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THESIS

BOILER TEST

at the

POWER HOUSE

of the

Knoxville Railway & Light Company

For the degree of

Bachelor of Science.

in

Mechanical and Electrical Engineering.

By-

L. W. Lang

under

Prof. J. A. Switzer.

1912

THESIS.

BOILER TEST.

Knoxville Railway & Light Co.

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THESIS.

BOILER TEST.

Knoxville Railway & Light Company.

The boiler equipment of the power plant of the Knoxville Railway and Light Company consists of a battery of eight boilers, five (5) being 600 H.P. Babcock and Wilcox and three (3) being 300 H.P. Sterling. There is of course, a corresponding equipment of pumps, feed water heaters, etc. All of these boilers are hand fired and are equipped with automatic jet smoke preventers.

The test herein described was of twenty-four hours duration and for the purpose of making further checks and comparisons, is reported as three separate and consecutive tests of twelve, five and seven hours, respectively. By this division of the test, we can compare the efficiencies, coal consumption, output, etc. of the plant for different parts of the twenty-four hours when the loads and number of boilers are different and also when different crews are at work. It will be found that the average of most of the results of these tests are close to the results found in the single report of the twenty-four hour test. The test was started at twelve o'clock noon, February 27th, 1912 and ended at twelve o'clock noon, February 28, 1912. A second division of students were, during this time, making a com-

plete test of a 3100 K.W. Allis Chalmers Parsons turbine generating unit. During the test only Babcock and Wilcox boilers were used; two for the night load, three for the day load and four for the peak load. All grates operate on natural draught, the entire battery of boilers being cross connected to two chimneys. Coal was brought from the bins to the space before the boilers in a bucket conveyor, each load being weighed as brought in. The average weights of these loads was about twenty-two hundred (2200) pounds net. A large special test platform scale was used for this purpose. A shovel-ful was taken from each load before weighing and placed aside for a sample. The total ash accumulating during each part of the test was also weighed in a like manner in the conveyor bucket. Tests of the heat value of and moisture in the coal were made in the university laboratory and are further described on another page.

Feed water was measured by means of a three (3") venturi meter, this being also taken up further on another page. This meter was especially set up for the test and worked without any mishap or delay throughout the entire time.

The boilers are equipped with superheaters and steam temperatures were taken at thermometer wells in the pipe lines on top of the boilers. Temper-

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atures of escaping gases were measured with a pyrometer placed in the breeching above the boilers. Boiler room outside air, feed water temperatures, etc. were also all observed with thermometers that have been tested in the laboratory.

Draught pressure was measured by a simple U-tube water gauge which was tested occasionally to make sure that it was working freely.

The plant was in good condition generally. The boiler settings are heavy but not as tight as they should be. All boilers are well covered on top with fire brick and cement. The steam lines are covered with packing and are not exposed to any temperature lower than that of the boiler room. The boiler tubes are kept practically free from soot by the steam-jet.

The test was carried on by the alternate method proposed by the American Society of Mechanical Engineers. Observations were made every fifteen minutes and every effort made to avoid error.

Steam pressures were read for each boiler, the averages being given in these reports. The same is also true of steam temperatures. Observations of boiler room temperature and outside air were made only every thirty minutes. Smoke observations were made during the daylight hours by an observer stationed about a hundred and fifty yards from the stacks. Ringelmann charts were used. While there was at nearly all times a sufficient

amount of smoke to give a perceptible amount of color, its volume was really very small for a plant of this size. Smoke charts will be found among the following pages.

Samples of flue gas were taken frequently throughout the test from different places about the breeching and boiler settings and analyzed immediately with the Orsat apparatus. It will be found by referring to the report of flue gas analysis in the following pages that the combined per cent of $C O_2$ and O is frequently lower than it should be. This is due to the fact that there are evidently leaks in the breeching close to the boilers.

