THESIS

Test of Babcock and Wilcox Boiler situated at The Pasadena Municipal Light Plant

by

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Class of Nineteen Hundred and Fifteen

Department of Mechanical Engineering.

THROOP COLLEGE OF TECHNOLOGY

Pasadena, California

1915

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Test of Babcock and Wilcox Boiler

Job No. 5836 - - 1906

situated at

The Pasadena Municipal Light Plant

- - - -

The object of this test was to determine the efficiency of the boiler over a range of loads.

At the plant this boiler is known as Boiler No. (1). It is used to supply steam for the generating units.

The method of procedure consisted in making and recording seven tests of the boiler at loads ranging from fifty per cent of the builders' rating to one hundred thirty per cent. The following data and conclusions were obtained from these tests.

Chas. H. Wilcox

General Information

Boiler

Built by the Babcock and Wilcox Company.

Job No. 5836 - - 1906.

81 water tubes, 18 ft. long by 4 in. diam.

1 drum, 23 ft. 3.625 in. long by 42 in. diam.,

Thickness of drum = 0.5 in.

15 superheater tubes, 16 ft. 4 in. long by 2 in. diam.

15 superheater tubes ,17 ft. 6 in. long by 2 in. diam.

Water heating surface - - - - - - - - - - - 1703 sq.ft.

Superheating surface - - - - - - - - - - - 266 sq.ft.

The boiler is made of open-hearth steel, elastic limit = 58000lb. per sq.in., to carry 200 lb. gage pressure with 100 deg. fahr. or more superheat.

Builders rating - - - - - - - - - - - - - - 170 bl.h.p.

Cost of boiler including erection of stack - $ 7000.

Extra equipment includes Webster Automatic Damper Regulator and American Gage Company's Thermofeed Regulator.

A Leyhe Burner was used to atomize the fuel oil. This burner fired forward.

Steam for atomizing the oil was furnished by a separate boiler but it was assumed that 2 per cent of the steam generated was necessary for atomizing the oil. This assumption was based on Hammel Oil Burner tests and may be too low.

Boiler, continued

The original baffles have been removed from the boiler. The present arrangement is shown in accompanying drawing.

The setting is built so that part of the air may pass between heated brick walls before it enters the furnace.

The boiler was clean at the time the first six tests were made. It had not been cleaned for a period of six weeks before test No. (7) was made.

Economizer

Manufactured by the Green Fuel Economizer Co.

128 vertical tubes, 9 ft. long by 4.5625 in. diam.

Heating surface --- - - - - - - - - - - 1536 sq.ft.

Cost, erected - - - - - - - - - - - - $ 2000.

The economizer was dirty at the time test No. (1) was made but in good condition for the other tests.

Fuel Oil

The oil used in all the tests was supplied by the Union Oil Co. and was from the Whittier district.

A sample of oil was taken during each test. Two determinations of the calorific value were made from each sample by means of the Parr Calorimeter. The average calorific value of the oil used in the first six tests was used in the calculations for these tests, the average of the two determinations made on sample

Fuel Oil, continued

No. (7) was used in the calculations for test No. (7).

Calorific Value by Parr Calorimeter

Test	No.(1)	Sample	No.(1) - - -	19050	B.t.u.	per lb.
"	No.(1)	"	No.(2) - - -	18940	"	" "
"	No.(2)	"	No.(1) - - -	19500	"	" "
"	No.(2)	"	No.(2) - - -	19100	"	" "
"	No.(3)	"	No.(1) - - -	19560	"	" "
"	No.(3)	"	No.(2) - - -	19060	"	" "
"	No.(4)	"	No.(1) - - -	18780	"	" "
"	No.(4)	"	No.(2) - - -	19200	"	" "
"	No.(5)	"	No.(1) - - -	18750	"	" "
"	No.(5)	"	No.(2) - - -	18700	"	" "
"	No.(6)	"	No.(1) - - -	18840	"	" "
"	No.(6)	"	No.(2) - - -	19000	"	" "
"	No.(7)	"	No.(1) - - -	19240	"	" "
"	No.(7)	"	No.(2) - - -	19230	"	" "
Average for first six tests - -				19050	"	" "
Average for test No.(7) - - -				19235	"	" "

It was necessary to know approximately the proportions of carbon and hydrogen in the oil in order to calculate the heat leaving the boiler in the flue gas. The analysis of several oils of approximately the same heating value was found and the average of these values used in the calculations.

Fuel Oil, continued

Chemical Analyses of California and Similar Oils

Place	Carbon %	Hydrogen %
Fresno	86.24	13.80
Santa Barbra	86.32	11.70
Baku	86.89	13.11
Baku	86.30	13.60
Baku	86.70	12.94
Average	86.50	13.03

Fuel oil was measured just before it entered the burner by a 0.75 in. Worthington Meter. This meter was calibrated in gallons and when tested at Throop College of Technology the meter constant was found to be 0.985 .

Weight of oil passing meter=

$$= \frac{0.985 \times 62.4 \times G\ (M-M')}{7.48} = \text{lb.}$$

G = specific gravity of oil at temperature it entered the burner.

M' = initial meter reading.

M = final meter reading.

Oil Pressure Gage

This was made by the Chas. C. More Co. It was not calibrated as the reading did not enter into the calculations.

Feedwater

This was measured after it left the economizer and before it entered the boiler by passing it thru a 1.5 in. Worthington Meter. This meter measured the quantity passing in cubic feet. By tests made at Throop the meter constant was found to be 0.90 . This correction and the effect of temperature on the specific gravity were allowed for in calculating the amount of water passing thru the meter.

Weight of water passing meter =

= 0.90 x 62.4 x G x(M-M') = lb.

G = specific gravity at temperature at which feedwater enters the boiler.

M = final meter reading.

M' = initial meter reading.

Draft

It was found impossible to obtain a draft gage reading because the connection was turned at the wrong angle in the flue.

Thermometers

All thermometers except the one in the oil line measuring the temperature of the oil to the burners were tested for freezing and boiling point and found correct. The steam line temperature readings were corrected for stem exposure.

Thermometers, continued

Stem correction = K = 0.000088D (T-t) deg. fahr.

This correction is to be added.

D = number of degrees on the scale from the surface of the oil in the thermometer well to the end of the mercury colum.

T = observed reading.

t = temperature of air surrounding stem.

The temperature of the steam leaving the boiler was measured by placing a well in a 0.5 in. drip connection to the steam pipe connecting the boiler and the main line. The valve in the drip connection was opened wide and steam allowed to escape continuosly thru a 0.125 in. orifice in a calorimeter connection placed below the thermometer well. The drip and the thermometer well were covered with magnesia in tests No.4 to No.(7) inclusive. In tests No.(1), No.(2), and No.(3) ten deg. fahr. should be added to the observed steam temperature readingsto correct for the drop in the uncovered pipe. This correction is based on observed rise at time when the pipe was covered.

The temperature of the water entering and leaving the economizer was obtained by thermometers placed in wells extending into the feedwater pipes.

Thermometers, continued

The stems of these thermometers were protected from air currents by a glass and metal case, therefore no stem correction was applied.

The temperature of the flue gas entering the economizer was measured by a special long stemmed thermometer extending well into the current of the gas. No stem correction was applied.

The temperature of the flue gas leaving the economizer was measured with an ordinary thermometer reading to 700 deg. fahr. This thermometer was let down thru a hole in the economizer top by a wire. In tests No.(1), No.(2), No.(3), and the first seven readings of test No.(4) an approximate correction of 60 deg. fahr. should be added to the observed readings as it was found that stuffing up the hole thru which the thermometer was inserted made this difference in the temperature recorded.

The fuel oil temperature was measured on the main oil line at the oil pump.

Steam Pressure

This was measured by an Ashcroft Mfg. Company's gage placed on the front of the boiler. A record of the calibration of this gage with Crosby Dead Weight Tester is included with the data sheets.

Flue Gas Analysis

The gas sample was taken just in front of the damper, after the gas had made the last pass. A sampling pipe, 0.75 in. in diam.,extended thru the boiler setting. Outside the wall it was reduced to 0.25 in. diam. The gas was drawn into a bottle by siphoning water out thru a rubber tube. In this way two liters of the gas was collected in about five minutes. After the gas had been collected the valve to the sampling pipe was closed, the valve to the Orsat Flue Gas Sampling Apparatus opened, and a sample to be tested drawn into the apparatus. Tests were made for carbon dioxide (CO_2), carbon monoxide (CO), and oxygen (O_2). The residue contained nitrogen (N), unburned hydrogen (H), and hydrocarbons. As only two or three tenths of one per cent of CO was detected once or twice during a test it was omitted in the calculations.

Remarks

As the test was made under operating conditions it was impossible to blank off the boiler, but all valves thru which steam or water might escape were tightly closed. The boiler was blown down once each shift during the tests.

Remarks, continued

The water level in the boiler was maintained the same by the Thermofeed Regulator.

A graphical log similar to the one included for test No.(4) was kept during each test.

Calibration of Steam Pressure Gage on Boiler No.(1) at Pasadena Municipal Light Plant, November 29, 1914.

Calibration made with Crosby Dead Weight Tester.

Gage lb.	Weight lb.	Error lb.	Gage lb.	Weight lb.	Error lb.
0	0	0	107	95	12
20	5	15	113	100	13
25	10	15	118	105	13
29	15	14	122.5	110	12.5
34	20	14	128	115	13
39	25	14	133	120	13
43	30	13	138	125	13
48	35	13	143	130	13
53	40	13	147.5	135	12.5
57.5	45	12.5	152	140	12
62	50	12	157	145	12
67	55	12	162	150	12
72	60	12	167	155	12
77	65	12	172	160	12
82	70	12	176.5	165	11.5
87	75	12	181.5	170	11.5
92	80	12	186	175	11
97	85	12	191	180	11
102	90	12	196	185	11
107	95	12	201	190	11

Test No. (1)

Time	Obs. No.	Water Meter cu. ft.	Oil Meter gal.	Oil Pressure lb. per sq. in.	Oil Temp. deg. fahr.	Steam Pressure lb. per sq. in.	Steam Temp. deg. fahr.	Water to Econ. deg. fahr.	Water from Econ. deg. fahr.	Flue Gas to Econ. deg. fahr.	Flue Gas from Econ. deg. fahr.	CO_2	O_2	N + H
11:30	0	26936	21846	59	108	157.5	370	130	158	510	350	--.-	-.-	--.-
12:00	1	27011	21877	58	117	157.5	375	136	162	510	350	--.-	-.-	--.-
12:30	2	27031	21903	58	117	157.5	376	124	162	25	350	10.5	7.5	82.0
1:00	3	27076	21931	60	117	157.5	376	122	164	525	360	10.0	7.2	82.5
1:30	4	27126	21958	58	120	157.5	374	144	164	505	350	--.-	-.-	--.-
2:00	5	27176	21986	55	116	157.5	376	132	164	520	360	--.-	-.-	--.-
2:30	6	27218	22012	60	114	157.5	373	142	168	515	350	11.8	6.9	81.3
3:00	7	27260	22038	58	116	157.5	374	132	172	510	350	--.-	-.-	--.-
3:25	8	27300	22060	60	120	158.0	374	134	170	495	340	9.2	7.2	83.6
3:45	9	27327	22082	60	110	158.0	371	120	172	575	350	--.-	-.-	--.-
4:00	10	27358	22100	58	108	157.0	372	110	168	585	370	--.-	-.-	--.-
4:30	11	27415	22135	58	110	157.0	372	118	160	580	370	10.2	5.4	84.4

