THESIS.

SERVICE TEST OF THE STEAMSHIP HARVARD.

ECONOMY.

May 1909.

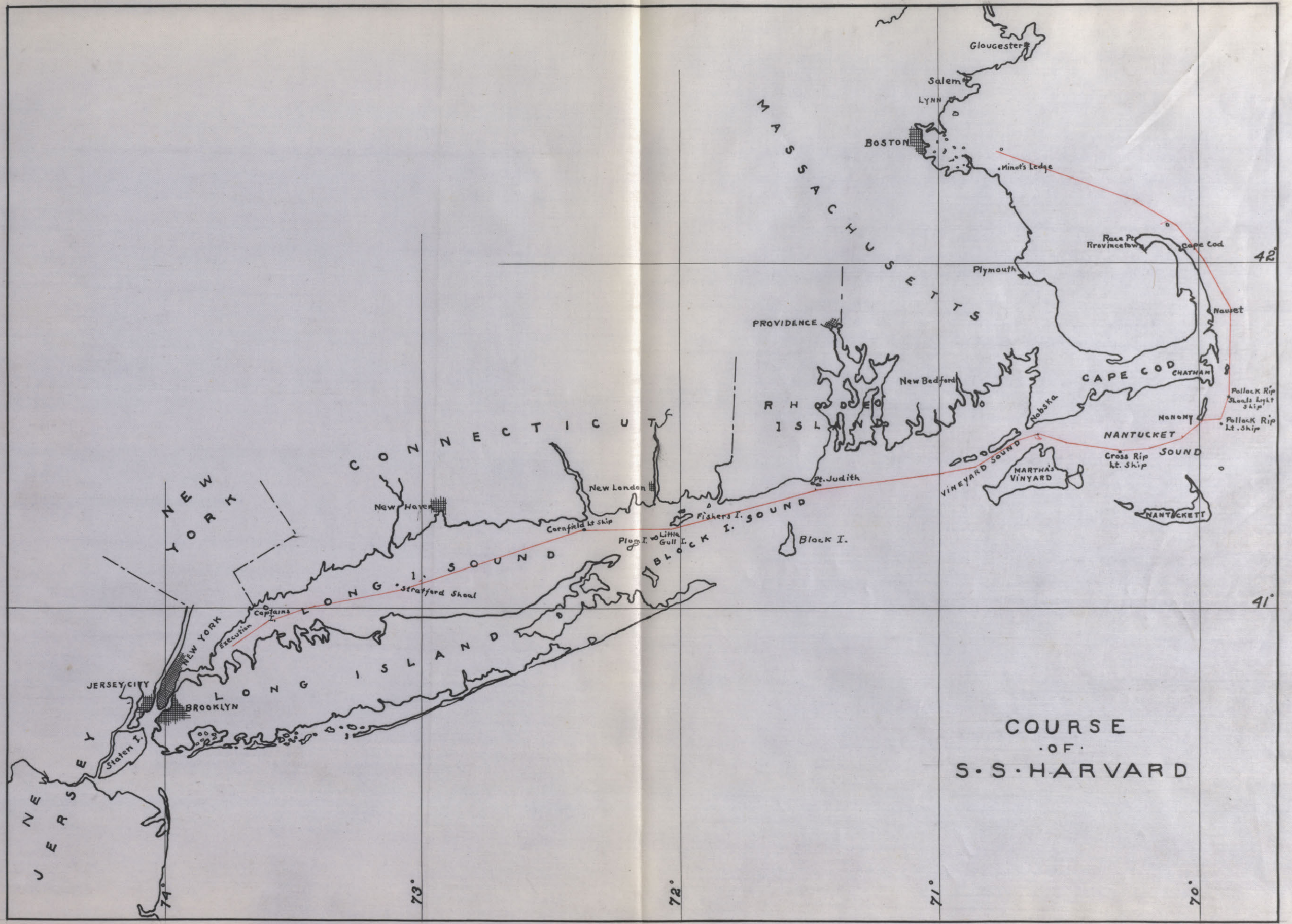
John F. Davis. Carleton W. Hubbard.