There are also places about the boiler settings where air may enter. These settings are not solid brick walls but have openings or small holes covered by metal caps on the sides for convenience in cleaning tubes.

Grate areas, heating surfaces, etc. in the reports are figured on a pro rata basis. That is where a boiler was in use during only part of the test, its grate area, etc. is reported as only so much of its actual value as the percent of the time of the test during which it was in use.

Every effort was made to have a minimum limit of error. All weights that were used have been calibrated and found correct. The thermometers have been tested in

the university laboratory and are correct to within one or two degrees. Feed water or Venturi meter readings were made every minute and it is not likely that there is an error of more than one per cent in the one minute interval readings as taken from the rating curve. The steam gauges were tested in the university laboratory a year ago when a test was made of this plant and are assured to be correct. ^{assumed} Personal error was guarded against as much as possible.

The actual data as taken on the test is too bulky to be included in this report but will be kept on file and may be referred to at any time.

Test from 12:00 Noon to 12:00 Midnight.

Mechanical Laboratory—UNIVERSITY OF TENNESSEE

REPORT OF BOILER TEST

Made by Boilers fired Nos. 1, 3, 8. No. 2 4 Hours.

Total K.W. Hours 22979

Coal per K.W. Hour 3.02#

Date

Kind of Boiler Babcock & Wilcox.

Manufactured by

Duration of trial	Hours.	12	FLUE GAS.		
DIMENSIONS.			CO ₂	Per cent. of volume	4.96
Grate surface: length	ft., width	Sq. ft.	CO	" " "	.056
Water heating surface	"	"	H	" " "	14.4
Superheating surface	"	"	Free oxygen	" " "	
Height, chimney	Ft.	134	Air	Excess co-efficient.	
Ratio of draught area to grate		.218	Quality of steam	Per cent.	
Area, chimney	Sq. ft.	63.4	Superheat	Degrees.	40.7
Tubes: Diameter	4" X 18"	No. 294	TOTAL WATER.		
Ratio heating to grate surface		55.3:1.	Total weight water used	Pounds	628442
PRESSURE.			Total evaporated, dry steam	"	1.105
Barometer	Inches mercury	28.95	Factor of evaporation		694428
Steam gauge	Pounds	161.4	Equivalent evaporated from and at 212°	"	
Absolute steam pressure	Pounds	175.6	WATER—PER HOUR.		
Draught gauge, near damper	Inches water	.31	Amount used	Pounds.	52370
" " in ash pit	" "		Evaporated dry steam	"	57869
TEMPERATURE.			Equivalent evaporated from and at 212°	"	
External air	Degrees F.	36.8	ECONOMIC EVAPORATION.		
Boiler room	"	50.9	Per Pound of Fuel.		
Escaping gases	"	355.6	Actual, per lb. dry coal	Pounds.	9.34
Furnace	"		Equivalent from and at 212° [dry coal]	"	10.33
Feed water	"	162	Per Pound of Combustible		
Steam	"	411.6	Actual	Pounds	10.62
FUEL.			Equivalent evaporated from and at 212°	"	11.65
Kind of coal	Jellico		RATE OF EVAPORATION.		
Locality			Per Sq. Foot of Grate per Hour		
Size of coal	Small lump, nut & slack		Actual from feed-water temperature	Pounds	179.6
Fixed carbon	Per cent.		Equivalent from and at 212°	"	198.5
Volatile matter	"	3.67	Per sq. Foot of Water-heating Surface per Hour.		
Moisture	"	11.63	Actual	Pounds	3.245
Ash	"	12686	Equivalent from and at 212°	"	3.586
B. T. U. per pound coal		14945	Per sq. Foot of Least Draught Area per Hour.		
" " combustible			Actual	Pounds.	
Carbon in ash	Per cent.	69788	Equivalent from and at 212°	"	
Total coal consumed	Pounds.		HORSE POWER.		
Total wood	"		*On basis 34½ pounds equiv. evap. per hour		
Moisture in coal	Per cent.	3.67	Builders' rating	H. P.	1676
Dry coal consumed	Pounds.	67250	Ratio of commercial to builders' rating	%	83.8
Total refuse, dry	"	8114	Heat generated per pound dry coal		
Total refuse, dry	Per cent.	59136	Heat absorbed per pound dry coal		
(c) Total combustible	Pounds.		Heat lost in flue per pound dry coal		
COMBUSTION—PER HOUR.			" " incomplete combustion lb. of coal		
Dry coal		5604	" " in refuse, lb. of coal		
(c) Combustible		4928	" " by radiation, etc., lb. coal		
Dry coal per square foot of grate		19.21	(a) Efficiency of boiler		
Combustible per " " "		16.93	(b) Efficiency of boiler and grate		
Dry coal per " " heating surface		.347			
Combustible per " " "		.305			