Test No. (1)

Time	Obs. No.	Water Meter cu. ft.	Oil Meter gal.	Oil Pressure lb. per sq.in.	Oil Temp. deg fahr.	Steam Pres. lb. per sq.in.	Steam Temp. deg. fahr.	Water to Econ. deg. fahr.	Water from Econ. deg. fahr.	Flue Gas to Econ. deg. fahr.	Flue Gas from Econ. deg. fahr.	CO_2	O_2	N + H
5:00	12	27476	22172	60	108	157.0	372	125	158	575	380	--.-	-.-	--.-
5:30	13	27534	22207	60	106	157.0	372	120	160	585	380	11.3	5.5	83.2
5:55	14	27580	22237	57	106	157.5	371	110	160	595	380	--.-	-.-	--.-
6:15	15	27619	22254	57	126	147.0	367	120	158	495	310	11.6	4.2	84.2
6:30	16	27642	22268	57	117	147.0	366	104	154	545	340	--.-	-.-	--.-
7:00	17	27691	22299	58	118	148.0	366	116	154	535	350	--.-	-.-	--.-
7:30	18	27739	22330	58	118	147.0	365	112	156	550	360	10.2	3.4	86.4
8:00	19	27776	22362	58	120	147.0	364	---	---	530	350	--.-	-.-	--.-
8:30	20	27856	22399	57	110	147.0	366	96	145	585	350	--.-	-.-	--.-
9:00	21	27912	22436	57	116	147.0	366	108	145	550	350	10.5	2.2	87.3
9:00	22	27939	22471	57	118	147.0	366	112	150	565	380	--.-	-.-	--.-
10:00	23	28021	22506	57	120	147.0	366	115	152	560	360	--.-	-.-	--.-

Test No. (1)

Time	Obs. No.	Water Meter cu. ft.	Oil Meter gal.	Oil Pressure lb. per sq. in.	Oil Temp. deg. fahr.	Steam Pressure lb. per sq. in.	Steam Temp. deg. fahr.	Water to Econ. deg. fahr.	Water from Econ, deg. fahr.	Flue Gas to Econ. deg. fahr.	Flue Gas from Econ. deg. fahr.	CO_2 per cent	O_2 per cent	N + H per cent
10:30	24	28077	22540	57	118	147.0	366	110	154	570	360	--.-	-.-	--.-
11:00	25	28137	22575	57	118	147.0	366	110	154	565	380	--.-	-.-	--.-
11:30	26	28194	22609	57	118	147.0	366	120	154	565	370	11.9	4.1	84.0
12:00	27	28240	22642	57	126	147.0	366	110	154	565	360	--.-	-.-	--.-
Corr. av.				58	116	140.0	389	120	159	547	418	10.5	5.3	84.2
Totals		1305	796											

Test No. (2)

Time	Obs. No.	Water Meter cu. ft.	Oil Meter gal.	Oil Pressure lb. per sq. in.	Oil Temp. deg. fahr.	Steam Pressure lb per sq. in.	Steam Temp. deg. fahr.	Water to Econ. deg. fahr.	Water from Econ. deg. fahr.	Flue Gas to Econ. deg. fahr.	Flue Gas from Econ. deg. fahr.	CO_2 per cent	O_2 per cent	N + H per cent
10:30	0	28606	23968	65	90	190	385	135	156	488	292	10.8	6.4	82.8
11:00	1	28616	24000	65	92	190	388	132	159	523	304	--.-	-.-	--.-
11:30	2	28685	24034	65	100	193	392	129	153	518	306	11.0	5.5	83.5
12:00	3	28755	24068	65	101	192	390	134	183	522	310	10.8	6.0	83.2
12:30	4	28799	24098	65	101	184	389	130	196	505	310	--.-	-.-	--.-
1:00	5	28842	24125	65	103	182	390	130	194	505	310	--.-	-.-	--.-
1:30	6	28886	24152	65	103	183	388	134	204	505	310	8.2	9.1	82.7
2:00	7	28918	24179	65	102	183	388	122	210	505	310	--.-	-.-	--.-
2:30	8	28972	24207	65	102	184	390	142	196	505	320	--.-	-.-	--.-
3:00	9	29010	24232	65	102	182	389	128	204	500	310	7.8	7.0	84.8
3:30	10	29047	24259	65	102	182	388	124	212	505	320	9.4	3.0	82.5

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Test No. (2)

Time	Obs. No.	Water Meter cu. ft.	Oil Meter gal.	Oil Pressure lb. per sq. in.	Oil Temp. deg. fahr.	Steam Pressure lb. per sq. in.	Steam Temp. deg. fahr.	Water to Econ. deg fahr.	Water from Econ. deg. fahr.	Flue Gas to Econ. deg. fahr.	Flue Gas from Econ. deg. fahr.	CO_2 per cent	O_2 per cent	N + H per cent
4:00	11	29093	24286	65	101	182	388	126	200	505	320	--.-	-.-	--.-
4:30	12	29142	24314	65	101	182	388	126	198	505	320	--.-	-.-	--.-
5:00	13	29178	24342	65	98	182	386	117	194	507	305	9.2	7.6	83.2
5:30	14	29228	24373	65	100	182	388	117	194	511	320	--.-	-.-	--.-
6:00	15	29286	24405	65	94	180	385	117	186	511	320	10.6	5.9	84.5
6:30	16	29333	24434	65	104	182	388	120	192	508	320	--.-	-.-	--.-
7:00	17	29380	24463	65	102	182	388	119	192	509	320	10.0	6.2	83.8
7:30	18	29436	24491	65	100	182	389	122	187	506	320	-- -	-.-	--.-
8:00	19	29484	24518	65	102	182	388	119	192	507	315	8.4	7.3	84.3
8:30	20	29529	24548	65	100	183	386	120	194	490	315	--.-	-.-	--.-
9:00	21	29573	24578	65	101	183	390	122	190	500	320	9.8	7.0	83.2

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Test No. (2)

Time	Obs. No.	Water Meter cu. ft.	Oil Meter gal.	Oil Pressure lb. per sq. in.	Oil Temp. deg. fahr.	Steam Pressure lb. per sq.in.	Steam Temp. deg. fahr.	Water to Econ. deg. fahr.	Water from Econ. deg. fahr.	Flue Gas to Econ. deg. fahr.	Flue Gas from Econ. deg. fahr.	CO_2 per cent	O_2 per cent	N + H per cent
9:30	22	29623	24608	65	103	184	392	124	180	480	320	--.-	-.-	--.-
10:00	23	29686	24638	65	103	184	392	130	182	480	320	--.-	-.-	--.-
10:30	24	29736	24667	65	104	184	392	124	190	500	320	10.0	6.9	83.1
Corr. av.				65	101	173	408	127	190	504	375	9.7	6.4	83.9
Totals		1130	700											

Test No. (3)

Time	Obs. No.	Water Meter cu. ft.	Oil Meter gal.	Oil Pressure lb. per sq. in.	Oil Temp. deg. fahr.	Steam Pressure lb. per sq. in.	Steam Temp. deg. fahr.	Water to Econ. deg. fahr.	Water from Econ. deg. fahr.	Flue Gas to Econ. deg. fahr.	Flue Gas from Econ. deg. fahr.	CO_2 per cent	O_2 per cent	N + H per cent
11:00	0	33225	25194	65	90	190	400	125	157	500	285	--.-	-.-	--.-
11:30	1	33278	25223	65	100	190	392	135	167	485	285	11.3	5.5	82.2
12:00	2	33325	25251	65	102	180	392	135	182	475	285	12.2	4.8	83.0
12:30	3	33365	25279	65	108	180	392	138	195	470	285	11.8	5.2	83.0
1:00	4	33403	25307	65	108	180	392	135	200	470	285	--.-	-.-	--.-
1:30	5	33450	25335	65	106	180	392	126	192	475	285	11.8	5.2	83.0
2:00	6	33511	25364	65	108	180	396	126	178	450	300	11.3	6.7	83.0
2:30	7	33563	25393	65	108	180	394	128	184	455	300	--.-	-.-	--.-
3:00	8	33608	25422	65	110	180	392	136	190	465	290	11.4	6.0	82.6
3:30	9	33644	25449	65	110	180	393	136	200	475	285	--.-	-.-	--.-
4:00	10	33687	25478	65	108	180	393	134	200	480	310	11.8	5.4	82.8

Test No. (3)

Time	Obs. No.	Water Meter cu. ft.	Oil Meter gal.	Oil Pressure lb. per sq. in.	Oil Temp. deg. fahr.	Steam Pressure lb. per sq. in.	Steam Temp. deg. fahr.	Water to Econ. deg. fahr.	Water from Econ. deg. fahr.	Flue Gas to Econ. deg. fahr.	Flue Gas from Econ. deg. fahr.	CO_2 per cent	O_2 per cent	N + H per cent
4:30	11	33748	25518	65	106	180	394	135	186	490	310	12.5	4.5	83.0
5:00	12	33793	25540	65	108	180	390	122	192	505	310	12.6	4.4	83.0
5:30	13	33850	25573	65	106	180	392	117	180	505	310	--.-	-.-	--.-
6:00	14	33924	25606	65	106	180	395	120	168	500	310	12.7	4.4	82.9
6:30	15	33990	25639	65	106	180	392	124	178	500	310	--.-	-.-	--.-
7:00	16	34040	25670	65	104	180	392	117	182	495	310	12.2	5.0	82.8
7:30	17	34093	25700	65	100	180	394	120	180	485	310	--.-	-.-	--.-
8:00	18	34148	25737	65	108	180	394	125	184	470	310	12.0	4.5	83.5
8:30	19	34172	25759	65	100	180	394	126	190	450	300	--.-	-.-	--.-
9:00	20	34220	25789	65	100	185	396	126	186	510	340	11.2	5.4	83.4
9:30	21	34289	25820	65	104	200	398	124	186	510	340	--.-	-.-	--.-

Test No. (3)

Time	Obs. No.	Water Meter cu. ft.	Oil Meter gal.	Oil Pressure lb. per sq. in.	Oil Temp. lb. per sq. in.	Steam Pressure lb. per sq. in.	Steam Temp. deg. fahr.	Water to Econ, deg. fahr.	Water from Econ. deg. fahr.	Flue Gas to Econ. deg. fahr.	Flue Gas from Econ, deg. fahr.	CO_2 per cent	O_2 per cent	N + H per cent
10:00	22	34328	25851	65	104	190	399	134	190	495	320	11.8	5.2	83.0
10:30	23	34377	25880	65	104	190	403	134	190	490	310	--.-	-.-	--.-
11:00	24	34420	25910	65	104	190	399	124	192	495	320	12.8	3.7	83.3
11:30	25	34490	25942	65	104	190	402	122	180	500	320	--.-	-.-	--.-
12:00	26	34554	25973	65	108	190	408	136	172	500	320	11.7	5.4	82.9
Corr. av.				65	104	173	415	129	185	485	364	12.0	5.1	82.9
Totals		1329	779											

Test No. (4)