INDEX.

The"HARVARD".


18155-Harvard

Left New York	5.00 P. M.
Captains Island	7.05
Eatons Neck	7.34
Stratford Shoals	8.19
Cornfield Light Ship	10.02
Little Gull Rock	10.35
Block Island	11.39
Gay Head	1.22 A. M.
Nobska	2.00
Cross Rip Light Ship	2.54
Handkerchief Light Ship	3.29
Pollock Rip Light Ship	3.54
Pollock Rip Shoals Light Ship	4.09
Nauset Light	4.56
Cape Cod	5.34
Race Point	6.00
Minots Ledge	7.17
Arrive in Boston	8.00


Gloucester
Salem
LYNN
BOSTON
Minot's Ledge
MASSACHUSETTS
Race Pt.
Provincetown
Cape Cod
42°
Plymouth
Nauset
PROVIDENCE
New Bedford
RHODE ISLAND
Nobska
CAPE COD
CHATHAM
Pollock Rip
Shoals Light Ship
NANTUCKET
NANTUCKET SOUND
Pollock Rip Lt. Ship
Cross Rip lt. Ship
VINEYARD SOUND
MARTHA'S VINYARD
NANTUCKET
Pt. Judith
New London
Fishers I.
Cornfield lt Ship
Plum I.
Little Gull I.
BLOCK I. SOUND
Block I.
CONNECTICUT
NEW YORK
New Haven
LONG I. SOUND
Stratford Shoal
Captains I.
Execution
NEW YORK
LONG ISLAND
JERSEY CITY
BROOKLYN
Staten I.
NEW JERSEY
41°
74°
73°
72°
71°
70°
COURSE
·OF·
S·S·HARVARD

SERVICE TEST ON THE S. S. HARVARD.

On June 25 and 26 1908 a service test was made on the boilers and engines of the S. S. Harvard. This test was divided up into two parts--that on the engines, which was worked up by Howard C. Fisher and Philip E. Young--and the following, which is an account of the test on the boilers. This test was made under actual service conditions while the steamer was making daily trips between Boston and New York.

OBJECT OF TEST.

The object of the test was to find out what the engines and boilers were doing in actual service and not what they could be made to do under ideal conditions, such as often obtain on trial trips. The specific object of the boiler test was to find the steam and coal consumption in conjunction with the test on the turbine engines by Messrs Fisher and Young.

THE STEAMER HARVARD

The Harvard is owned by the Metropolitan Steamship Co. and was built in 1906-1907 by the Delaware River Iron Shipbuilding and Engine Works (Roach's Yard). Her engines and boilers were built by the W. & A. Fletcher Co. She is in service during the summer months

between Boston and New York, making the run of 300 Nautical miles daily in fifteen hours, her average speed being 20 knots. The general dimensions of the vessel are given below.