NOTE.—Actual evaporation signifies the evaporation from feed-water temperature to dry steam at gauge pressure. It is apparent evaporation corrected for calorimeter determination.

*Standard commercial H. P. (a) Computed from combustible. (b) Computed from coal.

(c) This is dry coal less refuse.

Total K.W.H

Test from 12:00 Midnight to 5:00 A.M.
 Mechanical Laboratory—UNIVERSITY OF TENNESSEE

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REPORT OF BOILER TEST

Made by Boilers fired Nos. 3&8. No. 1. 3/4 Hour.

Total K.W. Hours 3440

Coal per K.W. Hour 4.98#

Date

Kind of Boiler Water Tube

Manufactured by B.&W.

Duration of trial	Hours. 5	FLUE GAS.		
DIMENSIONS.		CO ₂	Per cent. of volume	3.77
Grate surface: length..... ft., width..... ft.	Sq. ft. 188.1	CO	" " "	.16
Water heating surface	" 10406	H	" " "	
Superheating surface	"	Free oxygen	" " "	16.44
Height, chimney	Ft. 134	Air	Excess co-efficient,	
Ratio of draught area to grate	.337	Quality of steam..... Per cent.		
Area, chimney	Sq. ft. 63.4	Superheat		
Tubes: Diameter 4" X 18'	No. 244	Degrees. 32.7		
Ratio heating to grate surface	55.3:1	TOTAL WATER.		
PRESSURE.		Total weight water used	Pounds.	142200
Barometer	Inches mercury 29.04	Total evaporated, dry steam	"	
Steam gauge	Pounds 161.0	Factor of evaporation		1.135
Absolute steam pressure	Pounds 175.26	Equivalent evaporated from and at 212°	"	161397
Draught gauge, near damper	Inches water .25	WATER—PER HOUR.		
" " in ash pit	" "	Amount used	Pounds.	28440
TEMPERATURE.		Evaporated dry steam	"	
External air	Degrees F. 30.1	Equivalent evaporated from and at 212°	"	32279
Boiler room	" 44.0	ECONOMIC EVAPORATION.		
Escaping gases	" 316.0	Per Pound of Fuel.		
Furnace	"	Actual, per lb. dry coal	Pounds.	8.63
Feed water	" 134.3	Equivalent from and at 212° [dry coal]	"	9.78
Steam	" 403.5	Per Pound of Combustible		
FUEL.		Actual	Pounds	9.80
Kind of coal	Jellico	Equivalent evaporated from and at 212°	"	11.14
Locality		RATE OF EVAPORATION.		
Size of coal	Small lump, nut & slack	Per Sq. Foot of Grate per Hour		
Fixed carbon	Per cent.	Actual from feed-water temperature	Pounds	151.4
Volatile matter	"	Equivalent from and at 212°	"	171.6
Moisture	"	Per sq. Foot of Water-heating Surface per Hour.		
Ash	11.6	Actual	Pounds	2.734
B. T. U. per pound coal	12686	Equivalent from and at 212°	"	3.100
" " combustible	14975	Per sq. Foot of Least Draught Area per Hour.		
Carbon in ash	Per cent.	Actual	Pounds.	
Total coal consumed	Pounds. 17133	Equivalent from and at 212°	"	
Total wood	"	HORSE POWER.		
Moisture in coal	Per cent. 3.67	*On basis 34½ pounds equiv. evap. per hour		
Dry coal consumed	Pounds. 16500	H. P. 936		
Total refuse, dry	" 1987	Builders' rating		
Total refuse, dry	Per cent.	Ratio of commercial to builders' rating		
(c) Total combustible	Pounds. 14513	%		
COMBUSTION—PER HOUR.		Heat generated per pound dry coal		
Dry coal	3300	B. T. U. 12686		
(c) Combustible	2903	Heat absorbed per pound dry coal		
Dry coal per square foot of grate	17.55	" " " incomplete combustion lb. of coal		
Combustible per " " "	15.45	" " in refuse, lb. of coal		
Dry coal per " " heating surface	.327	" " by radiation, etc., lb. coal		
Combustible per " " "	.279	(a) Efficiency of boiler		
		%		
		(b) Efficiency of boiler and grate		
		%		