Time	Obs. No.	Water Meter cu. ft.	Oil Meter gal.	Oil Pressure lb. per sq. in.	Oil Temp. deg. fahr.	Steam Pressure lb. per sq. in.	Steam Temp. deg. fahr.	Water to Econ. deg. fahr.	Water from Econ. deg. fahr.	Flue Gas to Econ. deg. fahr.	Flue Gas from Econ. deg. fahr.	CO_2 per cent	O_2 per cent	N + H per cent
11:00	0	40404	26620	65	98	194	410	134	169	545	320	--.-	-.-	--.-
11:30	1	40456	26656	65	104	195	402	135	189	550	320	12.8	3.8	83.4
12:00	2	40515	26690	65	104	194	404	133	189	548	320	12.6	4.2	83.2
12:30	3	40570	26725	65	100	193	404	132	192	550	300	11.6	5.4	83.0
1:00	4	40631	26765	65	102	193	404	132	192	550	320	13.5	3.2	83.3
1:30	5	40697	26803	65	102	194	405	134	194	555	310	13.2	3.7	83.1
2:00	6	40747	26841	65	102	194	404	130	196	585	300	12.4	4.2	83.4
2:30	7	40820	26879	65	102	193	405	130	194	580	340	12.8	4.6	82.6
3:00	8	40880	26918	65	102	193	404	126	196	580	380	12.8	3.4	83.8
3:30	9	40943	26959	65	102	192	403	130	186	580	370	12.6	5.9	81.5
4:00	10	41018	27009	65	102	192	402	128	192	580	370	--.-	-.-	--.-

Test No. (4)

Time	Obs. No.	Water Meter cu. ft.	Oil Meter cu. ft.	Oil Pressure lb. per sq. in.	Oil Temp. deg. fahr.	Steam Pressure lb. per sq. in.	Steam Temp. deg. fahr.	Water to Econ. deg. fahr.	Water from Econ. deg. fahr.	Flue Gas to Econ. deg. fahr.	Flue Gas from Econ. deg. fahr.	CO_2 per cent	O_2 per cent	N + H per cent
4:30	11	41080	27040	65	102	192	400	124	184	575	380	13.8	2.2	84.0
5:00	12	41148	27085	65	102	191	399	124	184	570	370	13.3	0.7	86.0
5:30	13	41219	27129	65	102	191	400	124	176	570	370	13.6	1.8	84.6
6:00	14	41281	27173	65	100	191	404	124	184	615	400	13.3	3.0	83.7
6:30	15	41347	27212	65	104	194	408	127	189	595	400	12.6	4.0	83.4
7:00	16	41408	27251	65	100	193	408	129	195	600	400	13.0	3.8	83.2
7:30	17	41471	27290	65	100	193	407	127	195	600	400	12.8	4.2	83.0
8:00	18	41530	27322	65	100	193	405	120	193	540	400	11.2	5.8	83.0
8:30	19	41586	27358	65	100	192	402	122	190	560	380	12.8	4.0	83.2
9:00	20	41647	27400	65	100	192	404	122	186	610	400	14.2	1.8	84.0
9:30	21	41717	27444	65	95	191	401	128	186	600	400	14.1	1.5	84.4

Test No. (4)

Time	Obs. No.	Water Meter cu. ft.	Oil Meter gal.	Oil Pressure lb. per sq. in.	Oil Temp. deg. fahr.	Steam Pressure lb. per sq. in.	Steam Temp. deg. fahr.	Water to Econ. deg. fahr.	Water from Econ. deg. fahr.	Flue Gas to Econ. deg. fahr.	Flue Gas from Econ. deg. fahr.	CO_2 per cent	O_2 per cent	N + H per cent
10:00	22	41777	27499	65	95	190	400	124	194	600	380	13.6	1.9	84.5
10:30	23	41848	27534	65	95	190	404	124	184	610	400	14.0	1.8	84.2
11:00	24	41931	27577	65	100	192	408	124	176	620	400	13.8	1.9	84.3
11:30	25	42006	27619	65	100	192	407	124	184	620	400	13.6	2.6	83.8
12:00	26	42075	27658	65	100	192	410	124	190	600	400	12.8	4.0	83.2
Corr. av.				65	101	182	413	127	188	582	385	13.1	3.3	83.6
Totals		1671	1038											

Test No. (5)

Time	Obs. No.	Water Meter cu. ft.	Oil Meter gal.	Oil Pressure lb. per sq. in.	Oil Temp. deg. fahr.	Steam Pressure lb. per sq. in.	Steam Temp. deg. fahr.	Water to Econ. deg. fahr.	Water from Econ. deg. fahr.	Flue Gas to Econ. deg. fahr.	Flue Gas from Econ. deg. fahr.	CO_2 per cent	O_2 per cent	N + H per cent
10:30	0	45733	28208	65	90	200	412	132	180	405	280	8.8	6.2	85.0
11:00	1	45765	28225	65	96	195	410	125	172	387	270	9.3	8.7	82.0
11:30	2	45797	28243	65	100	193	400	130	172	360	280	10.8	6.6	82.6
12:00	3	45827	28260	65	102	195	396	130	163	345	270	10.7	6.6	82.7
12:30	4	45857	-----	65	102	194	395	123	162	350	280	10.8	7.0	82.2
1:00	5	45888	28294	65	102	195	395	120	160	345	270	11.0	6.5	82.5
1:30	6	45919	28311	65	102	195	395	125	160	340	270	11.0	6.6	82.4
2:00	7	45952	28326	65	102	195	397	135	152	335	280	10.6	6.4	83.0
2:30	8	45977	28343	65	104	195	397	135	154	330	270	11.2	6.0	82.8
3:00	9	46001	28360	64	105	195	395	130	160	340	280	11.2	6.0	82.8
3:30	10	46035	28378	65	103	195	396	120	156	360	280	11.0	6.2	82.8

Test No. (5)

Time	Obs. No.	Water Meter cu. ft.	Oil Meter gal.	Oil Pressure lb. per sq. in.	Oil Temp. deg. fahr.	Steam Pressure lb. per sq. in.	Steam Temp. deg. fahr.	Water to Econ. deg. fahr.	Water from Econ. deg. fahr.	Flue Gas to Econ. deg. fahr.	Flue Gas from Econ. deg. fahr.	CO_2 per cent	O_2 per cent	N + H per cent
4:00	11	46073	28399	65	98	195	392	116	154	355	280	12.8	4.2	83.0
4:30	12	46097	28418	65	107	195	392	146	156	340	280	13.2	3.4	83.4
5:00	13	46128	28439	65	94	193	395	122	154	400	330	13.3	3.3	83.4
5:30	14	46171	28468	65	93	191	406	122	156	460	340	11.3	5.7	83.0
6:00	15	46215	28497	65	91	192	406	124	162	500	360	11.0	6.0	83.0
6:30	16	46260	28525	65	98	192	410	122	170	460	340	10.3	6.9	82.9
7:00	17	46303	28553	65	93	193	409	124	166	495	350	9,5	8.1	82.4
7:30	18	46349	28581	65	93	192	408	124	170	495	340	9.0	8.5	82.5
8:00	19	46391	28599	65	96	193	406	136	170	350	280	9.6	7.4	83.0
8:30	20	46427	28617	65	96	193	402	122	166	360	280	12.0	4.8	83.2
9:00	21	46451	28632	65	95	192	380	124	162	270	240	9.4	8.2	82.4

Test No. (5)

Time	Obs. No.	Water Meter cu. ft.	Oil Meter gal.	Oil Pressure lb. per sq. in.	Oil Temp. deg. fahr.	Steam Pressure lb. per sq. in.	Steam Temp. deg. fahr.	Water to Econ. deg. fahr.	Water from Econ. deg. fahr.	Flue Gas to Econ. deg. Fahr.	Flue Gas from Econ. deg. fahr.	CO_2 per cent	O_2 per cent	N + H per cent
9:30	22	46476	28642	65	96	193	386	124	156	250	220	10.4	6.6	83.0
10:00	23	46494	28656	65	96	192	392	124	154	295	250	12.3	3.9	83.8
10:30	24	46513	28673	65	96	192	392	128	154	330	280	12.0	5.5	82.5
11:00	25	46556	28691	65	100	195	396	130	154	340	280	11.6	5.2	83.2
11:30	26	46584	28703	65	98	195	398	130	154	335	270	12.0	5.0	83.0
12:00	27	46618	28726	64	98	195	400	130	150	340	300	11.2	5.8	83.0
Corr. av.				65	98	183	407	127	161	367	288	10.4	6.1	83.5
Totals		885	518											

Test No. (6)

Time	Obs. No.	Water Meter cu. ft.	Oil Meter gal.	Oil Pressure lb. per sq. in.	Oil Temp. deg. fahr.	Steam Pressure lb. per sq. in.	Steam Temp. deg. fahr.	Water to Econ. deg. fahr.	Water from Econ. deg. fahr.	Flue Gas to Econ. deg. fahr.	Flue Gas from Econ. deg. fahr.	CO_2 per cent	O_2 per cent	N + H per cent
10:30	0	47326	29201	67	88	187	415	132	144	365	285	8.0	9.2	82.8
11:00	1	47351	29225	70	88	188	409	132	142	340	250	10.0	8.0	82.0
11:30	2	47370	29226	72	94	188	410	132	142	350	270	8.0	10.3	81.7
12:00	3	47398	29241	70	97	185	400	135	152	335	270	7.5	11.0	81.5
12:30	4	47421	29256	70	95	185	392	135	160	285	230	9.0	9.0	82.0
1:00	5	47441	29270	70	96	185	382	130	162	300	260	9.6	5.0	86.0
1:30	6	47463	29285	70	98	185	388	132	160	300	260	10.0	6.0	84.0
2:00	7	47486	29299	70	96	185	390	130	160	300	260	10.0	5.2	84.8
2:30	8	47512	29312	70	97	185	390	148	160	290	240	10.0	5.3	84.7
3:00	9	47535	29327	68	93	185	396	126	154	285	240	13.0	2.3	84.7
3:30	10	47563	29342	67	94	185	390	126	155	300	250	11.2	3.8	85.0

Test No. (6)

Time	Obs. No.	Water Meter cu. ft.	Oil Meter gal.	Oil Pressure lb. per sq. in.	Oil Temp. deg. fahr.	Steam Pressure lb. per sq. in.	Steam Temp. deg. fahr.	Water to Econ. deg. fahr.	Water from Econ. deg. fahr.	Flue Gas to Econ. deg. fahr.	Flue Gas from Econ. deg. fahr.	CO_2 per cent	O_2 per cent	N + H per cent
4:00	11	47587	29357	68	97	185	392	140	155	290	250	10.2	4.2	85.8
4:30	12	47612	29370	67	96	185	392	134	152	290	240	11.0	6.0	83.0
5:00	13	47634	29386	67	94	185	392	130	152	295	240	11.8	4.8	83.4
5:30	14	47659	29401	67	94	185	390	132	152	295	240	12.4	5.1	82.5
6:00	15	47687	29417	67	94	185	395	130	150	295	240	12.4	4.6	83.4
6:30	16	47711	29429	65	96	180	388	131	150	276	220	9.0	7.8	80.9
7:00	17	47733	29442	65	96	180	377	128	150	260	220	11.3	5.7	81.7
7:30	18	47768	29454	65	96	180	376	128	144	260	215	12.6	3.6	85.4
8:00	19	47796	29467	65	96	180	383	120	144	258	210	13.0	3.0	84.8
8:30	20	47815	29478	65	104	180	376	---	---	255	210	10.2	7.0	82.8
9:00	21	47834	29489	65	100	180	383	140	144	256	210	11.6	5.4	83.0