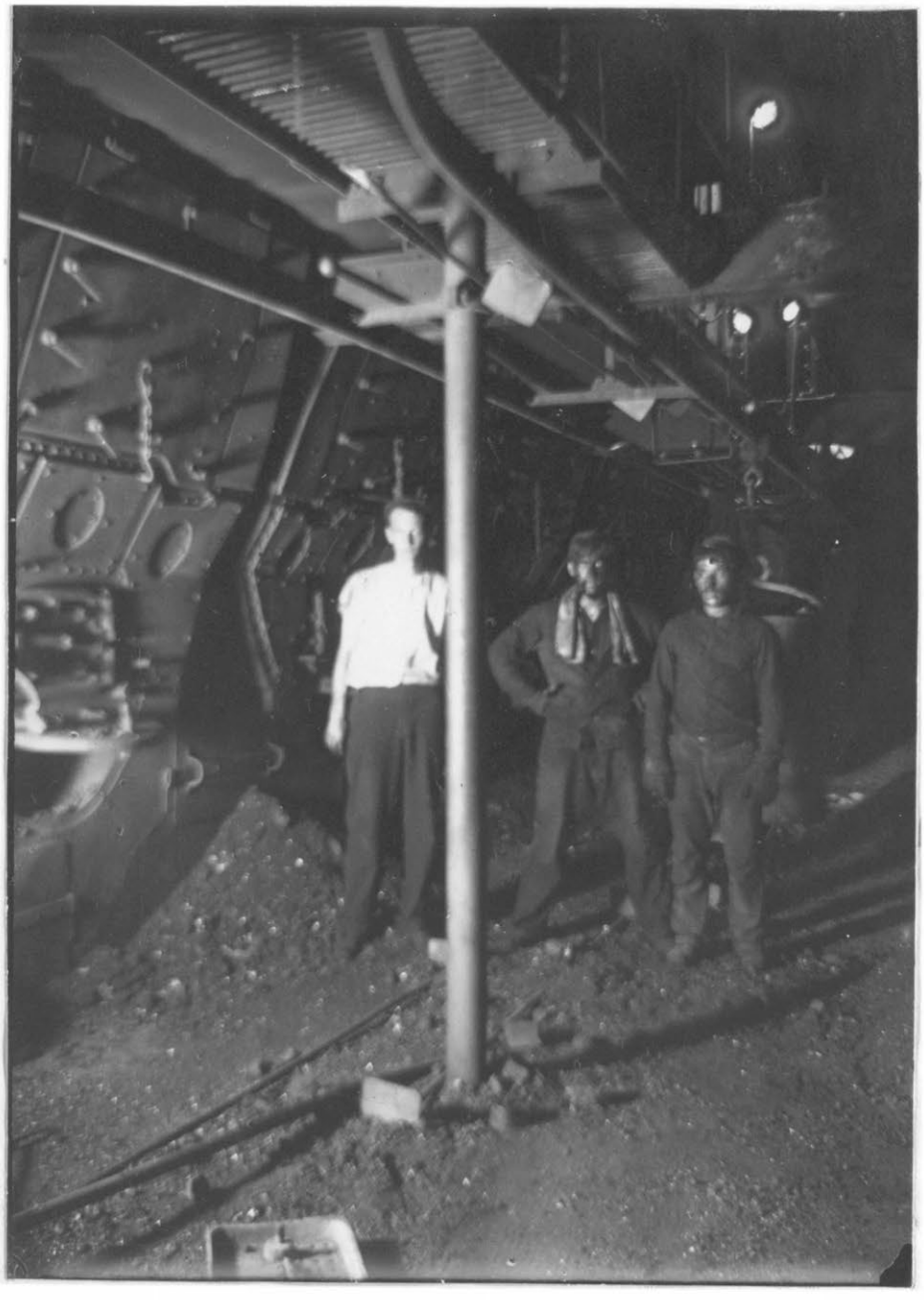
Length between perpendiculars . .	386 ft. 6 in.
Breadth of hull moulded	50 ft. 6 in.
Breadth over guards	63 ft.
Depth moulded	22 ft.
Draught normal	16 ft.
Draught at trial, (mean N. Y. to Boston)	16 ft. 2 in.

DESCRIPTION OF BOILERS.

