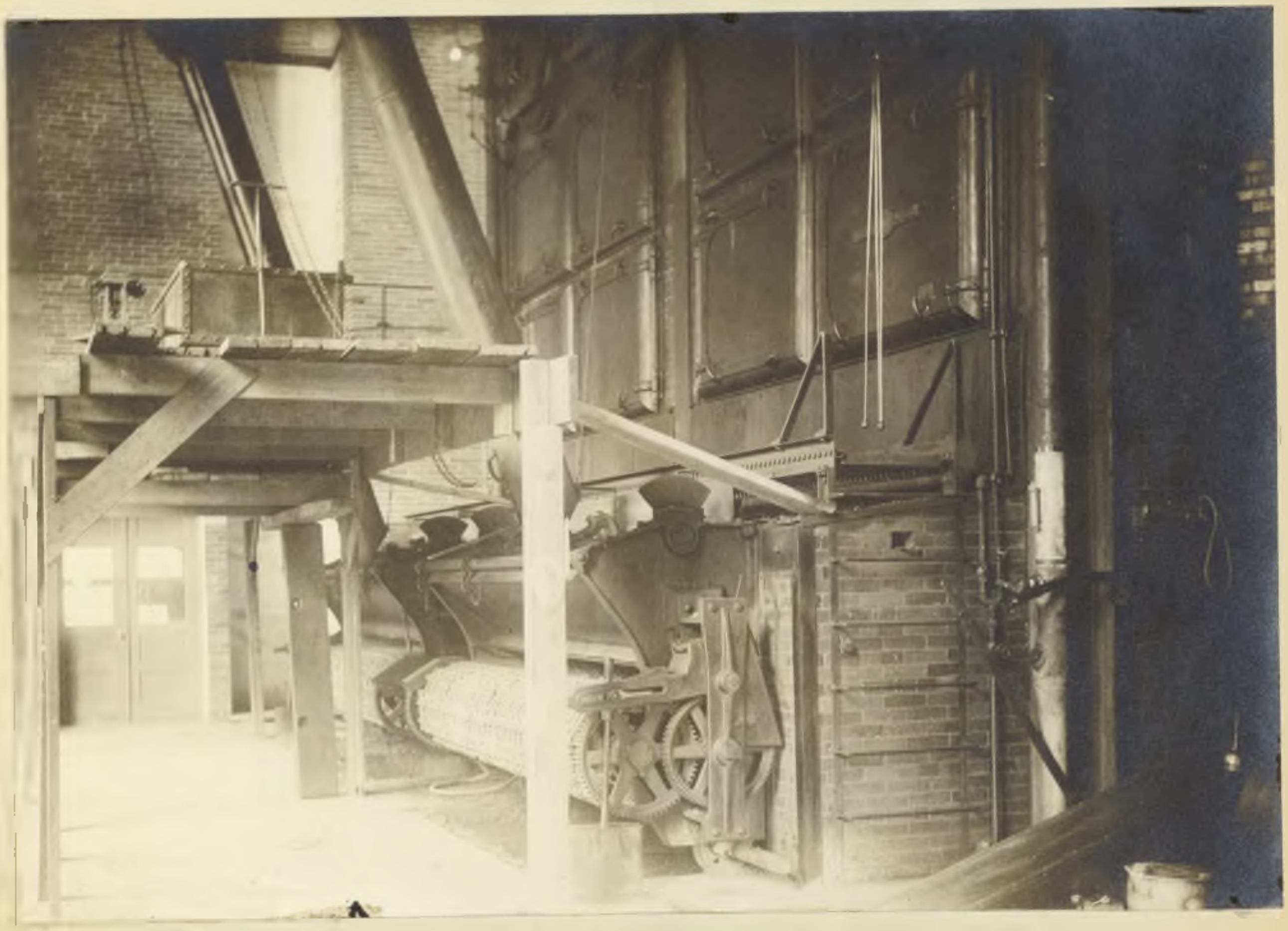
During the test the charging car was filled and weighed and the coal fed to the hopper requiring fuel. A separate record of the fuel supplied to each hopper was kept, the time and weight of the charge being recorded.

The ash was taken care of each hour. The pit beneath the boiler was kept closed for the hour. At the end of each interval the pit door was opened and the ashes scraped out and weighed a wheel-barrow full at a time. The weight of each barrow was recorded.

The refuse that fell through the grate was fed back to the hopper at frequent intervals.

Sampling Coal and Ash. In collecting the coal samples, a shovel full of coal was taken from each charge and put in

Fig. III.



View of Front of Boilers Showing Method of Weighing and Firing Coal.

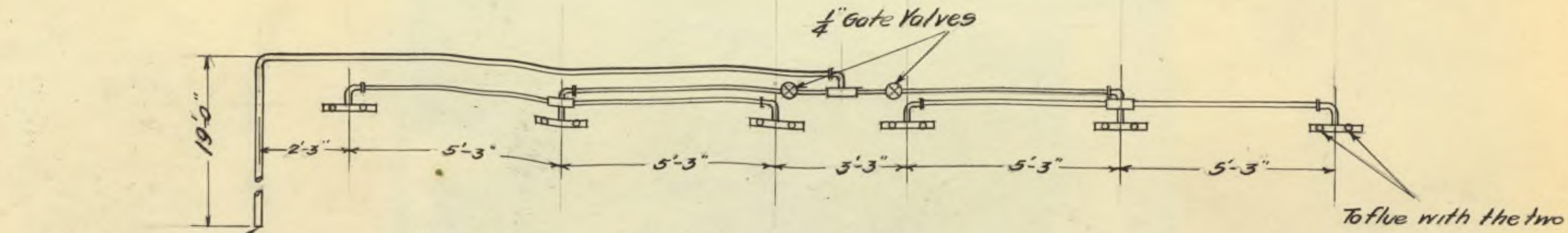
a covered can. At the close of the test this composite sample was dumped upon the concrete floor, mixed, crushed and quartered. Then the two opposite quarters were discarded and the two remaining ones again mixed, crushed and quartered. This process was continued until enough of the sample remained to fill two quart jars. These jars were then labeled and one sent to the chemical laboratory where it was analysed under the direction of a chemist, the other sample being retained for checking purposes.

The ash sample was obtained and analysed in a similar manner.