Test No. (6)

Time	Obs. No.	Water Meter cu. ft.	Oil Meter gal.	Oil Pressure lb. per sq. in.	Oil Temp. deg. fahr.	Steam Pressure lb. per sq. in.	Steam Temp. deg. fahr.	Water to Econ. deg. fahr.	Water from Econ. deg. fahr.	Flue Gas to Econ. deg. fahr.	Flue Gas from Econ. deg. fahr.	CO_2 per cent	O_2 per cent	N + H per cent
9:30	22	47854	29501	65	104	180	376	134	142	260	220	12.0	4.6	83.4
10:00	23	47875	29517	66	100	180	390	130	150	330	280	13.2	2.8	83.0
10:30	24	47918	29538	66	104	180	---	---	144	350	---	13.4	3.2	83.4
Corr. av.				67	96	173	399	133	150	296	238	10.6	5.9	83.5
Totals		592	337											

Test No. (7)

Time	Obs. No.	Water Meter cu. ft.	Oil Meter gal.	Oil Pressure lb. per sq. in.	Oil Temp. deg. fahr.	Steam Pressure lb. per sq. in.	Steam Temp. deg. fahr.	Water to Econ. deg. fahr.	Water from Econ. deg. fahr.	Flue Gas to Econ. deg. fahr.	Flue Gas from Econ. deg. fahr.	CO_2 per cent	O_2 per cent	N + H per cent
1:30	0	47968	30058	60	---	190	400	115	154	480	350	--.-	-.-	--.-
2:00	1	48010	30078	60	---	190	396	110	154	480	340	--.-	-.-	--.-
2:30	2	48058	30105	60	110	190	402	115	152	540	370	--.-	-.-	--.-
3:00	3	48104	30133	60	---	190	391	115	156	535	370	11.0	4.0	85.0
3:30	4	48165	30162	60	---	190	395	110	154	545	370	10.0	5.0	85.0
4:00	5	48223	30192	60	---	190	396	110	150	600	400	11.0	4.0	85.0
4:30	6	48270	30222	60	---	190	400	110	156	555	380	10.6	2.4	87.0
5:00	7	48328	30249	60	---	190	398	110	156	570	380	--.-	-.-	--.-
5:30	8	48374	30275	60	---	190	398	110	156	505	360	--.-	-.-	--.-
6:00	9	48414	30305	60	---	190	400	120	156	495	360	8.3	6.0	85.7
6:30	10	48451	30316	60	---	187	398	110	160	475	340	8.8	6.2	85.0

Test No. (7)

Time	Obs. No.	Water Meter cu. ft.	Oil Meter gal.	Oil Pressure lb. per sq. in.	Oil Temp. deg. fahr.	Steam Pressure lb. per sq. in.	Steam Temp. deg. fahr.	Water to Econ. deg. fahr.	Water from Econ. deg. fahr.	Flue Gas to Econ. deg. fahr.	Flue Gas from Econ. deg. fahr.	CO_2 per cent	O_2 per cent	N + H per cent
7:00	12	48497	30337	50	110	185	396	110	152	475	340	9.4	-.-	--.-
7:30	12	48546	30360	60	---	185	396	110	150	535	360	9.5	6.0	85.5
8:00	13	48599	30386	75	100	190	398	110	154	525	360	10.0	5.0	85.0
8:30	14	48636	30410	77	100	190	398	110	156	515	360	--.-	-.-	--.-
9:00	15	48666	30434	75	100	190	398	110	156	510	360	9.3	4.4	86.3
9:30	16	48705	30458	75	100	190	398	110	160	515	360	10.3	3.3	86.4
10:00	17	48740	30482	75	100	190	396	115	160	515	360	9.4	4.0	86.6
10:30	18	48780	30505	75	100	190	398	110	160	515	360	10.0	3.4	86.6
11:00	19	48820	30530	77	96	190	398	125	164	515	360	9.6	4.8	86.6
11:30	20	48859	30553	77	96	195	400	115	162	510	360	10.0	3.0	87.0
12:00	21	48896	30574	75	100	190	398	115	164	475	340	10.6	4.8	84.6

Test No. (7)

Time	Obs. No.	Water Meter cu. ft.	Oil Meter gal.	Oil Pressure lb. per sq. in.	Oil Temp. deg. fahr.	Steam Pressure lb. per sq. in.	Steam Temp. deg. fahr.	Water to Econ. deg. fahr.	Water from Econ. deg. fahr.	Flue Gas to Econ. deg. fahr.	Flue Gas from Econ. deg. fahr.	CO_2 per cent	O_2 per cent	N + H per cent
12:30	22	48982	30598	75	100	190	410	120	154	515	360	10.6	5.1	84.3
1:00	23	49025	30620	75	110	190	402	115	154	510	350	9.3	7.1	83.6
1:30	24	49095	30643	75	110	190	408	130	150	500	350	--.-	-.-	--.-
2:00	25	49151	30666	75	110	190	408	142	150	515	360	10.2	7.1	82.7
Corr. av.				68	105	179	407	115	155	517	360	9.9	4.3	85.8
Totals		1183	608											

GENERAL DATA AND RESULTS

Test Number	No.	1	2	3	4	5	6	7
Date of Test		11/29 1914	12/24 1914	12/26 1914	12/28 1914	12/30 1914	1/1 1915	3/29 1915
Duration of Test	hr.	12.5	12.0	13.0	13.0	13.5	12.0	12.5
Approximate Barometer	in.	29	29	29	29	29	29	29
Steam Pressure (Gage)	lb.	140	173	173	182	183	173	179
Steam Temperature	deg.F.	389	408	415	413	407	399	407
Superheat	deg.F.	29	32	39	33	27	23	28
Temperature Feed Water								
to Economizer	deg.F.	120	127	129	127	127	133	115
to Boiler	deg.F.	159	190	185	188	161	150	155
Temperature Flue Gas								
to Economizer	deg.F.	547	500	485	582	367	296	517
to Stack	deg.F.	418	375	364	385	288	238	360
Approximate Temperature								
Outside Air	deg.F.	50	50	50	50	50	50	50
Carbon Dioxide	%	10.5	9.7	12.0	13.1	10.4	10.6	9.9
Oxygen	%	5.3	6.4	5.1	3.3	6.1	5.9	4.3
Nitrogen + Hydrogen								
(by difference)	%	84.2	83.9	82.9	83.6	83.5	83.5	85.8
Excess Air	%	34.0	41.3	30.8	18.0	38.8	37.1	23.6
Gravity of Oil, Beaume,								
at 60 deg. fahr.	deg.B.	18.5	18.5	18.5	18.5	18.5	18.5	18.5
Total Oil Burned	lb.	6075	5370	5980	7960	3980	2595	4670
Total Water Fed	lb.	71600	61400	52350	90800	48600	32500	65000
Oil Burned per hr.	lb.	485.5	447.5	461	612	295	216.2	347
Water Fed per hr.	lb.	5730	5120	5570	6980	3605	2708	5200
Water Evaporated per hr.								
per sq. ft. H.S.	lb.	3.36	3.01	3.27	4.10	2.12	1.59	3.05
Factor of Evaporation	--	1.119	1.091	1.102	1.098	1.121	1.129	1.127

GENERAL DATA AND RESULTS

Test Number	No.	1	2	3	4	5	6	7
Equivalent Evaporation F.&.A. 212deg.F. per hr.	lb.	6420	5675	6135	7660	4040	3055	5860
Equivalent Evaporation F.&.A. 212 deg.F. per sq.ft. H.S. per hr.	lb.	3.77	3.33	3.60	4.50	2.38	1.795	3.44
Steam Used by Burner	lb.	115	120	111	140	72	54	104
Boiler Horsepower Developed	bl.h.p.	182	158.7	174	217.5	115	86	166.5
Rated Capacity, Evap. F.&.A. 212 deg.F. per hr.	lb.	5860	5860	5860	5860	5860	5860	5860
Rated Boiler Horsepower	bl.h.p.	170	170	170	170	170	170	170
Per cent of Rated Capacity Developed	%	107	93.4	102.5	128	67.6	51.2	98
Boiler Horsepower Develop-ed by Economizer	bl.h.p.	6.7	9.65	9.32	12.75	3.66	1.38	6.22
Water Fed per lb. of Oil Burned	lb.	11.80	11.45	12.10	11.41	12.20	12.52	13.91
Equivalent Evaporation F.&.A. 212 deg.F. per lb. of Oil Fired	lb.	13.14	12.70	13.31	12.52	13.70	14.10	15.65
Calorific Value of One lb. of Oil	B.t.u.	19050	19050	19050	19050	19050	19050	19235
Eff. of Boiler & Furnace	%	66.1	63.2	66.5	62.4	68.3	70.5	77.3
Eff. of Economizer	%	65.1	98.8	115	77.8	95.0	65.2	61.6
Ideal Eff. of Economizer	%	12.5	21.3	23.1	21.4	16.5	10.3	15.9
Saving by Economizer	%	2.42	3.8	3.5	3.7	2.2	1.1	2.9
Eff. of Boiler, Furnace and Economizer	%	68.5	67.0	70.0	66.1	70.5	71.6	80.2

GENERAL DATA AND RESULTS

Test Number	No.	1	2	3	4	5	6	7
Cost of Oil per bbl.	¢	70	70	70	70	70	70	70
Cost of Oil per lb.	¢	.2113	.2113	.2113	.2113	.2113	.2113	.2113
Cost of Oil to Evaporate 1000 lb. of Steam F.&.A. 212 deg.F.	¢	16.4	17.0	16.2	17.2	15.7	15.3	13.8
Cost of Oil per Year	$	8120	7520	7780	10400	4880	2590	6200

HEAT BALANCE

Heat to Stack	%	17.1	16.5	13.5	14.5	13.5	10.8	14.6
Heat to Feedwater by Economizer	%	2.4	3.8	3.6	3.7	2.2	1.1	2.9
Radiation from Economizer	%	1.3	---	---	1.0	---	0.5	1.8
Heat to Feedwater by Boiler	%	66.1	63.2	66.5	62.4	68.3	70.5	77.3
Heat to Oil Burner	%	1.4	1.5	1.4	1.3	1.4	1.4	1.7
Heat Unaccounted For * Boiler Radiation & Unburned Hydrogen	%	11.7	15.0	15.0	17.1	14.6	15.7	1.7

Conclusion

The reason for undertaking these tests was to determine the efficiency of the boiler over a wide range of load, if practicable up to three hundred per cent. of the builder's rating, but as the tests had to be made under operating conditions it was not possible to hold a constant load on the boiler at the high ratings due to the fluctuation on the electrical output of the plant.

The tests show that the efficiency of the boiler and furnace decreases as the load on the boiler increases but that the saving by the economizer increases as the load increases. This is to be expected however as the temperature of the gases leaving the boiler is highest when the boiler is doing the most work, thus more heat is removed from the boiler and made available for heating the feedwater in the economizer.

The high boiler efficiency shown in test No. (7) is probably due to an error in the test caused by an undetected leak in the feedwater line or blow-off valve. As the boiler was dirty at the time this test was made it is not probable that the efficiency should be so far aboe that shown by the former tests.