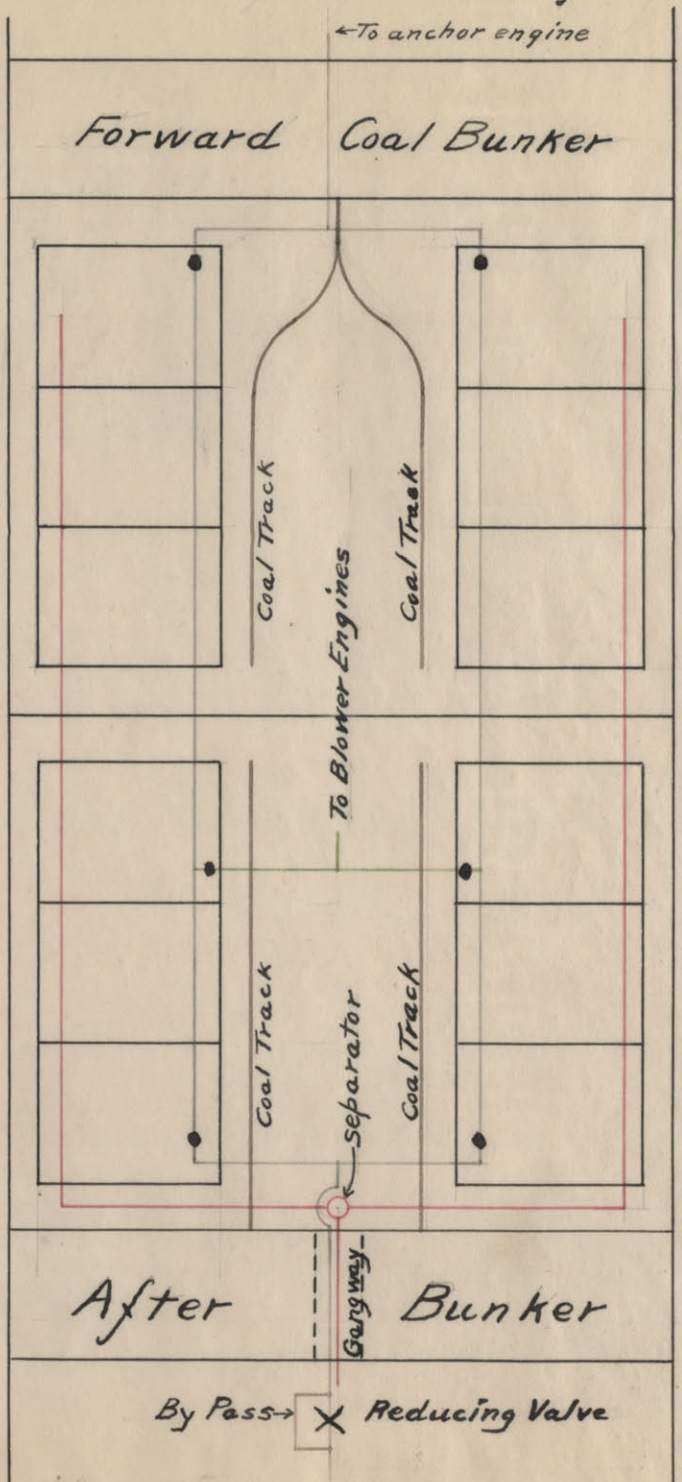
The Harvard is fitted with twelve single ended Scotch boilers placed athwart ship, having a fire room running along the center line of the vessel on each side of which are six boilers. This fire room is divided into two parts by a transverse bulkhead, there being six boilers on each side of the bulkhead. Each boiler has three furnaces. The Howden system of forced draft is installed, air being supplied under a pressure of 1.75" of water by blowers.

Total grate area	756 sq. ft.
Total heating surface	29520 sq. ft.
Ratio heating surface to grate area	39.0

Fire Room.



Diagrammatic Plan of Fire Room of S.S. Harvard



Main Steam Piping - Red
Auxiliary Steam Piping - Green
Valve - ●

DESCRIPTION OF FIRE ROOM AND APPARATUS INSTALLED.

At the forward end of the fire room there is a coal bunker placed athwart ship from which coal is supplied to the six boilers forward of the bulkhead. At the after end of the fire room there is another bunker, also placed athwart ship, there being through this a narrow passageway connecting the fire room with the engine room. The six boilers abaft of the bulkhead are supplied from this bunker, which has a door on both starboard and port sides. Overhead trolley tracks, which carry coal buckets, lead from these doors along in front of the boilers on the same side of the boat. In the forward compartment there are two tracks similarly arranged in front of the boilers, but these converge to a single door in the forward bunker. The capacity of the buckets was about 500 lbs. of the kind of coal used.