The apparatus for obtaining the flue gas samples is shown in Fig. IV, page 13 Six sets of sampling tubes to obtain the flue gas were placed in the flue below the damper. Each set of tubes was then brought to the back of the flue, and cross-connected as shown in the figure. The two gate valves as shown made it possible to obtain a sample from either or both boilers. Samples were drawn from the junction box by means of an aspirator placed on the main floor of the boiler room. Samples of gas from each boiler separately and from the battery as a whole were taken every hour. This meant that an analysis of flue gas was completed every twenty minutes.

Feed Water. By reference to the photograph of Fig. V, page 14 the apparatus for obtaining the amount of feed water used can be seen. The feed water was accounted for by two

FIG. IV



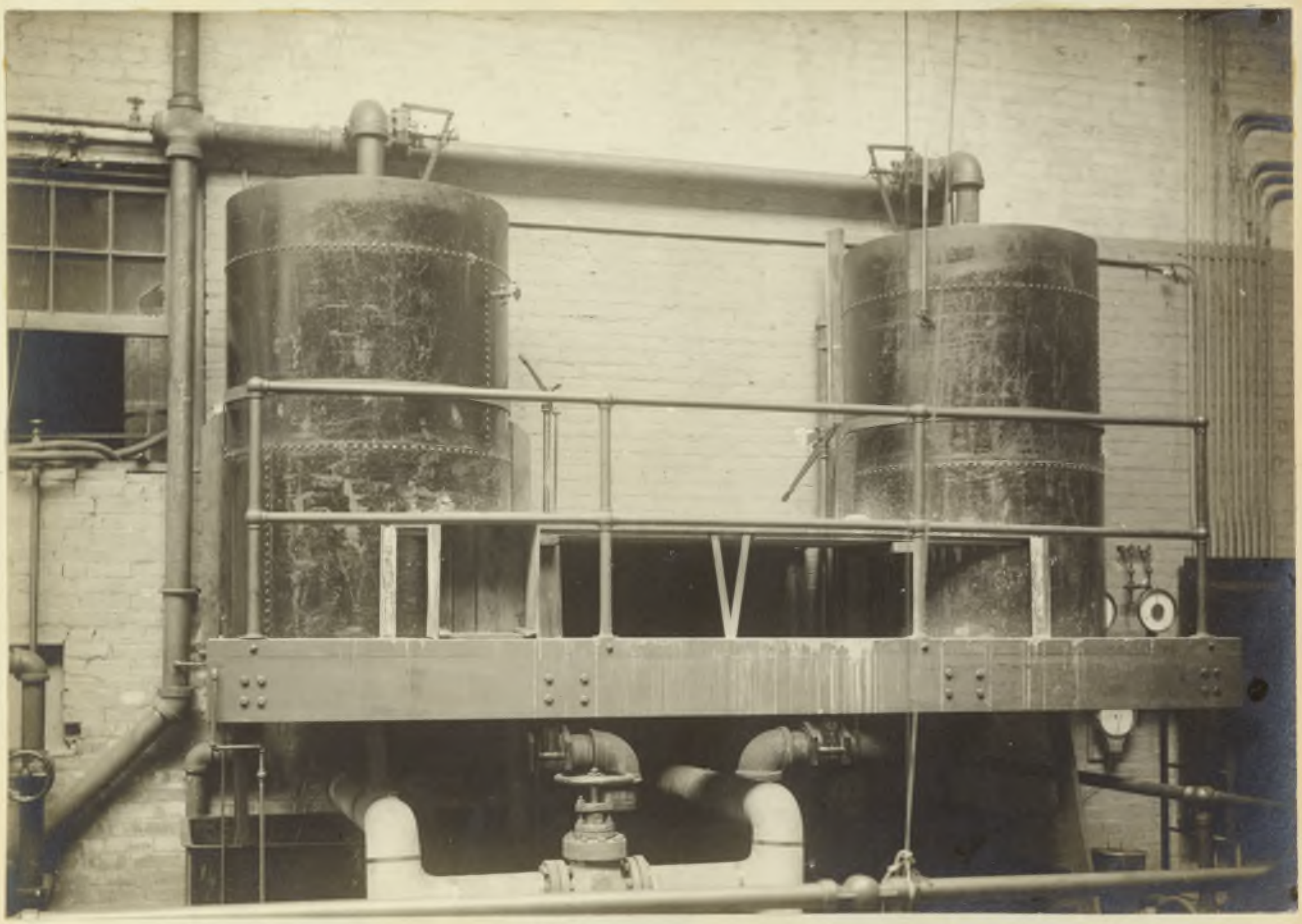
LAYOUT OF GAS SAMPLING APPARATUS – ELEVATION

SAMPLING TUBES

Note:-

Sampling tubes are to be made of ¼" iron pipe, 6 straight and 6 U tubes, each having 32-1/16" holes drilled around the tube as shown. The first hole is to be 1" from the end of the tube and the successive holes 1 15/16" apart.

Fig. V.



View of Feed Water Tanks

calibrated measuring tanks whose capacities were approximately 4700 lbs. at a temperature of 150°F. The water was supplied to the tanks through a 4-in. pipe, the water being pumped from the feed water heater by one of the two feed pumps. The feed water was controlled by means of two Crane quick opening valves shown in Fig. V. It required an average of two minutes to fill either tank. The tanks discharged through 6-in. pipes into a common feed tank whose capacity was about 8500 pounds of water. It required about one minute to empty either measuring tank. The calibration of the feed tank showed that it required 215 pounds of water at 65° per rising inch. A sensitive float was placed in the feed tank and so arranged that it enabled the operator to know the height of water. The suction pipe of the feed pump was connected to the bottom of the supply tank. By referring back to Fig. II an idea of the general location of the tanks may be obtained. They were located in the engine room directly above the pump pit.

The temperature of the water upon filling and at the time of emptying was recorded. The amount of feed water was corrected for temperature by means of Marks and Davis' steam tables. The amount of feed water fed to the boiler was the weight determined by the measuring tanks corrected for the following items:

1. Difference in quantity of water fed to the boiler from that measured, shown by the difference in level of water in feed tank at start and close of test.

2. Difference in quantity of water fed to boiler as shown by difference of level of water in boilers at start and close of test.

3. Water equivalent to difference in total heat of boiler water at start and close of test due to difference of steam pressure at those events.

4. Pump leakage.

Quality of Steam. To determine the quality of steam, throttling calorimeters with calibrated gauges were used. These calorimeters were connected to the steam main of each boiler in the vertical run just below the expansion curve which leads from the steam drums. The quality of steam delivered from each boiler was determined by means of Marks and Davis' steam tables and charts. To obtain the final quality the two average qualities were averaged.