Difficulty was encountered in making the burner throw the oil in all directions in equal amounts. The tendency being for one side of the burner to clog thus throwing most of the oil to one side of the furnace. A burner which would insure an even distribution of oil would make it possible to obtain complete combustion with less air.

Reducing the air supply would raise the percentage of carbon dioxide in the flue gas. This should be higher than was obtained. Fifteen or sixteen per cent is a possible value. The reduction of excess air would be carried into the furnace. The high percentage of hydrogen in the fuel may be partly responsible for the low percentage of carbon dioxide. The hydrogen unites with the oxygen of the air to form water and leaves free nitrogen thus increasing the relative amount of nitrogen in the flue gas and reducing the percentage of carbon dioxide.

The difference between the heat absorbed from the flue gas by the economizer and the heat absorbed by the feedwater in passing thru the economizer is so small that an error of ten degrees in the flue gas temperature combined with an error of two or thre per cent. in the carbon abd hydrogen assumed in the oil would make considerable difference in the efficiency shown by the economizer. This may account for the wide differences in the efficiencies found.

The saving by the economizer can however be accurately determined.

When the boiler is operated at 51.2 per cent. rating the saving in oil per year is

$$\frac{2595 \times 1.1 \times 24 \times 345 \times .70}{100 \times 12 \times 335} = \$41.20$$

at 128 per cent. rating the saving per year is

$$\frac{7960 \times 3.7 \times 24 \times 345 \times .70}{100 \times 13 \times 335} = \$386.00$$

Assuming that the life of the economizer is twenty years and that the sinking fund to replace it is earning four per cent. the annuity necessary to replace it at the end of that time is

$$\frac{0.04 \times 2000}{(1 + 0.04)^{20} - 1} = \$62.30$$

Interest charges at six per cent. amount to $0.06 \times 2000 = \$120.$ Total fixed charges equal $\$120. + \$62.30 = \$182.30$ per year. The saving by the economizer equals this amount when the boiler is operated at about 85% normal rating. The operation and repair charges should be small, therefore the economizer should be a good investment if the boiler is operated at about rated load where the saving would be about $\$250.$ per year.

The boiler is assumed to have a life of fifteen years with a wrecking value of $\$500.$ at the end of that time. The actual life of the boiler is probably greater than this but the growth of the plant will necessitate its replacement by a larger unit before it wears out. If the sinking fund earns four per cent. the annuity necessary to replace the investment is

$$\frac{0.04 \ (7000 - 500)}{(1 + 0.04)^{15} - 1} = \$325.$$

The interest charge at six per cent. amounts to $7000 \times 0.06 = \$420.$

Total fixed charges on boiler and economizer equal $\$927.$

This value is plotted on the curve sheet with the total cost of fuel oil per year.

Reference to the curve shows that the cost of oil per year is more than twice as much when the boiler is operated at 120 per cent. rated load as when it is operated at 60 per cent. The increased space, labor, and repairs required, if two boilers are operated at light load, generally make it cheaper to force one boiler as high as 200 per cent. rating or more, than to operate two boilers. The range of these tests is unfortunately not great enough to indicate how high the cost would go in this case, but with the showing made by the boiler it is doubtful if it would be good economy to force it very far beyond the builder's rating.

Formulas for Calculations

T_1 = temperature of water entering economizer.

T_2 = temperature of feedwater leaving economizer.

T_3 = temperature of flue gas leaving the boiler.

T_4 = temperature of flue gas leaving the economizer.

T_5 = approximate temperature of outside air.

C_1 = mean specific heat of carbon dioxide at constant pressure.

C_2 = mean specific heat of oxygen at constant pressure.

C_3 = mean specific heat of carbon monoxide and nitrogen at constant pressure.

C_4 = mean specific heat of hydrogen at constant pressure.

CO_2 = per cent of carbon dioxide in flue gas by volume.

O_2 = per cent of oxygen in flue gas by volume.

CO = per cent of carbon monoxide in flue gas by volume.

N = per cent of nitrogen in flue gas by volume.

H = per cent of hydrogen in oil by weight.

Y = per cent of carbon in oil by weight.

(40)

Efficiency of Boiler and Furnace, per cent

$$= \frac{.98 \times 100(\text{equivalent evaporation from and at 212 deg. fahr. per hr.})(907.4)}{\text{calorific value of oil fired per hr.}}$$

The factor (.98) is introduced to allow for the steam used to atomize the oil.

Heat supplied by Economizer, B.t.u. per hr.

$= (\text{weight of water fed per hr.})(\text{rise in temperature}) = W(T_2 - T_1)$

Saving by Economizer, per cent

$$= \frac{\text{heat supplied by economizer per hr. x 100}}{\text{calorific value of oil fired per hr.}}$$

Efficiency of Boiler, Furnace and Economizer, per cent

= efficiency of boiler and furnace + saving by economizer.

Efficiency of Economizer, per cent

$$= \frac{\text{lb. of water fed per hr. } (T_2 - T_1)(100)}{(A(T_3 - T_1) + 9H \times .46(T_3 - T_1))(\text{lb. of oil fed per hr.})}$$

Ideal efficiency of Economizer, per cent

$$= \frac{\text{lb. of water fed per hr. } (T_2 - T_1)\ (100)}{(A(T_3 - T_5) + 9H(1690.7 + .455 \times T_3 - T_5))(\text{lb. of oil fed per hr.})}$$

Cost of Oil to evaporate 1000 lb. of Steam from and at 212 deg. fahr., cents

$$= \frac{1000 \times \text{lb. of oil fed per hr. x cost per lb.}}{.98 \times \text{equivalent evaporation per hr.}}$$

Heat available for heating Feedwater in Economizer, B.t.u. per lb. of oil.

$$= \frac{Y(11 \times CO_2 \times C_1)+(8 \times O_2 \times C_2)+(7(CO+N)C_3)}{3(CO_2 + CO)} \quad (T_3 - T_1)$$

$$+ 9H(1090.7 + .455T_3 - T_1) \quad = \quad A(T_3 - T_1) + B$$

Heat absorbed by Economizer , B.t.u. per lb. of oil

$$A(T_3 - T_4) + 9H \times C_4(T_3 - T_4)$$

Radiation from Economizer, B.t.u. per hr.

= heat absorbed by economizer per hr. - heat supplied to feedwater by economizer.

Heat to Stack, B.t.u. per lb. of oil.

$$= A(T_4 - T_5) + 9H(1090.7 + .455\ T_4 - T_5)$$

Excess Air, per cent

$$= \frac{(8\ (O) - 4(CO + H)\ )\ (100)}{.299 \times 7N - (8\ (O_2) - 4(CO + H)\ )}$$

All calculations were made with a ten inch slide rule.

Test No.(1).

Efficiency of Boiler and Furnace, per cent

$$= \frac{.98 \times 100 \times 970.4 \times 6420}{19050 \times 485.6} = 66.1$$

Heat supplied by Economizer, B.t.u. per hr.

$$= 5730(127 - 88) = 223500$$

Saving by Economizer, per cent

$$= \frac{223500 \times 100}{19050 \times 485.6} = 2.42$$

Efficiency of Boiler, Furnace and Economizer, per cent

$$= 66.1 + 2.42 = 68.5$$

Efficiency of Economizer, per cent

$$= \frac{223500 \times 100}{343000} = 65.1$$

Ideal efficiency of Economizer, per cent

$$= \frac{223500 \times 100}{1810000} = 12.5$$

Cost of Oil to evaporate 1000 lb. of Steam F.&.A. 212 deg.F.

$$= \frac{1000 \times 485.5 \times .002113}{.98 \times 6420} = \$\ 0.163$$

Heat available for heating Feedwater in Economizer,

B.t.u. per lb. of Oil

$$= \frac{.865(11 \times 10.5 \times .217 + 8 \times 5.3 \times .217 + 7 \times 84.2 \times .246)}{3 \times 10.5}$$

$$(547 - 88) + 9 \times .13(1090.7 + .455 \times 547 - 88)$$

$$= 4.93 \times 459 + 1465 = 3730$$

or $485.5 \times 3730 = 1810000$ B.t.u. per hr.

Test No.(1)

Heat absorbed by the Economizer, B.t.u. per lb. of Oil

$= (4.93 + 9 \times .13 \times .46)(547 - 418) = 706.5$

or $485.5 \times 706.5 = 343000$ B.t.u. per hr.

Radiation from Economizer, B.t.u. per hr.

$= 343000 - 223500 = 119500$

Heat to Stack, B.t.u. per lb. of Oil

$= 4.93(418 - 50) + 9 \times .13(1090.7 + .455 \times 418 - 50)$

$= 3257$ or $485.5 \times 3257 = 1580000$ B.t.u. per hr.

Excess Air, per cent

$$= \frac{8 \times 5.3 \times 100}{(.299 \times 7 \times 84.2) - (8 \times 5.3)} = 34.0$$

Test No.(2)

Efficiency of Boiler and Furnace, per cent

$$= \frac{.98 \times 5675 \times 970.4 \times 100}{19050 \times 447.5} = 63.2$$

Heat supplied by Economizer, B.t.u. per hr.

$$= 5120 \times (190 - 127) = 322000$$

Saving by Economizer, per cent

$$= \frac{322000 \times 100}{19050 \times 447.5} = 3.8$$

Efficiency of Boiler, Furnace and Economizer

$$= 63.2 + 3.8 = 67.0$$

Efficiency of Economizer, per cent

$$= \frac{322000 \times 100}{326000} = 98.8$$

Ideal efficiency of Economizer, per cent

$$= \frac{322000 \times 100}{1510000} = 21.3$$

Cost of Oil to evaporate 1000 lb. of Steam F.&A. 212 deg.F.

$$= \frac{1000 \times 447.5 \times .002113}{5675 \times .98} = \$\ 0.170$$

Heat available for heating Feedwater in Economizer,

B.t.u. per lb. of Oil.

$$= \frac{86.5(11 \times 9.74 \times .217 + 8 \times 6.42 \times .217 + 7 \times 83.0 \times .246)}{3 \times 9.74}$$

$$(500 - 127) + 9 \times .13(1090.7 + .455 \times 500 - 127)$$

$$= 5.29 \times 373 + 1480 = 3368$$

or $3368 \times 447.5 = 1510000$ B.t.u. per hr.

Test No.(2)

Heat absorbed by Economizer, B.t.u. per lb.of Oil

= 5.29(500 - 375) + 9 x .13 x .46(500 - 375) = 728

or 728 x 447.5 = 326000 B.t.u. per hr.

Radiation from Economizer. B.t.u. per hr.

= 326000 - 322000 = 4000 B.t.u. per hr.

Heat to Stack, B.t.u. per lb. of Oil

= 5.29(375 - 50) + 9 x .13(1090.7 + .455 x 375 - 50)

= 3140 or, 447.5 x 3140 = 1405000 B.t.u. per hr.