The water consumption was measured by a Hersey hot water meter loaned for this purpose by the Hersey Manufacturing Co. of South Boston. The meter was installed in the suction line between the hot well and the feed pump.

The steam supplied to the auxiliaries was measured by means of orifices. These were made from plates about three sixteenths of an inch thick, and had circular openings the edges of which were rounded on both sides of the plate.

All auxiliaries except the forced draft blowers were supplied from the starboard auxiliary steam pipe.

METHOD OF TESTING.

The test was begun at 7.10 P.M. on June 25, 1908 on the run from New York to Boston. Neither the standard nor alternate methods of starting a boiler test as recommended by the A.S.M.E. could be used. The standard method involves the drawing of all the fires at the start and the alternate method requires the cleaning of all the fires at the start and neither of these things could be done without causing great inconvenience in the cramped fire room and unnecessarily delaying the boat.

When the test was started the steamer was off Captains Island light in Long Island Sound and was well up to speed, being in open water and having been under way for two hours. In starting and stopping this test we estimated the amount of coal on the fire room floor. Although a thorough inspection of the fires in all the 36 furnaces could not be made, a considerable number of them were looked at, and in the judgment of the engineer on watch and those in charge of the test, they were in service condition. To make the speed required by the schedules on which these boats run it seems practically certain to us that the condition of the fires at the start was the actual service condition, and although individual fur-

naces may not have been in the same condition at the end as they were at the beginning of the test, we believe that taking an average of the 36 furnaces, the condition of the fires at start and finish was practically the same, for the end of the test came at 7.00 A.M. June 26 when the steamer was off Minots Ledge Light, an hours run from the dock. That other conditions were constant during the test is shown by the steadiness of the boiler pressure as plotted, and by the fact that the total coal and total feed water curves are nearly straight lines.

The A.S.M.E. specifications for boiler trials require that the coal shall be weighed in buckets and then fired directly from these. Owing to the cramped space in the fire room and the rapidity with which the coal had to be passed out, it appeared impossible to weigh coal during the test and no attempt was made to do so. As one bucket supplied nine furnaces it was manifestly impossible to fire the coal directly from the bucket, so the coal was dumped on the floor in front of the furnaces and fired from there.

The coal used was determined by counting the number of buckets taken from the bunkers, a man being stationed in each compartment of the fire room whose sole duty it was tocount them. Care was taken to have the buckets filled flush with the top. After the test we weighed

four buckets full and empty thereby getting our average value for the coal contained in one bucket. This weight agreed to a pound with the average obtained from some weighings made by the Steamship Company. It is interesting to note that, crude as this method appears, it gave us a value for the coal used which agrees within 1%, with the figure obtained by the chief engineer of the company as the average coal consumption per trip based on the runs of a whole season.

The feed water was measured by a 6" Hersey Hot Water Meter. This meter was calibrated by its makers and was found to under run 1/2 of 1%. Tests on a 4" Hersey meter made at the Institute showed with cold water an under run of 1/2 of 1% but with hot water an under run of 1%. From this it would seem that the 6" meter would probably under run from 1/2 of 1% to 1% and it is certainly reasonable to assume that it was accurate within 2% which is well within the error of the test. It should be noted that this meter was so placed that the water from the hot well flowed to it by gravity. The A.S.M.E. regulations require that feed water for boilers undergoing test shall be weighed in tanks. When it is considered that about 3000 lbs of water went to the boilers every minute, and the cramped space on ship board is taken into account, it is evident that measuring the water by a meter was the best we could

do. With a boiler placed athwart ship a very slight motion of the vessel makes the water glass indication valueless and so no attempt was made to ascertain the level in the boilers in this way. The engineers on the steamer have found that by admitting a certain amount of water on each trip the level in the boilers is practically the same at the end of a run as at the beginning. During the test the 3/4" pipe which admits this fresh water was opened for about fifteen minutes. This water was admitted to the hot well and so passed through the meter, which measured all the condensation, the leakage only being lost. It seems to us that the necessity for keeping up speed and the fact that the steamer had been under way for two hours when the test started, and still had an hours steaming to do when the test stopped, would make it very probable that the height of water in the boilers was governed by service conditions. A strong check on this is the total feed water curve which is a straight line.