The Water Back. The water used in the water backs was measured by calibrated water meters, one placed in each of the two supply pipes. By noting the temperature of the inflowing and outflowing water and knowing the amount of water flowing, the total heat was determined. By reference to the water back sample calculations these results will be seen. See page 30.

In calculating the efficiencies the boilers were credited with the amount of heat taken up by the water back. The amount of heat taken up by the water back is approximately 1 per cent of the heat taken up by the boiler.

Draft. Because of the unusual method of baffling, the draft was determined in all passes. Ellison's differential draft gauges were used. By referring to Fig. II the location of the draft tubes in the setting may be noted.

No. 1. Insert for the ash-pit draft.

No. 2. Furnace draft taken through furnace door.

No. 3. Combustion chamber.

No. 4. First Pass. At this point the draft was determined for the gases after they have passed the tubes for the first time.

No. 5. Third Pass. At this point the draft was determined for the gases after leaving the tubes for the last time.

No. 6. Under the damper.

Drafts No. 2, 3, 4, 5 and 6 were determined for each boiler. No. 1 was taken between the grates of the East boiler. The stack draft was determined at the entrance of the flue to the chimney. A table of the average drafts for the tests is given on page 34.

Care of the Boilers. Each morning before starting the tests the soot and dust were removed from the heating surface by means of an air blast inserted through the openings in the sides of the boiler settings.

Starting and Stopping the Tests. The alternate method of starting and stopping the tests was used. Each hopper was filled level full at the start and end of tests.

IV. DISCUSSION OF DATA AND RESULTS.

Tests No. 2, 3 and 4 were run under practically the same conditions and using the same kind of coal, Illinois screenings. Test No. 6 was run using Springfield pea coal. Therefore averages of the results in tests 2, 3 and 4 will be compared with the results obtained in test No. 6. By reference to the graphical log sheets, pages 33 to 38 the performance of the boilers during the four tests may be seen.

Before obtaining the amount of feed water fed to the boiler, numerous corrections were necessary. These corrections will be found on page 33. The boilers were credited with the amount of heat taken up by the water back.

Fuel and Capacity. The fuel used in tests 2, 3 and 4 had an average calorific value per pound of dry coal of 11646 B.t.u. while this value for the coal in test No. 6 was somewhat higher, being 11986 B.t.u. On the other hand, the average calorific value per pound of combustible in tests No. 2, 3 and 4 was 14442, slightly higher than for test No. 6 which was 14101. From the proximate analyses of the two coals it will be seen that the pea coal contains 3.55% more carbon, and practically the same amount of volatile matter, about 1% more moisture and 4.2% less ash. Considerably more ash and refuse was obtained in tests 2, 3 and 4 than in test No. 6, the difference being 1341 lb. An analysis of ash and refuse shows 2.64% more carbon in the ash from the pea coal. The earthy matter was nearly the same for both coals, being .18% higher in the pea coal. During test No. 2 the ash was wet for about an hour and thus the readings of the amounts of.ash during that time were thrown out and average readings taken from the rest of the test, and these substituted for the wet readings. This correction was so small that it caused no appreciable difference in the final results. The above considerations indicate that the pea coal was of a better quality than the other.

Fuel Consumption. Test No. 6 shows a somewhat higher fuel consumption than the other tests, the average dry coal consumed per hour in pounds in tests 2, 3 and 4 being 5349 and in test No. 6, 5970 lb. The dry coal per sq.ft. of grate surface per hour in lb. was found to be 29.31 in the case of the screenings and 33.16 for the pea coal.

In tests No. 2, 3 and 4 the average overload was 22.9% while in test No. 6 this was 41.4% The results of the four tests tend to show that the efficiency varies slightly considering the overloads; as it is shown in test No. 6, the boilers operating with load equivalent to 141.4% of the Builders' rating is only 0.9% higher than the unit operating at 113.8% of the Builders' rating. By comparison of coal cunsumption to overload it is found that the amount of coal burned in proportion to the overload is less with the higher overload.

Quality of Steam. The steam in test No. 6 contained more moisture than in any of the other tests, the percentage being 3.0 against 2.52 in the other tests. Although various conditions may have caused this large amount of moisture, one explanation may be that the boilers were run at an over-load during all the tests.

Gas Analysis. The best combustion was obtained in test No. 6 as shown by the large amount of CO_2, 9.63%, and the small amount of CO, .18%. These values for the other testswere 9.47% CO_2 and .63% CO. The reason for the high percentage of CO in tests 2, 3 and 4 may be attributed to the excessive dampness of the coal which tended to cool down the fire. In test No. 6 there was less moisture present and a hotter fire was maintained.

Economic Results and Cost.

	Water apparently evaporated per pound of Coal as Fired.		Efficiency		Cost of Fuel for Evaporating 1000-lb. of water under observed Conditions.	
		Average		Average		Average
Test 2.	6.32		65.9		.0974	
Test 3	6.24	6.26	68.03	66.94	.0989	.0983
Test 4	6.23		66.9		.0988	
Test 6	6.57		67.4		.1447	

From the above comparisons it will be seen that the highest evaporation occurred in test No. 6. This was probably due to the more complete combustion obtained in that test, the hotter fire and the use of the graded coal. In taking into consideration the cost of evaporation, it will be seen that the pea coal is more expensive. By comparison of the costs of evaporating 1000-lb. of water under observed conditions the pea coal cost 47% more than the screenings.

Efficiency. In comparing the efficiencies, test No. 6 was found to give an efficiency of 67.4% and the average of the other three tests 66.94%. These values are about 6 or 7% above the average for power boilers. Due to the fact that the pea coal used in test No. 6 had a higher per cent of fixed carbon than the other coal, the efficiency in test No. 6 should be slightly higher than in the other tests. The better combustion and all around conditions present in test No. 6 also warrant a somewhat higher efficiency.

Heat Balance. The distribution of the heat units of the combustible show that the losses unaccounted for with tests No. 2, 3, 4 and 6 respectively were 9.9%, 3.36%, 2.84% and 6.93%. The loss due to the heat carried away in the dry chimney gas was low in test No. 2, which thus partially caused the large unaccounted for loss of 9.9%. The average weight of gas per pound of combustible in tests No. 2, 3 and 4 was practically the same as in test No. 6, the values being 18.78 lb. and 19.1 lb. respectively.