NOTE.—Actual evaporation signifies the evaporation from feed-water temperature to dry steam at gauge pressure. It is apparent evaporation corrected for calorimeter determination.

*Standard commercial H. P. (a) Computed from combustible. (b) Computed from coal.

(c) This is dry coal less refuse.

Test from 5:00 A.M. to 12.00 Noon.

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Mechanical Laboratory—UNIVERSITY OF TENNESSEE

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REPORT OF BOILER TEST

Made by Boilers fired Nos. 1, 3, 8.

Total K.W.Hours 13547

Coal per K.W.Hour 2.86#

Date

Kind of Boiler Water tube.

Manufactured by B. & W.

Duration of trial	Hours.	7	FLUE GAS.		
DIMENSIONS.			CO ₂	Per cent. of volume	4.66
Grate surface: length	ft., width	Sq. ft.	CO	" " "	.16
Water heating surface			H	" " "	
Superheating surface			Free oxygen	" " "	15.30
Height, chimney		Ft.	Air	Excess co-efficient.	
Ratio of draught area to grate			Quality of steam	Per cent.	
Area, chimney		Sq. ft.	Superheat	Degrees.	52
Tubes: Diameter		No.	TOTAL WATER.		
Ratio heating to grate surface			Total weight water used	Pounds.	318060
PRESSURE.			Total evaporated, dry steam	"	
Barometer	Inches mercury	29.09	Factor of evaporation		1.12
Steam gauge	Pounds	161.5	Equivalent evaporated from and at 212°	"	356227
Absolute steam pressure	Pounds	175.7	WATER—PER HOUR.		
Draught gauge, near damper	Inches water	.25	Amount used	Pounds.	45437
" " in ash pit	" "		Evaporated dry steam	"	
TEMPERATURE.			Equivalent evaporated from and at 212°	"	50889
External air	Degrees F.	35.3	ECONOMIC EVAPORATION.		
Boiler room	"	47.2	Per Pound of Fuel.		
Escaping gases	"	382.3	Actual, per lb. dry coal	Pounds.	8.53
Furnace	"		Equivalent from and at 212° [dry coal]	"	9.56
Feed water	"	150.5	Per Pound of Combustible		
Steam	"	423.0	Actual	Pounds	9.72
FUEL.			Equivalent evaporated from and at 212°	"	10.87
Kind of coal	Jellico		RATE OF EVAPORATION.		
Locality			Per Sq. Foot of Grate per Hour		
Size of coal	Small lump, nut & slack		Actual from feed-water temperature	Pounds	173.2
Fixed carbon	Per cent.		Equivalent from and at 212°	"	194.0
Volatile matter	"		Per sq. Foot of Water-heating Surface per Hour.		
Moisture	"	3.67	Actual	Pounds	2.131
Ash	"	11.76	Equivalent from and at 212°	"	3.510
B. T. U. per pound coal		12686	Per sq. Foot of Least Draught Area per Hour.		
" " combustible		14975	Actual	Pounds.	
Carbon in ash	Per cent.		Equivalent from and at 212°	"	
Total coal consumed	Pounds.	38758	HORSE POWER.		
Total wood	"		*On basis 34½ pounds equiv. evap. per hour		
Moisture in coal	Per cent.	3.67	Builders' rating	H. P.	1475
Dry coal consumed	Pounds.	37300	Ratio of commercial to builders' rating	%	82.0
Total refuse, dry	"	4520	Heat generated per pound dry coal		
Total refuse, dry	Per cent.		B. T. U.		
(c) Total combustible	Pounds.	32780	Heat absorbed per pound dry coal		
COMBUSTION—PER HOUR.			Heat lost in flue per pound dry coal		
Dry coal		5329	" " incomplete combustion lb. of coal		
(c) Combustible		4683	" " in refuse, lb. of coal		
Dry coal per square foot of grate		20.3	" " by radiation, etc., lb. coal		
Combustible per " " "		17.85	(a) Efficiency of boiler		
Dry coal per " " heating surface.		.367	(b) Efficiency of boiler and grate		
Combustible per " " "		.323			