As has been stated, the steam for all the auxiliaries except the blowers came from the starboard auxiliary steam pipe. The port line was entirely closed and the by-pass around the reducing valve in the starboard line was opened wide, so that all the reduction in the pressure of the steam supplied to the auxiliaries was due

to the throttling action of the 1-13/16" orifice which was placed in the line. The steam for the blowers came from the port line and was measured by means of a 7/8" orifice.

The quality of the steam was determined by a Peabody calorimeter which was inserted in the main steam pipe at the point where the main steam gauge was tapped in. Calorimeter readings were taken three times during the test and the results obtained were practically in agreement.

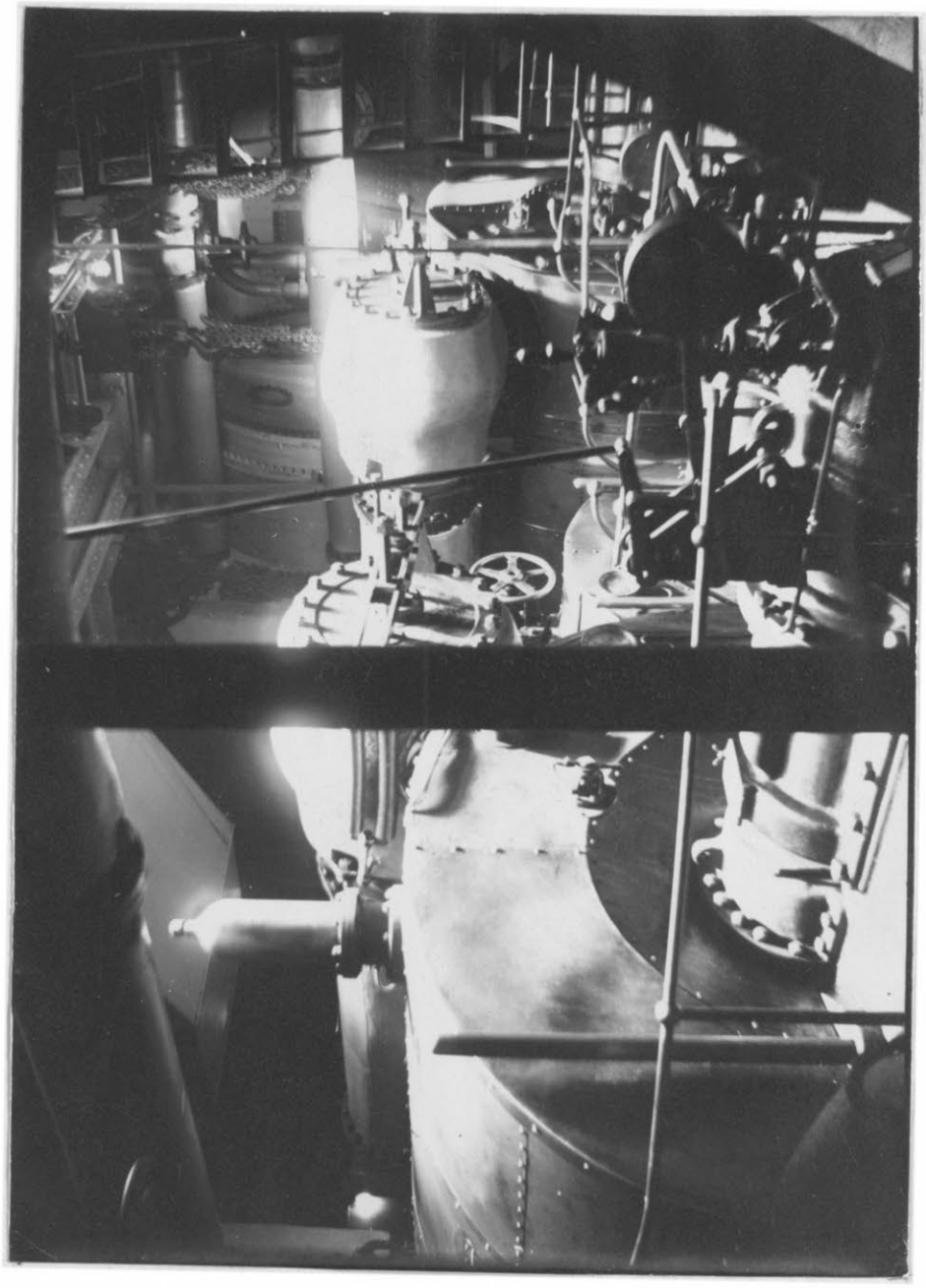
The A.S.M.E. boiler trial specifications call for samples of flue gas for analysis. Such an analysis is very valuable when good fair samples of flue gas can be obtained and gives an excellent indication of what the boiler plant is doing. But in the case of a steamer the uptakes are usually leaky and as a result a flue gas sample is of little value when obtained. This being so, no attempt was made to obtain flue gas samples during this test.