Excess Air, per cent

$$= \frac{100 \times 8 \times 6.42}{.299 \times 7 \times 83.84 - 8 \times 6.42} = 41.3$$

Test No.(3)

Efficiency of Boiler and Furnace , per cent

$$= \frac{.98 \times 100 \times 970.4 \times 6135}{19050 \times 461} = 66.5$$

Heat supplied by Economizer B.t.u. per hr.

$$= 5570 \times (185 - 129) = 311800$$

Saving by Economizer, per cent

$$= \frac{100 \times 311800}{19050 \times 461} = 3.5$$

Efficiency of Boiler, Furnace and Economizer, per cent

$$= 3.5 + 66.5 = 70.0$$

Efficiency of Economizer, per cent

$$= \frac{100 \times 311800}{272000} = 115$$

Ideal efficiency of Economizer, per cent

$$= \frac{311800 \times 100}{1350000} = 23.1$$

Cost of Oil to evaporate 1000 lb. of Steam F.&A. 212 deg.F.

$$= \frac{1000 \times 461 \times .002113}{.98 \times 6135} = \$\ 0.162$$

Heat available for heating Feedwater in Economizer

B.t.u. per hr.

$$= \frac{86.5(11 \times 12 \times .217 + 8 \times 5.1 \times .217 + 82.9 \times 7 \times .256)}{3 \times 12}$$

$$(485 - 129) + 9 \times .13(1090.7 + .455 \times 485 - 129)$$

$$= 4.33 \times 356 + 1385 = 2927$$

or $2937 \times 461 = 1350000$ B.t.u. per hr.

Test No.(3)

Heat absorbed by the Economizer, B.t.u. per lb. of Oil

= (4.33 + 9 x .13 x .46)(485 - 364) = 590

or 461 x 590 = 272000 B.t.u. per hr.

Radiation from Economizer B.t.u. per hr.

= 272000 - 311800 = - - -

Heat to Stack, B.t.u. per lb. of Oil

= 4.33(364 - 5-) + 9x .13(1091.7 + .455 x 364 - 50)= 2566

or 461 x 2566 = 1180000 b.t.u. per hr.

Excess Air, per cent

$$= \frac{100 \times 8 \text{ ﬁ } 5.1}{(.299 \times 7 \times 82.9) - (8 \times 5.1)} = 30.8$$

Test No.(4)

Efficiency of Boiler and Furnace, per cent

$$= \frac{.98 \times 100 \times 7660 \times 970.4}{19050 \times 612} = 62.4$$

Heat supplied by Economizer, B.t.u. per hr.

$$= 6980(188 - 127) = 426000$$

Saving by Economizer, per cent

$$= \frac{426000 \times 100}{19050 \times 612} = 3.7$$

Efficiency of Boiler, Furnace and Economizer, per cent

$$= 62.4 + 3.7 = 66.1$$

Efficiency of Economizer, per cent

$$= \frac{100 \times 426000}{547000} = 77.8$$

Ideal efficiency of Economizer, per cent

$$= \frac{1000 \times 426000}{1,990,000} = 21.4$$

Cost of Oil to evaporate 1000 lb. of Steam F.&A. 212deg.F.

$$= \frac{1000 \times 612 \times .002113}{7660 \times .98} = \$\ 0.172$$

Heat available for heating Feedwater in Economizer

B.t.u. per lb. of Oil

$$= \frac{86.5(11 \times 13.1 \times .217 + 8 \times 3.34 \times .217 + 7 \times 83.6 \times .246)}{3 \times 13.1}$$

$$(582 - 127) + 9 \times .13(1090.7 + .455 \times 582 - 127$$

$$= 3.99 \times 455 + 1435 = 3250$$

or $612 \times 3250 = 1,990,000$ B.t.u. per hr.

Test No.(4)

Heat absorbed by Economizer, B.t.u. per lb of Oil

= (3.99 + 9 x .13 x .46)(582 - 385) = 893

or 612 x 893 = 547000 B.t.u. per hr.

Radiation from Economizer, B.t.u. per hr.

= 547000 - 426000 = 121000

Heat to Stack, B.t.u. per lb. of Oil

= 3.99(385 - 50) + .13 x 9(1090.7 + .455 x 385 - 50)

= 2760 or, 612 x 2760 = 1,690,000. B.t.u. per hr.

Excess Air, per cent

$$= \frac{100 \times 8 \times 3.34}{(.299 \times 7 \times 83.6) - (8 \times 3.34)} \quad 18.0$$

Test No.(5)

Efficiency of Boiler and Furnace, per cent

$$= \frac{.98 \times 100 \times 970.4 \times 4040}{19050 \times 295} = 68.3$$

Heat supplied by Economizer, B.t.u. per hr.

$$= 3605(161 - 127) = 122700$$

Saving by Economizer, per cent

$$= \frac{122700 \times 100}{19050 \times 295} = 2.2$$

Efficiency of Boiler, Furnace and Economizer, per cent

$$= 68.3 + 2.2 = 70.5$$

Efficiency of Economizer, per cent

$$= \frac{100 \times 122700}{129300} = 95.0$$

Ideal efficiency of Economizer, per cent

$$= \frac{100 \times 122700}{743000} = 16.5$$

Cost of Oil to evaporate 1000 lb. of Steam F.&.A. 212 deg.F.

$$= \frac{1000 \times 295 \times .002113}{4040 \times .98} = \$\ 0.157$$

Heat available for heating Feedwater in Economizer,

B.t.u. per lb. of Oil

$$= \frac{86.5(11 \times 10.4 \times .217 + 8 \times 6.1 \times .217 + 7 \times 83.5 \times .246)}{3 \times 10.4}$$

$$(367 - 127) + 9 \times .13(1090.7 + .455 \times 367 - 127)$$

$$= 5.0 \times 240 + 1320 = 2520$$

or $295 \times 2520 = 743000$ B.t.u. per hr.

Test No.(5)

Heat absorbed by Economizer, B.t.u. per lb. of Oil

$= (5.0 + 9 \times .13 \times .46)(367 - 288) = 382$

or $295 \times 382 = 129300$ B.t.u. per hr.

Radiation from Economizer, B.t.u. per hr.

$= 129300 - 122700 = 6600$

Heat to Stack, B.t.u. per lb. of Oil

$= 5.0(288 - 50) + 9 \times .13(1090.7 + .455 \times 288 - 50) = 2560$

or $295 \times 2560 = 755000$ B.t.u. per hr.

Excess Air, per cent

$$= \frac{100 \times 8 \times 6.1}{(.299 \times 7 \times 83.5) - (8 \times 6.1)} = 38.8$$

Test No.(6)

Efficiency of Boiler and Furnace, per cent

$$= \frac{.98 \times 100 \times 970.4 \times 3055}{19050 \times 216.2} = 70.5$$

Heat supplied by Economizer, B.t.u. per hr.

$$= 2708 \times (150 - 133) = 46100$$

Saving by Economizer, per cent

$$= \frac{46100 \times 100}{19050 \times 216.2} = 1.1$$

Efficiency of Boiler, Furnace and Economizer, per cent

$$= 70.5 + 1.1 = 71.6$$

Efficiency of Economizer, per cent

$$= \frac{46100 \times 100}{67500} = 68.2$$

Ideal efficiency of Economizer, per cent

$$= \frac{46100 \times 100}{448000} = 10.3$$

Cost of Oil to evaporate 1000 lb. of Steam F.&.A. 212 deg.F.

$$= \frac{1000 \times 216.2 \times .002113}{3055 \times .98} = \$\ 0.1525$$

Heat available for heating Feedwater in Economizer,

B.t.u. per lb. of Oil

$$= \frac{86.5(11 \times 10.6 \times .217 + 8 \times 5.9 \times .217 + 7 \times 83.5)}{3 \times 10.6}$$

$$(296 - 133) + 9 \times .13(1090.7 + .455 \times 296 - 133)$$

$$= 4.88 \times 163 + 1250 = 2077$$

or $216.2 \times 2077 = 448000$ B.t.u. per hr.

Test No.(6)

Heat absorbed by Economizer, B.t.u. per lb. of Oil

= (4.88 + 9 x .13 x.46)(296 - 238) = 314

or 216.2 x 314 = 67500 B.t.u. per hr.

Radiation from Economizer, B.t.u. per hr.

= 67500 - 46100 = 21400

Heat to Stack, B.t.u. per lb. of Oil

= 4.88(238 - 50) + 9 x .13(1090.7 + .455 x 238 - 50)

= 2067 or 216.2 x 2067 = 447000 B.t.u. per hr.

Excess Air, per cent

$$= \frac{100 \times 8 \times 5.9}{(.299 \times 7 \times 83.5) - (8 \times 5.9)} = 37.1$$

Test No.(7)

Efficiency of Boiler and Furnace, per cent

$$= \frac{.98 \times 100 \times 970.4 \times 5860}{19235 \times 374} = 77.3$$

Heat supplied by Economizer, B.t.u. per hr.

$$= 5200(155 - 115) = 208000$$

Saving by Economizer, per cent

$$= \frac{208000 \times 100}{19235 \times 374} = 2.9$$

Efficiency of Boiler, Furnace and Economizer, per cent

$$= 2.9 + 77.3 = 80.2$$

Efficiency of Economizer, per cent

$$= \frac{208000 \times 100}{338000} = 61.6$$

Ideal efficiency of Economizer, per cent

$$= \frac{208000 \times 100}{1310000} = 15.9$$

Cost of Oil to evaporate 1000 lb. of Steam F.&.A. 212 deg.F.

$$= \frac{1000 \times 374 \times .002113}{.98 \times 5860} = \$\ 0.1377$$

Heat available for heating Feedwater in Economizer,

B.t.u. per lb. of Oil

$$= \frac{86.5(11 \times 9.9 \times .217 + 8 \times 4.28 \times .217 + 7 \times 85.8 \times .246)}{3 \times 9.9}$$

$$(517 - 115) + 9 \times .13(1090.7 + .455 \times 517 - 115)$$

$$= 5.21 \times 402 + 1410 = 35000$$

or $374 \times 3500 = 1310000$ B.t.u. per hr.

Test No.(7)

Heat absorbed by Economizer, B.t.u per lb. of Oil

= 5.21(517 - 360) + 9 x .13(517 - 360) = 903

or 374 x 903 = 338000 B.t.u. per hr.

Radiation from Economizer, B.t.u. per hr.