NOTE.—Actual evaporation signifies the evaporation from feed-water temperature to dry steam at gauge pressure. It is apparent evaporation corrected for calorimeter determination.

*Standard commercial H. P. (a) Computed from combustible. (b) Computed from coal.

(c) This is dry coal less refuse.

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BOILER TEST

Knoxville Railway and Light Co.

Flue Gas Analysis.

Time	Co ₂	O	Co	Boiler No.	Remarks.
1:10	5.40	13.90	0.00	8	
1:40	4.20	15.80	0.00	3	Three boilers fired
2:15	8.20	13.00	0.00	Stack	" " "
2:35	6.20	13.00	0.00	"	" " "
2:45	5.60	13.80	0.20	"	
3:10	4.80	15.20	0.00	"	Boilers, 1,2,3,8
3:25	3.60	16.40	0.00	"	
3:33	4.70	15.90	0.00	"	
3:45	5.80	15.00	0.00	"	
4:10	7.20	11.70	0.00	"	
4:35	7.00	13.64	0.00	8	
4:55	4.60	15.50	0.00	3	
5:15	7.20	12.60	0.00	2	
5:45	7.00	12.00	0.00	2	
6:00	6.40	13.00	0.00	Stack	
6:45		13.00	0.40	"	Air in sample pump broken.
8:00	3.40	16.60	0.00	"	Fresh KOH Pump repaired.
8:25	3.60	16.60	0.00	"	Boiler No. 2 banked.
8:40	4.00	16.10	0.20	"	
9:15	3.20	17.00	0.00	"	
9:45	3.80	17.20	0.00	"	
10:10	4.60	15.00	0.00	"	

BOILER TEST

Knoxville Railway & Light Co.

Flue Gas Analysis (Con.)

Time	Co ₂	O	CO	Boiler No.	Remarks.
10:40	3.00	16.90	0.30	Stack.	
11:00	3.20	16.80	0.00	"	
11:30	2.00	18.40	0.00	"	
12:00 noon	2.50	18.60	0.00	"	
12:30AM	3.90	15.80	0.00	"	
1:00	2.20	18.00	0.20	"	
1:30	4.40	15.00	0.60	"	
2:00	4.20	15.40	0.20	"	
2:20	3.50	16.50	0.10	"	
2:45	2.70	17.00	0.20	"	
3:05	3.80	16.20	0.40	"	
3:25	1.60	15.60	0.00	"	
4:00	4.70	15.10	0.20	"	
4:20	4.00	16.20	0.10	"	
5:00	5.20	14.00	0.50	"	
5:20	3.10	16.80	0.20	"	
6:00	3.60	16.60	0.10	"	
7:15	6.80	12.40	0.20	"	
7:45	3.60	16.40	0.20	"	
8:30	6.80	13.80	0.10	"	
9:30	3.80	15.60	0.20	"	

BOILER TEST

Knoxville Railway & Light Co.