V. CONCLUSIONS.

1. The efficiency of the unit was 67.4 per cent when pea coal was fired and 66.94 per cent when screenings were fired. or a difference of .46 per cent in favor of the pea coal.

A greater number of tests with the pea coal, which is not the fuel regularly used at the power plant, might show a greater difference in favor of the graded coal.

2. The evaporation with the pea coal as fired was four per cent higher than the evaporation with the screenings.

3. The CO_2 and CO indications from the tests show better fire conditions when the pea coal was fired.

4. The draft necessary to complete combustion with the pea coal was .023 inches of water less over the fire than the draft when burning screenings.

5. The cost of pea coal to evaporate 1000 lb. of water under the observed conditions was 4.67 cents higher than with screenings.

6. The cost of pea coal was $1.90 per ton which was 54.5% higher than the cost of the screenings which was $1.23. The better results obtained in the test show that in steaming value the cost of pea coal is 47 per cent higher than the cost of screenings.

7. The slight increase in efficiency, the decrease in ash, the better fire conditions. the ease of firing and small

losses due to incomplete combustion obtained while firing the pea coal would not warrant the purchase of pea coal in preference to the screenings.

CALCULATED RESULTS.

	Test number	2	3	4	6
1.	Date of trial	April 19	April 20	April 22	May 2
2.	Duration of trial, hours	10	10	10	10
	DIMENSIONS AND PROPORTIONS				
3.	Grate surface, sq.ft. Both boilers	180	180	180	180
3.1	Width of grate, feet.	10	10	10	10
3.2	Length of grate, feet.	9	9	9	9
6.1	Area of chimney, sq.ft.	66	68	68	66
6.2	Height of chimney above grate, feet.	172	172	172	172
6.3	Length of flue to chimney, ft.	10'6"	10'6"	10'6"	10'6"
6.4	Kind of draft	Natural	Natural	Natural	Natural
7.	Total water heating surface, sq.ft.	20348	20348	20348	20348
7.1	Outside diameter of shell, in.	42	42	42	42
7.2	Length of shell (Outside heads), ft.	20'4"	20'4"	20'4"	20'4"
7.3	Number of tubes	14 ?	14	14	14
7.4	Diameter of tubes, in.	4	4	4	4
7.5	Length of tubes, ft.	18	18	18	18
9.	Ratio of water heating surface to grate surface	113.05	113.05	113.05	113.05
	AVERAGE PRESSURES.				
11.	Steam pressure, lb. per sq.in. gage.	128.9	126.5	126	125.8
11.1	Steam pressure. (East boiler)	129	122	125.9	124.6
11.2	Steam pressure. (West boiler)	128.5	126.5	126.1	126.5
12.	Draft between damper and boiler, in. water	.524	.597	.757	.709
13.	Draft in furnace, in. water	.262	.273	.389	.266
14.	Draft in ash pit, in. water	.019	.021	.021	.015
	AVERAGE TEMPERATURES.				
15.	Of external air, degrees F.	53.5	64	49	73.5
16.	Of fireroom, degrees F.	65.9	67.7	66.3	74.2
17.1	Of steam (East boiler), degrees F.	279	226.2	284.0	212.7
17.2	Of steam (West boiler), degrees F.	249	249.5	255	276
20.	Of feed water entering boiler, degrees F.	142.7	150.7	148.4	149.2
21.	Of escaping gases from boiler, degrees F.	512	516	535	548
	FUEL				
23.	Size and condition	1½-in. screenings	1½-in. screenings	1½-in. screenings	pea
25.	Weight of coal as fired, lbs.	66519	59361	57151	69978
26.	Moisture in coal, per cent.	17.1	17.72	15.87	14.61
27.	Total weight of dry coal fired, lbs.	55144	48842	58494	59754
28.	Total ash and refuse, lbs.	11595	8670	10234	8825
30.	Total combustible consumed, lbs.	42344	38731	42862	49196
	PROXIMATE ANALYSIS OF COAL.				
32.	Fixed carbon, per cent.	38.41	37.31	36.96	41.11
33.	Volatile matter "	41.14	42.17	40.30	40.60
34	Moisture "	2.43	2.48	2.74	[illegible]
35.	Ash	18.02	18.04	20.00	14.43
36.	Sulphur, separately determined, per cent	4.40	4.41	5.02	4.99
32.1	Fixed Carbon, coal as fired, per cent	32.84	31.48	31.95	36.51
33.1	Volatile matter, coal as fired, "	34.95	35.58	34.87	38.06
34.1	Moisture in coal as fired, "	17.10	17.72	15.87	14.61
35.1	Ash in coal as fired, "	15.31	15.22	17.31	12.82
32.2	Fixed carbon, combustible, per cent.	48.29	46.94	47.81	50.27
33.2	Volatile matter in combustible	51.71	53.06	52.19	49.73
	ULTIMATE ANALYSIS OF DRY COAL				
37.	Carbon	59.81	59.81	59.81	62.15
38.	Hydrogen	4.79	4.79	4.79	4.79
39.	Oxygen	8.80	8.80	8.80	8.8
40.	Nitrogen	.89	.89	.89	.90
41.	Sulphur	4.59	4.59	4.59	4.99