= 338000 - 208000 = 130000

Heat to Stack, B.t.u. per lb. of Oil

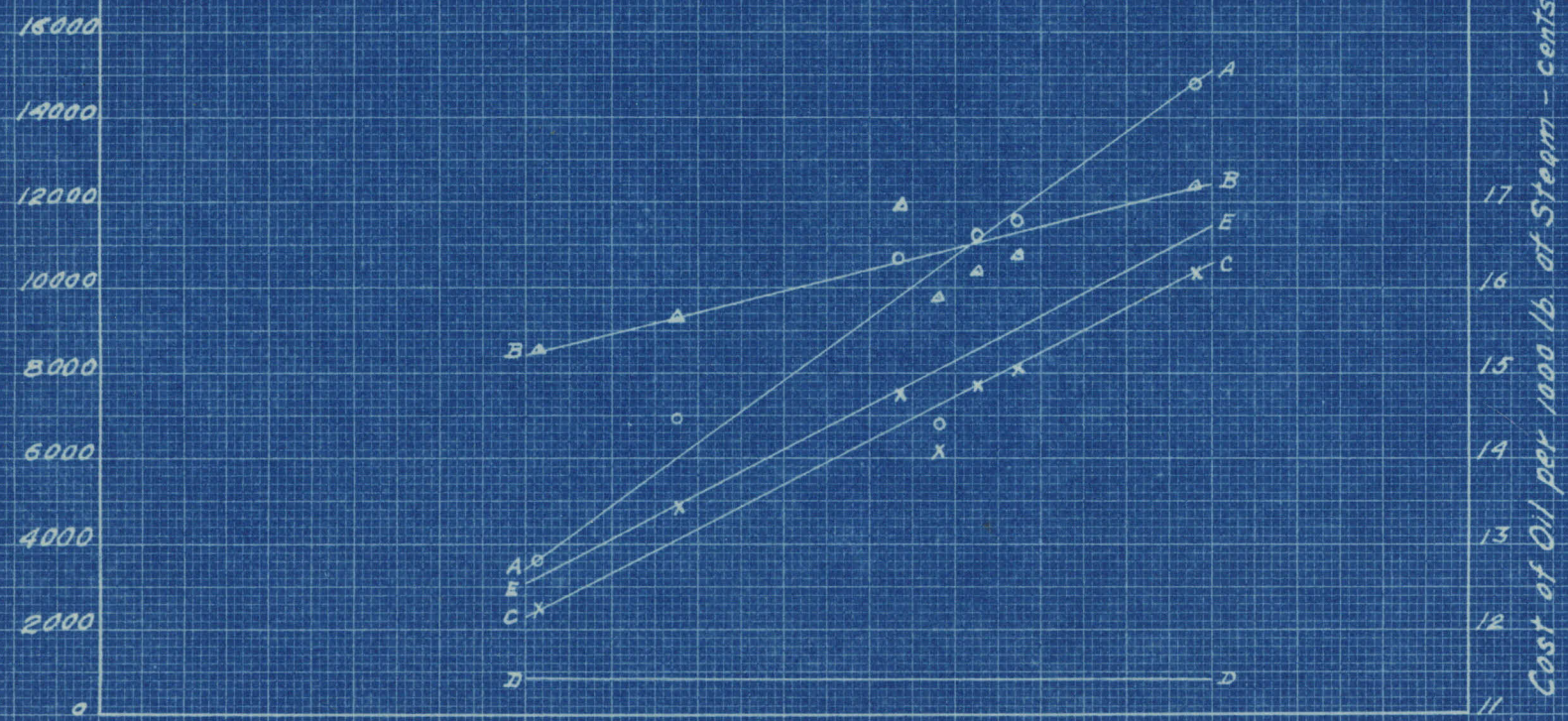
= 5.21(360 - 50) + 9 x .13(1090.7 + .455 x 360 - 50)

= 2816 or 374 x 2816 = 1052000 B.t.u. per hr.

Excess Air, per cent

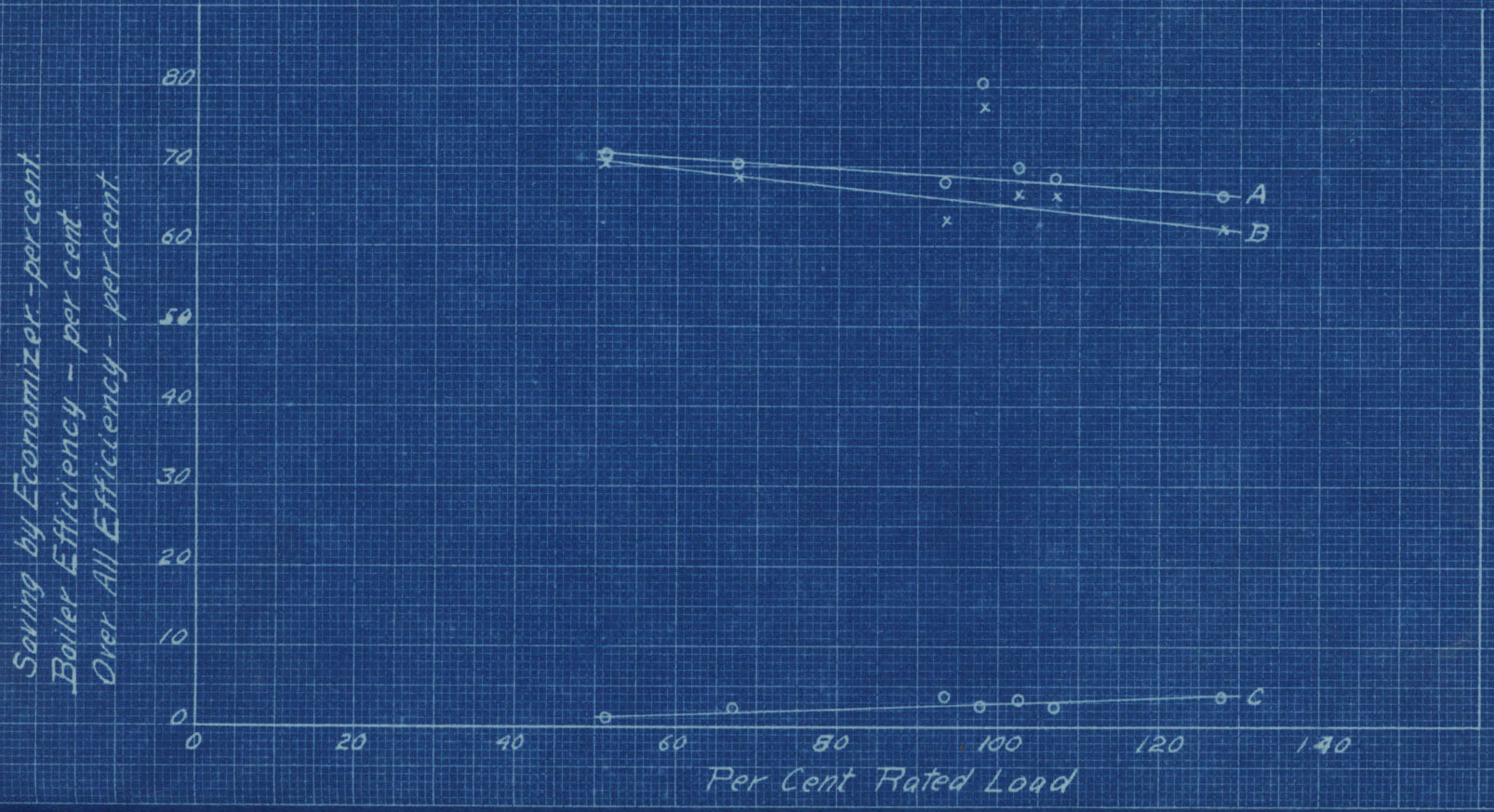
$$= \frac{100 \times 8 \times 4.28}{(.299 \times 7 \times 85.8)-(8 \times 4.28)} = 23.6$$

Test of Babcock and Wilcox Boiler – No 5836.
Curve A – Total Oil Consumed per Year.
Curve B – Cost of Oil per 1000 lb. of Steam.
Curve C – Total Cost of Oil per Year.
Curve D – Depreciation plus Interest.
Curve E – Depreciation and Interest plus Cost of Oil per Year.



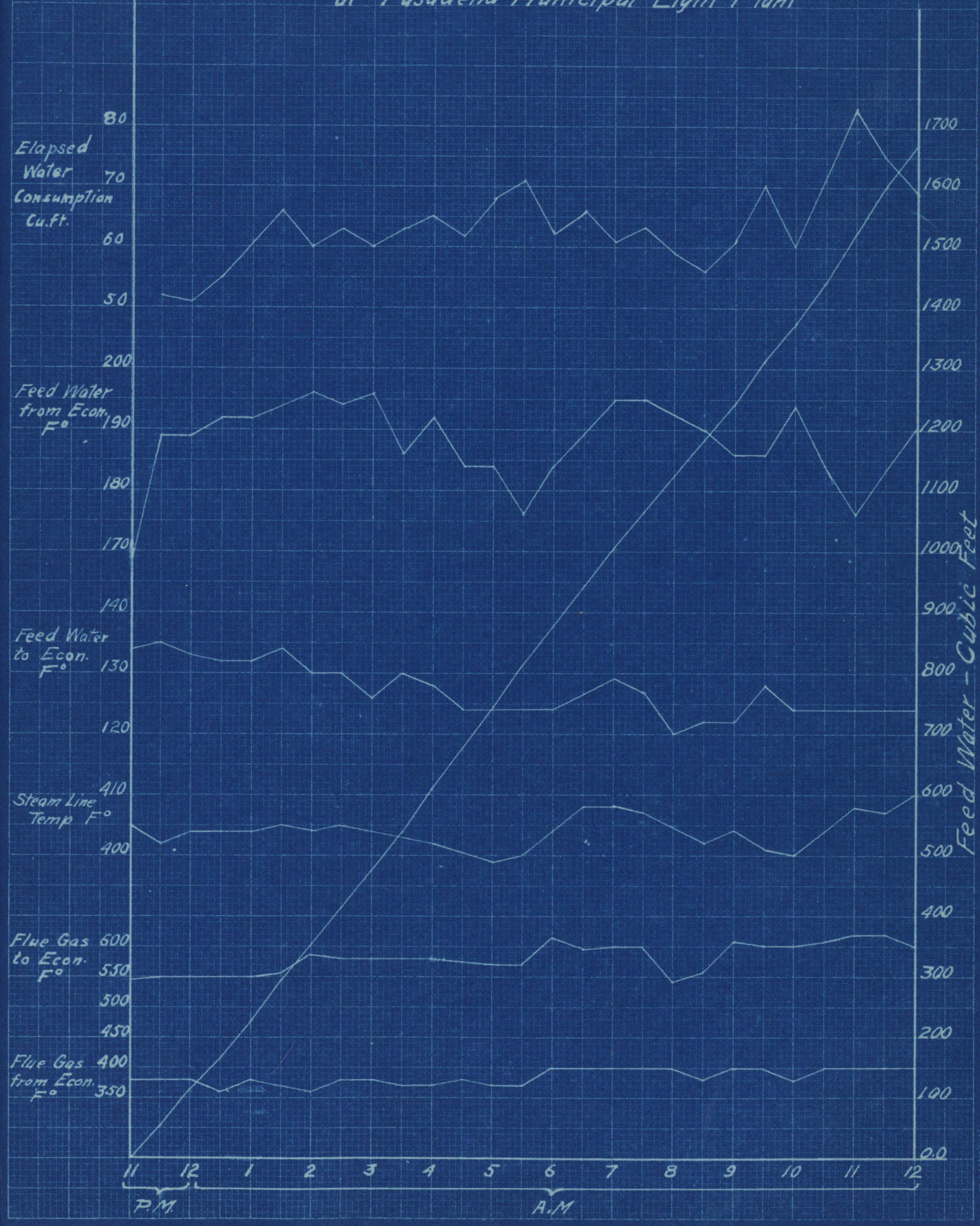
Test of Babcock and Wilcox Boiler - No 5836

Curve A - Over All Efficiency
Curve B - Boiler Efficiency
Curve C - Saving by Economizer