C Heat Value of Coal

By

Parr Calorimeter.

No. Temp. Room Temp.....74.40⁰ F.

1 71.75

2 71.77

3 71.77 Ignition

4 75.50

5 75.83

6 75.95

7 75.97

8 76.00

9 76.00

10 75.98

11 75.97

12 75.97

13 75.97

14 75.96

15 75.95

Calculations:-

76.010
<u>71.770</u>
4.240
<u>.015</u>
4.255
<u>.185</u>
4.070

Maximum

 $4.070 \times 3117 = 12686. \text{ X.B.T.U.}$

BOILER TEST

Knoxville Railway & Light Co.

Moisture in Coal.

The following results are given as typical examples of a number of determinations. These tests were made in the fuel testing laboratory at the university shortly after the test, the coal being kept in air tight vessels in the meantime. The average of all determinations is practically the same as that here given.

	(1)	(2)	(3)
Watch glass & coal	12.8852	12.2320	13.2560
Watch glass	9.4747	8.2444	9.6354
Coal	3.4105	3.9876	3.6506
Glass & Dry coal	12.7630	12.0835	13.1500
Moisture	.1222	.1485	.1360
Percent	3.58	3.72	3.72

Average percent- 3.67%

BOILER TEST

Knoxville Railway & Light Co.

Leakage through blow-off valves.

Average 24# in 85 ~~rev.~~ seconds.

$$\frac{24 \times 60}{85} = 17\# \text{ min.}$$

$$= 1020\# \text{ hr.}$$

Leakage on 12 hr. test = 12240#

" " 5 " " = 5100#

" " 7 " " = 7140#

Note: Hot water was found to be leaking continuously throughout the test from the blow-off valves. Several measurements were made at different times and it was found to average closely twenty-four pounds in eighty-five seconds

BOILER TEST

Knoxville Railway & Light Company

Rating curve for Venturi Meter.

Feed water during the test was measured with a three inch (3") Venturi meter set up for this test. This meter is the property of the University and is kept in the hydraulic laboratory. The rating curve furnished in this report is a copy of that kept as laboratory data, the calibration having been made in the laboratory.

The deflection in feet of mercury was read every minute and feed water temperature every five minutes by an observer.

100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400
Pounds per minute.