42. Ash	16.64	16.64	16.64	14.43
43. Moisture	2.49	2.49	2.49	2.49
37.1 Carbon in combustible consumed, per cent	75.92	75.18	74.62	75.26
38.1 Hydrogen in combustible consumed, "	5.45	6.38	6.35	6.08
43.1 Moisture in coal to per cent of combustible consumed	27.08	27.37	24.40	20.81
ANALYSIS OF ASH AND REFUSE.				
44. Carbon, per cent.	22.55	12.4	19.51	20.6
45. Earthy matter, per cent.	77.1	87.28	80.11	81.67
FUEL PER HOUR.				
46. Dry coal consumed per hour, lb.	5514	4882	5649	5970
47. Combustible consumed per hour, lb.	4234.4	3865.0	4288	4956
48. Dry coal per square foot of grate surface per hour, lb.	30.63	27.35	31.45	33.165
49. Combustible per square foot of water heating surface per hour, lb.	.211	.19	.2163	.2435
CALORIFIC VALUE OF FUEL				
50. Calorific value by oxygen calorimeter, per pound of dry coal, B.t.u.	11670	11654	11613	11968
50.1 Calorific value lb. of air dry coal by oxygen calorimeter, B.t.u.	11385	11365	11295	11523
51. Calorific value by oxygen calorimeter per pound of combustible, B.t.u.	14410	14299	14618	14101
QUALITY OF STEAM.				
54. Percentage of moisture in steam, per cent	2.5	3.2	1.85	3.0
56. Correction factor for quality of steam	.9799	.9736	.9850	.9758
WATER				
57. Total weight of water fed to boiler, corrected lb.	420,842	370,578	419,156	459,470
58. Equivalent water fed to boiler from and at 212 degrees, lb.	447,500	410,000	498,500	509,000
59. Water evaporated, corrected for quality of steam, lb.	411,200	360,500	411,000	447,900
60. Factor of evaporation	1.114	1.106	1.11	1.106
61. Equivalent water evaporated into dry steam from and at 212 degrees, (Item 59 x Item 60)	437,500	399,110	456,100	498,000
WATER PER HOUR.				
62. Water evaporated per hour, corrected for quality of steam, lb.	41120	36050	41100	44790
63. Equivalent evaporation per hour from and at 212 degrees, lb.	43750	39911	45610	49800
64. Equivalent evaporation per hour from and at 212 degrees per sq.ft. of water heating surface, lb.	2.15	1.96	2.26	2.46
HORSEPOWER.				
65. Horse-power developed.	1267	1157	1322	1437
66. Builder's rated horse-power	1016	1016	1016	1016
67. Percentage of builder's rated horse-power developed, per cent	125	113.8	130	141.4
ECONOMIC RESULTS				
68. Water apparently evaporated under actual conditions per pound of coal as fired.	6.32	6.24	6.23	6.57
69. Equivalent evaporation from and at 212 degrees per pound of coal as fired.	6.58	6.72	6.8	7.09
70. Equivalent evaporation from and at 212 degrees per pound of dry coal.	7.93	8.17	8.08	8.30
71. Equivalent evaporation from and at 212 degrees per pound of combustible.	10.32	10.30	10.65	10.07
EFFICIENCY				
72. Efficiency of the boiler; heat absorbed by the boiler per pound of combustible divided by the heat value of one pound of combustible, per cent.	69.40	69.9	70.0	69.4
73. Efficiency of boiler including the grate; heat absorbed by the boiler per pound of dry coal, divided by the heat value of one pound of dry coal, per cent	65.9	68.03	66.9	67.4
COST OF EVAPORATION.				
74. Cost of coal per ton, delivered in boiler room $	1.23	1.23	1.23	1.90
75. Cost of fuel for evaporating 1000 lb. of water under observed conditions, $	.0974	.0989	.0988	.1447
76. Cost of fuel used for evaporating 1000 lb. of water from and at 212 degrees, $	.0935	.0915	.094	.134

ANALYSIS OF THE DRY GASES.

84.	Carbon dioxide, per cent.	11.9	8.47	8.05	9.03
85.	Oxygen, per cent.	5.9	9.77	10.48	9.72
86.	Carbon monoxide, per cent.	.47	.688	.74	.18
88.	Nitrogen, by difference, per cent.	81.73	79.07	80.13	80.47

HEAT BALANCE, OR DISTRIBUTION OF THE HEATING VALUE OF THE COMBUSTIBLE.

		14410		14299		14818		14101	
	Total heat per pound of combustible,	B.t.u	per cent.	B.t.u.	per cent.	B.t.u.	per cent.	B.t.u	per cent.
1.	Heat absorbed by the boiler = evaporation from and at 212 degrees per pound of combustible x 970.4	10020	69.9	10020	69.4	10250	70.0	9780	69.4
2.	Loss due to moisture in coal = per cent of moisture referred to combustible ÷ 100 ((212 – t) + 970.4 + 0.48(T – 212)) (t = temperature of air in boiler room, T = that of flue gases.)	308	2.14	345	2.42	309	2.11	335	2.37
3.	Loss due to moisture formed by burning of hydrogen – per cent of hydrogen to combustible ÷ 100 x 9 x ((212–t) + 970.4 + 0.48 (T – 212))	734	5.1	722	5.05	724	4.95	692	4.90
4.	Loss due to heat carried away in the dry chimney gases – weight of gas per pound of combustible x 0.24 x (T – t).	1650	11.50	2180	15.27	2295	15.69	2170	15.40
5.	Loss due to incomplete combustion of carbon = $\frac{CO}{CO_2 + CO}$ x $\frac{\text{per cent C in combustible}}{100}$ x 10,150	292	2.03	574	4.02	646	4.42	141	1.00
6.	Loss due to unconsumed hydrogen and hydrocarbons, to heating the moisture in the air, to radiation and unaccounted for.	1422	9.33	458	3.36	394	2.84	983	6.93

VI. APPENDIX A.

1. Data and Results.

VII. APPENDIX B.

1. Methods of Calculation.
2. Feed Water Corrections.
3. Water Back Corrections.
4. Average Draft.
5. Flue Gas Analysis.
6. Graphical Log Sheets.

1. METHODS OF CALCULATION.

Wherever they apply, the methods of calculation set forth by the A.S.M.E. code for boiler testing were followed in detail to obtain the results given in the table of "Calculated and Observed Data". The results obtained are tabulated under the regular code item number. Wherever an item has a different significance than that of the A.S.M.E. code it is denoted by a decimal suffix to the regular code number.

When no mention of item calculation is made it will be understood that the result recorded was obtained directly from observation with a possible correction for inaccuracy of instrument.

Item 20. Average temperature of feed water entering boiler. Average of the total number of readings of both boilers. The temperature of the feed water entering each boiler was taken every twenty minutes.

Item 21. Average temperature of gases escaping from boiler. Average of total number of readings of both boilers. The temperature of the flue gas was taken from each boiler every twenty minutes.

Item 27. Total weight of dry coal fired. Item 25 x Item 27.

Item 30. Total combustible consumed. This is equal to the total combustible fired minus the carbon in the ash =

$$(\text{Item } 27 \times (1 - \frac{\text{Item } 35}{1 - \text{Item } 34})) - (\text{Item } 28 \times 44)$$

Item 32 to Item 46. Results obtained by the Chemistry department of the University of Illinois.

A composite sample was made for the coal burned in tests No. 2, 3 and 4 for the ultimate analysis. To obtain a composite sample that was approximately correct for the three tests, the per cent of coal burned during each test to the total coal burned for the three tests was calculated.