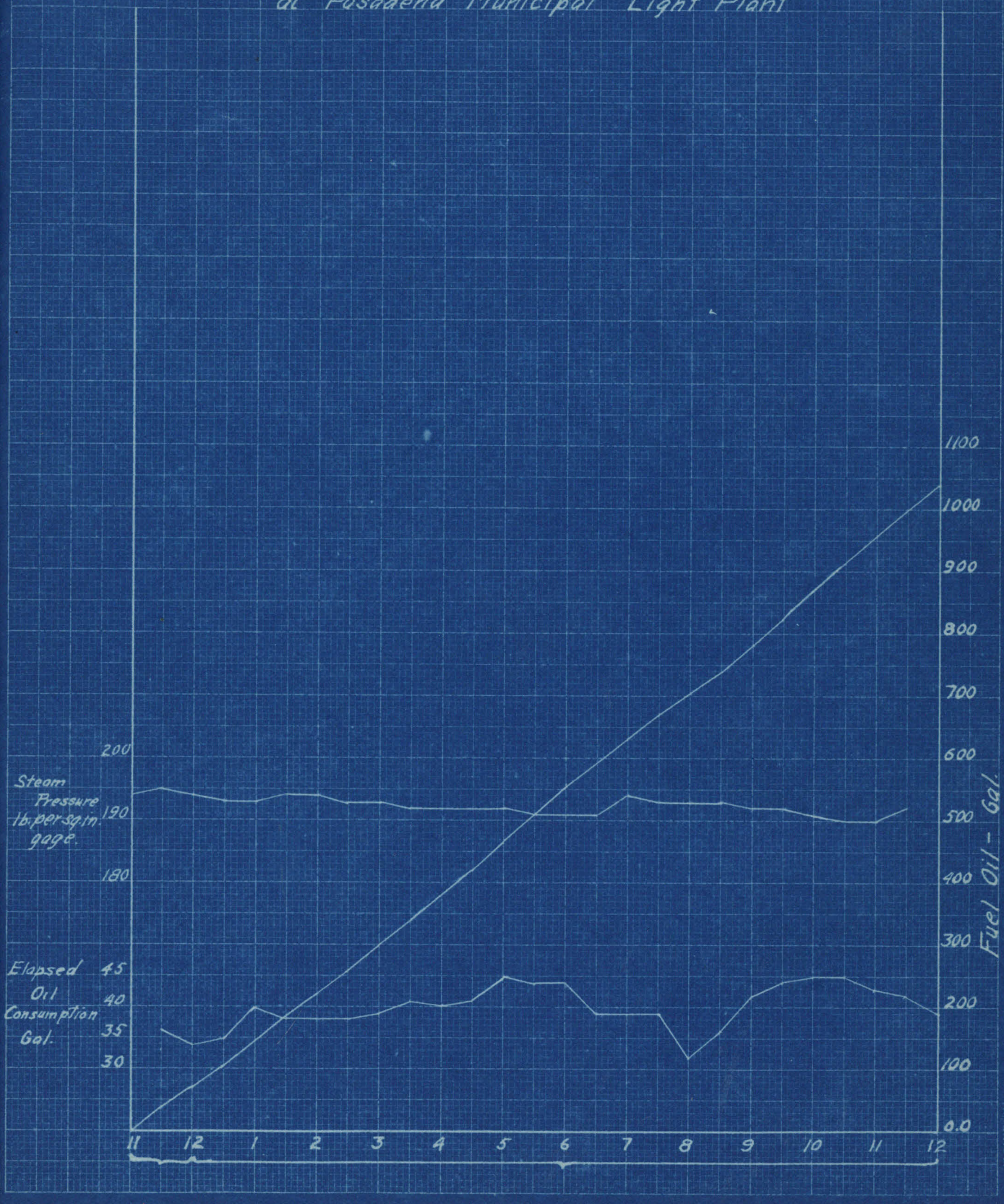
Log Sheet. Test No 4.
December 29, 1914.

Test of B & W Boiler No 5836 at Pasadena Municipal Light Plant



Log Sheet. Test № 4
December 29, 1914

Test of B & W Boiler № 5836 at Pasadena Municipal Light Plant



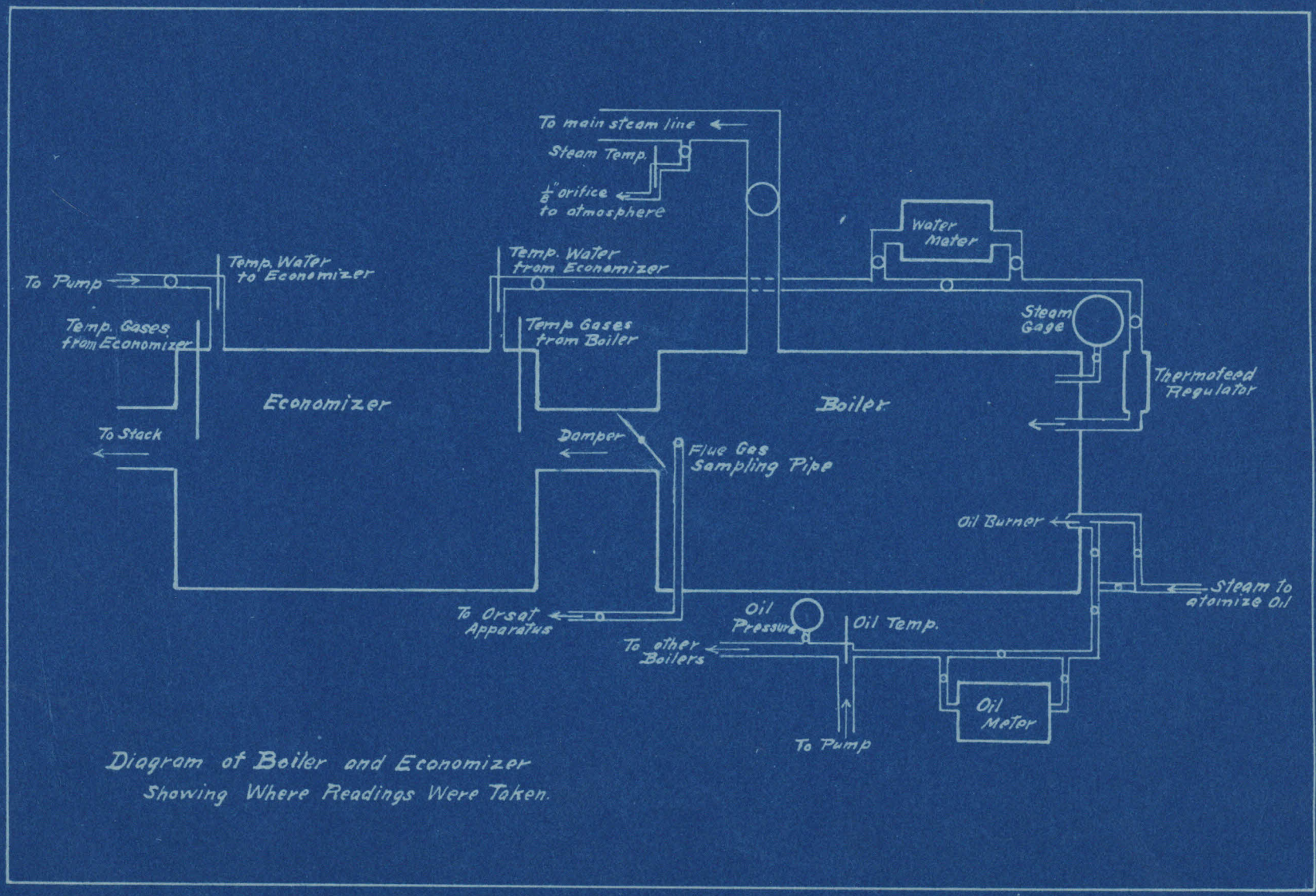
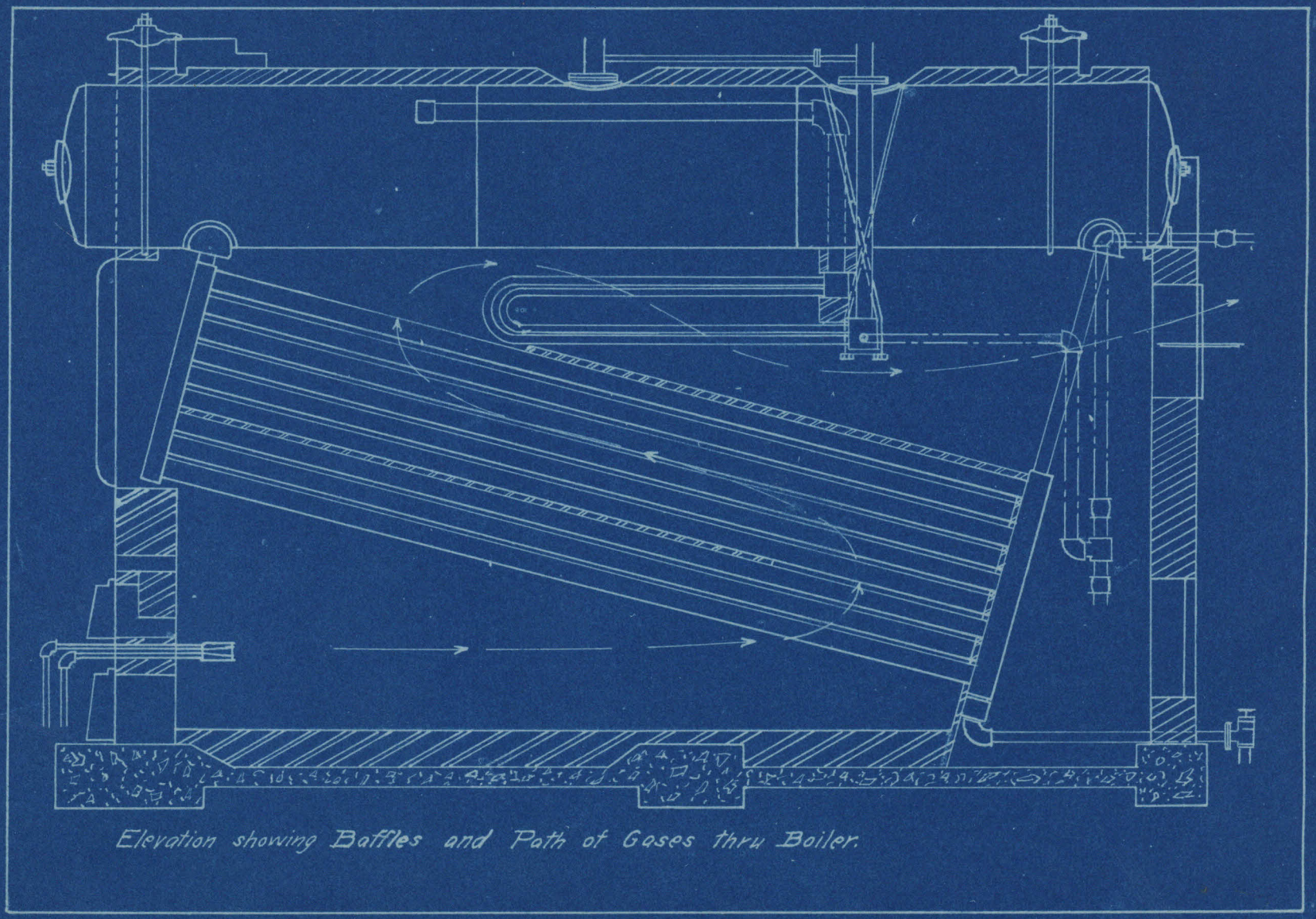


Diagram of Boiler and Economizer
Showing Where Readings Were Taken.



Elevation showing Baffles and Path of Gases thru Boiler.