1.3

1.2

1.1

1.0

0.9

0.8

0.7

0.6

0.5

0.4

0.3

0.2

0.1

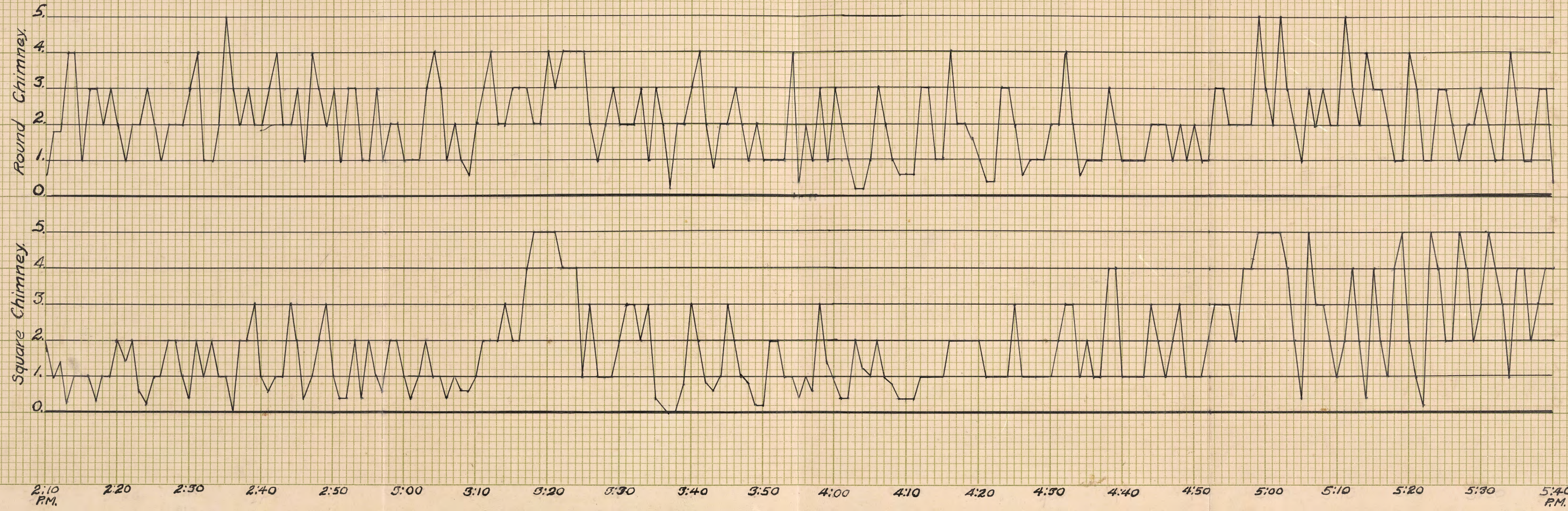
Deflection in Feet of Mercury.

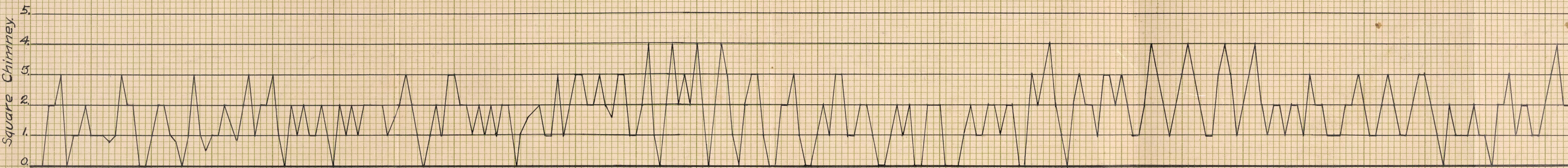
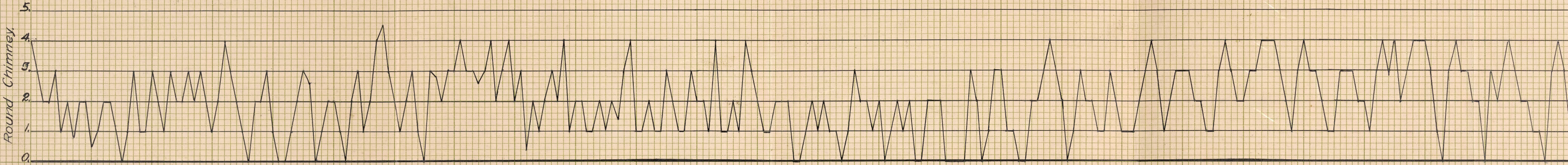
Temp = 200° F.
1800° F.
500° F.

Lbs. per min.

Cu. Ft. per Sec.

0.02 0.04 0.06 0.08 0.10 0.11 0.14 0.16 0.18 0.20 0.22 0.24 0.26 0.28
Cubic feet per Second.





8:00 A.M. 8:10 8:20 8:30 8:40 8:50 9:00 9:10 9:20 9:30 9:40 9:50 10:00 10:10 10:20 10:30 10:40 10:50 11:00 11:10 11:20 11:30 11:40 11:50 12:00 Noon. 12:10