Coal for Test No. 2 to Total Coal, Tests No.2,3,4	=	34.3%
" " " " 3 " " " " "		30.5%
" " " " 4 " " " " "		35.2%

The sample for ultimate analysis was made up of the three coals on the same percentage basis.

Item 46. Dry coal consumed per hour. Item 27 ÷ Item 2.

Item 47. Combustible consumed per hour, pounds. Item 30 ÷ Item 2.

Item 48. Dry coal per sq.ft. of grate surface, pounds. Item 46 ÷ Item 3.

Item 49. Combustible consumed per hour per sq.ft. of water heating surface. Item 47 ÷ Item 7.

Item 50. Calorific value per pound of dry coal, B.t.u. Item 50.1 ÷ (1 - Item 34)

Item 51. Calorific value per pound of combustible, B.t.u.

$$\text{Item } 50 \div \left(1 + \frac{\text{Item } 35}{1 - \text{Item } 34}\right)$$

Item 54. Percentage of moisture in steam. This value indicates the average moisture in steam for the two boilers. The quality of the steam was determined for each boiler by throttling calorimeters and the results averaged. 1 - average quality.

Item 56. Correction factor for quality of steam. (1 - Item 54) x

$$\text{Item } 54 \left(\frac{q - h}{H - h}\right)$$

q = heat of liquid at given pressure = Item 11.
h = heat of feed water = Item 20.
H = total heat in saturated steam at given pressure, Item 11.

Item 57. Total weight of water fed to boiler. Result entered is the equivalent amount of water actually fed to the boiler. The corrections for Item 57 are itemized on page 32.

Item A. Water actually measured by water tanks.

Item B. Difference in quantity of water fed to boiler as shown by difference in level of water in feed tank at start and close of test.

Item C. Water loss through leakage of feed pump.

Item D. Water at the boiler pressure equivalent to the amount necessary to absorb the amount of heat taken up by the water back. This is credited to the boiler.

$$\text{Item D} = \frac{W(T_2 - T_1)}{H - xr - h}$$

W = Total water through water back, measured by meters.
T_1 temperature of inflowing water back water
T_2 temperature of outflowing water back water
H total heat in steam at given pressure (Item 11).
x correction factor for steam (Item 56).
r latent heat of saturated steam at given pressure (Item 11).
h heat of feed water (Item 20).

Item E. Difference in quantity of water fed to boiler as shown by difference in level of water in boilers at start and close of test. Calibration of East boiler showed that it required approximately 1400 lb. per rising inch. Calibration of West boiler showed it required approximately 1600 lb. per rising inch.

Item F. Equivalent water fed due to difference in pressure at start and finish of test, $= \frac{W_1 q}{H + xr + h}$

W is initial or final weight of water in boiler according to whether there is more or less water in boiler at start or end of test, q is difference in temperature of liquid at start and close of test, H, xr and h have the same significance as like values in Item D.

Item H. Ratio of heat loss to the water back to total heat of fuel consumed. $\frac{W(T_2 - T_1)}{\text{Item 30} \times \text{Item 51}}$

W = total weight of water back water,
T_2 temperature of outgoing water,
T_1 temperature of ingoing water.

Item 58. Equivalent water fed to boiler from and at 212°F, lb. Item 51 x Item 60.

Item 59. Water actually evaporated, corrected for quality of steam. Item 57 x Item 56.

Item 60. Factor of evaporation, = $\frac{H - \text{Item 20}}{970.4}$. H is total heat in saturated steam at given pressure, Item 11..

Item 61. Equivalent evaporation into dry steam from and at 212°F. Item 59 x Item 60.

Item 62. Water evaporated per hour corrected for quality of steam. Item 52 ÷ Item 2.

Item 63. Equivalent evaporation per hour into dry steam from and at 212°. Item 61 ÷ Item 2.

Item 64. Equivalent evaporation per hour from and at 212° per sq.ft. of heating surface. Item 63 ÷ Item 7.

Item 65. Horsepower developed. Item 63 ÷ 34.5

Item 67. Percentage of builders rated horsepower, per cent. Item 65 ÷ Item 66.

ECONOMIC RESULTS.

Item 68. Water apparently evaporated under actual conditions per pound of coal as fired. Item 57 ÷ Item 25.

Item 69. Equivalent evaporation from and at 212° per pound of coal as fired. Item 61 ÷ Item 25.

Item 70. Equivalent evaporation from and at 212° per pound of dry coal. Item 61 ÷ Item 27.

Item 71. Equivalent evaporation from and at 212° per pound of combustible. Item 61 ÷ Item 30.

EFFICIENCY.

Item 72. Efficiency of boiler; heat absorbed by the boiler per pound of combustible divided by the heat value of one pound of combustible, per cent. (Item 71 x 970.4) ÷ Item 51.

Item 73. Efficiency of the boiler including the grate; heat absorbed by the boiler per pound of dry coal divided by the heat value of one pound of dry coal, per cent. (Item 70 x 970.4) ÷ Item 50.

COST OF EVAPORATION.

Item 75. Cost of fuel for evaporating 1000 lb. of water under observed conditions. Item 71 ÷ Item 68.

Item 76. Cost of fuel used for evaporating 1000 lb. of water from and at 212°. Item 71 ÷ Item 69.

The following tables contain the results of feed water and water back corrections as referred to on pages 29 and 30. in the method of calculation.

2. Corrections for feed water, Item 57.

Test Number	2	3	4	6
Item A.	417,172	369,714	416,137	453,495
Item B.	-9752	1920	2474	4199
Item C.	-2914	-3576	-3689	-3733
Item D.	6195	5200	6020	6550
Item E.	690	-2680	-1195	-860
Item F.	-326.5	0	-5925	-181

Note. Minus sign denotes a subtraction from water fed to boiler.