The boiler pressure, water meter, back pressures on the orifices in both the auxiliary and blower lines, number of buckets of coal, the draft and the temperature of the feed water were all observed at ten minute intervals up to 2 A.M. and at fifteen minute intervals thereafter. The boiler pressure was read on the engine room gauge

and this, (and all other engine room gauges used) was specially calibrated by the Crosby Steam Gauge and Valve Co. The internal pressure on the orifices was that of the boiler, since care was taken to have all the reduction in pressure in these lines due to the throttling action of the orifices. The back pressure on the orifice in the auxiliary line was read on an engine room gauge, while that on the orifice in the blower line was read from a gauge loaned by the Institute and calibrated by the authors in the Engineering Laboratories. This gauge failed at 11 P.M. and thereafter the steam supplied to the blowers was calculated from the data already obtained and modified to follow the curve of the plotted draft data. The number of buckets of coal passed out was kept by ten minute intervals and every hour the amount on the fire room floor was estimated. In this way a very fair curve was plotted showing the rate of coal consumption.

Samples of coal were taken at regular intervals during the test. The average of a number of tests on the calorific value of this fuel made in the Laboratory of Heat Measurements at the Institute was 14,510 B.T.U. per lb.

Engine Room.



METHOD OF CALCULATING RESULTS.

As soon as the data obtained in this test was plotted it was evident that the conditions were not constant throughout the twelve hours. As far as the boilers were concerned the conditions were most constant from 9 P. M. to 4 A. M., and therefore only these hours were taken into account in determining the performance of the boilers. Messrs Fisher and Young found that the engines were working steadily from 9 P. M. to 3 A. M. and they accordingly used these hours in working up the engine test. The value of the average shaft horse power that is quoted is the result of their work.

Whenever it was necessary to work out the feed water and coal rates it was done as shown below. It should be explained here that the red line on the coal curve is drawn through the points of estimated coal on the fire room floor and so indicates the coal rate.

METHOD OF DETERMINING THE COAL AND WATER RATES.

Total buckets at 4 A.M. (from curve)	277
Total buckets at 9 P.M. (from curve)	54
Buckets consumed in 7 hours	223
Weight of coal per bucket	506 lbs
Total coal consumed from 9 P.M. to 4 A.M. . .	112,800 lbs
Rate per hour	16,100 lbs.
. . . . .	
Cubic feet of water fed at 4 A.M. (from curve)	24,700
" " " " " " 9 P.M. " "	5,100
" " " " " in 7 hours	19,600
Add 1%	200
Total cubic feet in 7 hours	19,800
Average Temperature of Hot Well; (9 P.M. to 4 A.M.)	111.9 ° F
Weight of one cubic foot of water at 112°F	61,86 lbs
Pounds of water fed in 7 hours	1,225,000
Rate per hour	175,000 lbs

STEAM FOR AUXILIARIES.