3. Item H. Percentage of heat lost to water back to total heat generated.

Test No. 2	1.05 %
Test No. 3	.975 %
Test No. 4	.993 %
Test No. 6	.994 %

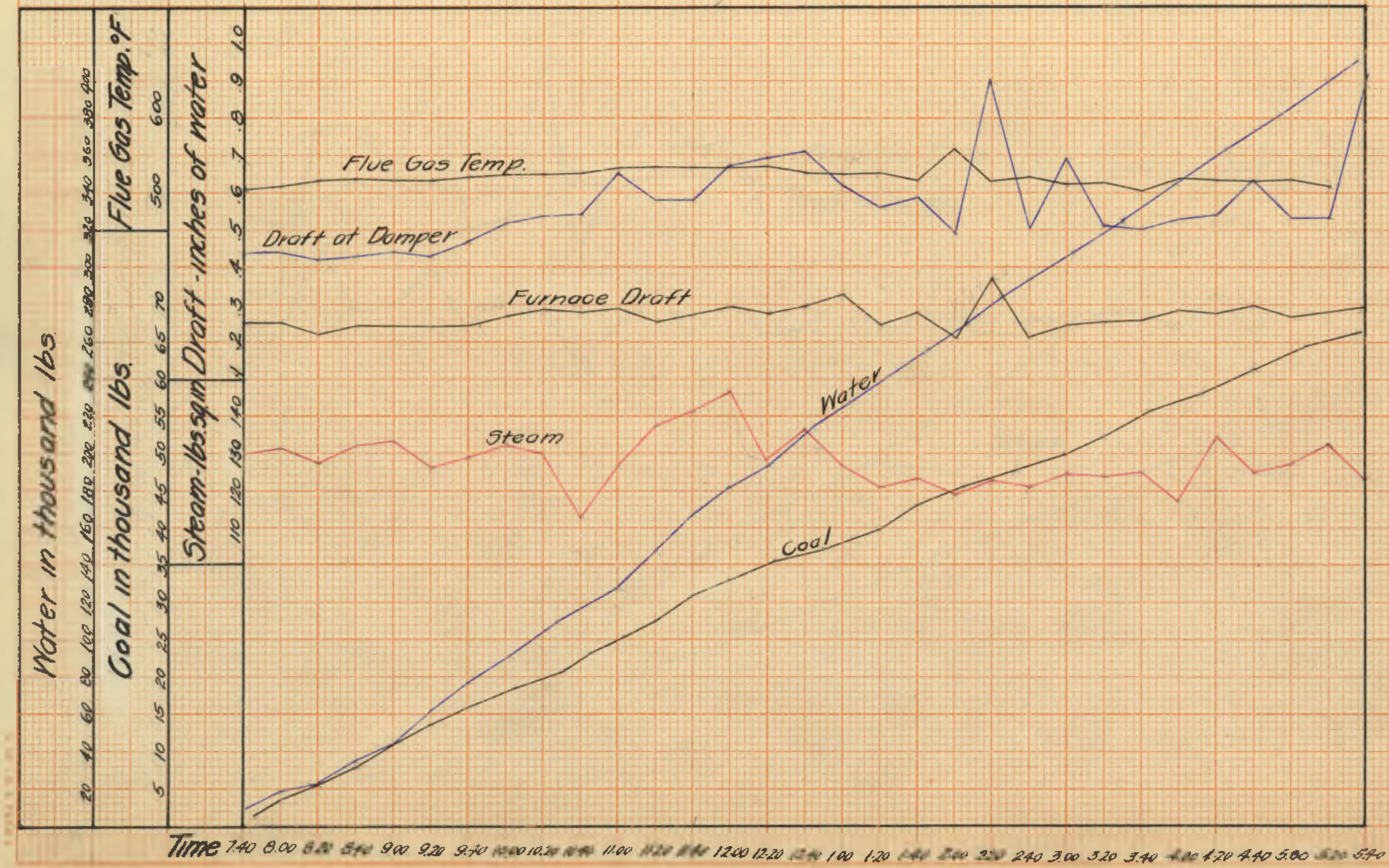
Average Draft – inches - water.								
TEST №	2		3		4		6	
BOILER.	E	W	E	W	E	W	E	W
DRAFT № 1	.019		.021		.0211		.015	
2	.265	.276	.276	.27	.37	.408	.285	.292
3	.287	.375	.312	.358	.427	.5	.346	.374
4	.227	.468	.31	.452	.484	.61	.425	.489
5	.35	.696	.526	.668	.732	.883	.68	.74
6	.372	.762	.553	.755	.719	.918	.69	.845
STACK	1.117		1.04		1.134		1.025	

Flue Gas Analysis - average results.									
TEST	3			4			6		
BOILER	E	W	E+W	E	W	E+W	E	W	E+W
CO_2	9.8	7.15	8.46	8.92	7.54	7.7	10.12	8.88	9.9
O_2	8.5	11.6	9.22	9.5	11.4	10.55	9.23	10.47	9.47
CO	.545	.84	.38	.54	.74	.95	.18	.19	.17

Test No. 2
Graphical Log Sheet

Date:- April 19, 1912

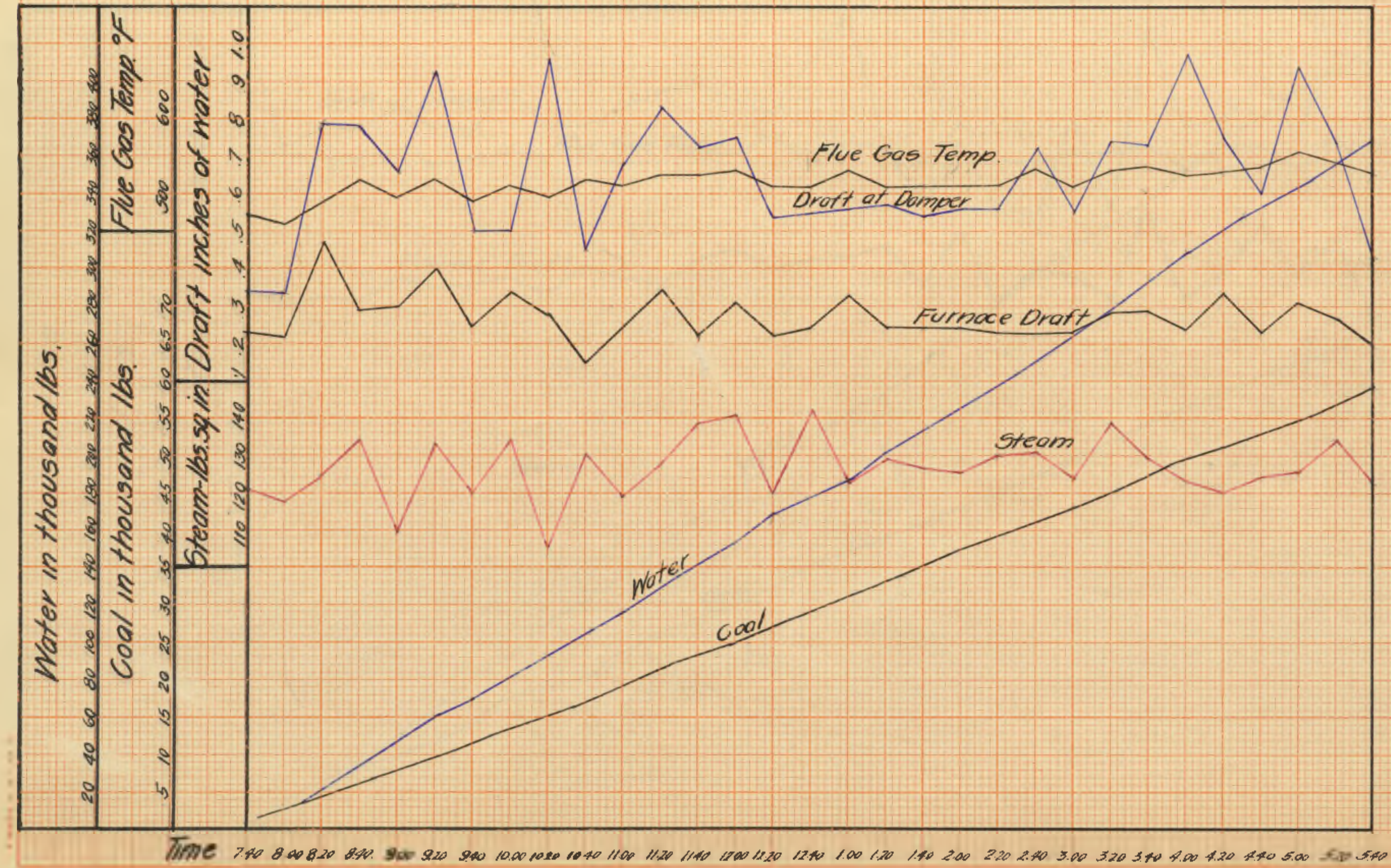
Coal:- Illinois Screenings



Test No. 3
Graphical Log Sheet

Date:- April 20, 1912

Coal:- Illinois Screenings

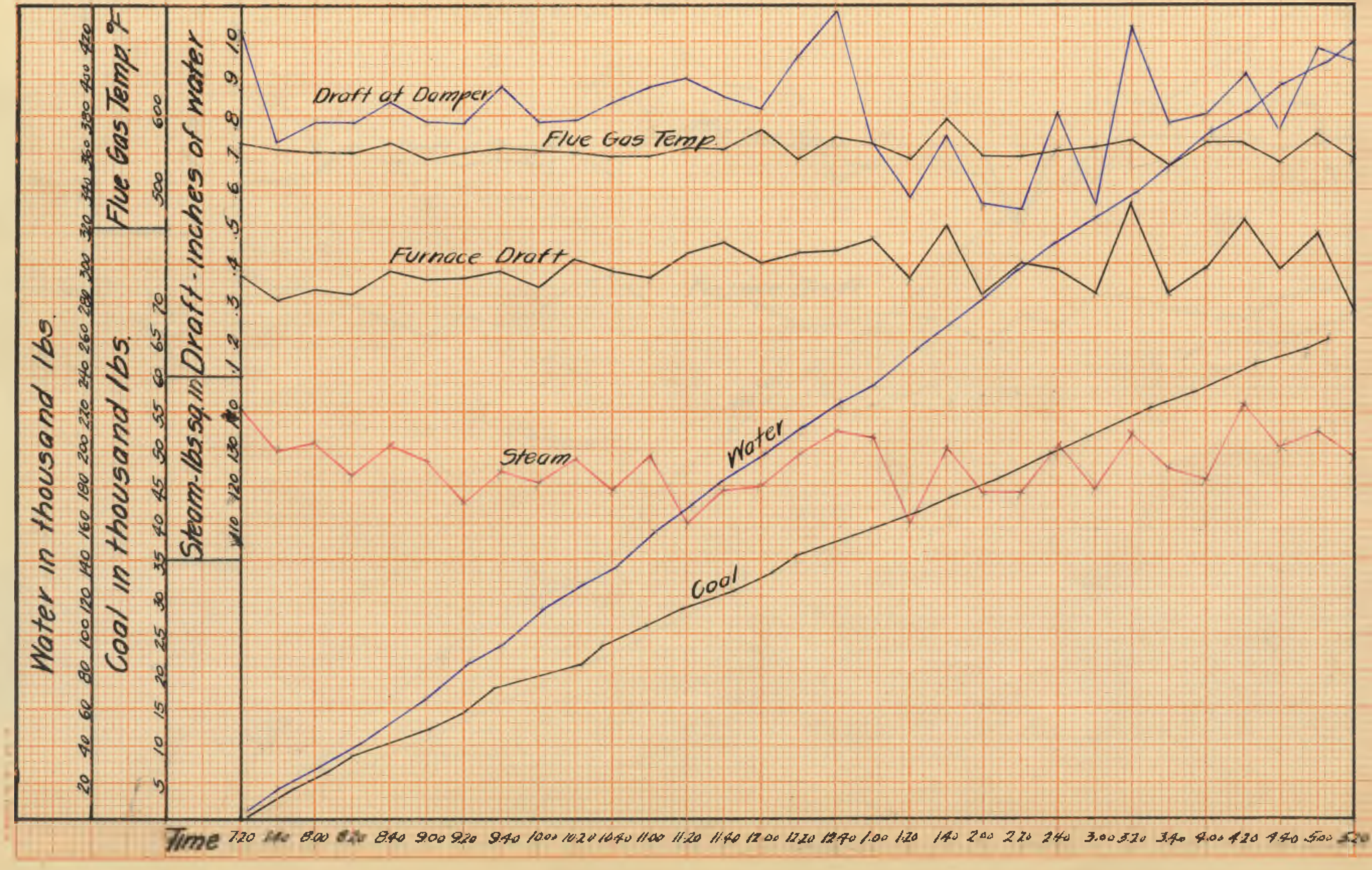


TEST No. 4

GRAPHICAL LOG SHEET

Date:- April 22, 1912

Coal:- Illinois Screenings



TEST No. 6

GRAPHICAL LOG SHEET

Date:- May 2, 1912

Coal:- Springfield Pea