In calculating the steam used by the auxiliaries the following formula by Grashoff was used.

$$W = 0.0165\ A\ P^{0.97}$$

Where W = weight in lbs. per second

A = area of the orifice in square inches

P = internal pressure in lbs. (absolute)

The weight as determined by this formula has to be multiplied by a quantity (called the " ratio of actual to computed discharge") which depends on the ratio of back pressure to internal pressure, when this is greater than 0.6, and upon the shape of the orifice. From previous experiment it was determined that for an orifice of the kimd used the factor by which W in the above formula must be multiplied is within 10% of the mean between the factors given by Grashoff for converging orifices and orifices in thin plates.

The most inaccurate term in the equation by which the steam was computed is undoubtedly the " ratio of actual to computed discharge". The error in this term is probably not greater than 10% which makes the errors in the other terms negligible. Since the auxiliary steam is only 12.5% of the total steam an error of 15% here would affect the engine steam by less than 2%.

A sample calculation is given here in order that there may be no misunderstanding as to how the " ratio of actual to computed discharge" was obtained.

Steam for blowers.

Size of orifice 7/8" dia. Area = 0.601 sq. in.

Boiler pressure 135# gage 150 lbs. abs.

Back pressure on orifice 94 lbs. gage-109 lbs. abs.

Ratio of back pressure to internal pressure 0.73

From the table on page 433 of the " Thermodynamics of the Steam Engine" by Professor C. H. Peabody

Ratio	Ratio of actual to computed discharge		
Back Pressure / Internal Pres.	Converging orifice	Thin Plate	Mean
0.75	0.89	0.64	0.77
0.70	0.94	0.69	0.82

Ratio of actual to computed discharge when ratio of back pressure to internal pressure is 0.73 is 0.79

$$150^{0.97} = 148$$

W (lbs. per min.) = 0.0165 x 0.601 x 148 x 0.79 x 60

= 70 lbs.

D A T A

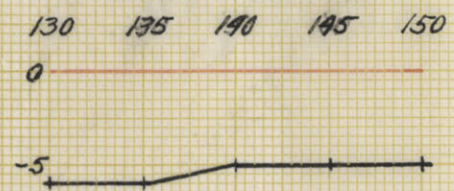
Duration of test 7 P. M. to 7 A. M.	12 hours
Barometer 29.97"	14.7 lbs
Boiler Pressure (average 9 P.M. to 4 A.M.)	140.2 lbs gage
Temperature of Feed Water (average 9-4)	202.7°F
Temperature of Hot Well " "	111.9°F
Feed Water per Hour	175,000 lbs.
Quality of Steam	96.0%
Draught (average 9 - 4)	1.76" of water
Total heating surface	29,520 sq. ft.
Total Grate Surface	756 sq. ft.
Ratio Heating Surface to Grate Surface	39.0
Vacuum (av. Sand P.- 9 P.M. to 4 A.M.)	27.44 in.
Coal fired per Hour	16,100 lbs.
Horse Power of Turbines, (av. 9 P.M. - 3.00 A. M.)	10,400 H.P.
Total Auxiliary Steam per Hour (9-3.00)	22,000 lbs.
Total Engine Steam per Hour (9-3.00)	153,000 lbs.

RESULTS

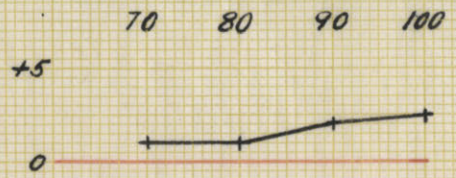
Heat of Combustion of Coal	14,510 B.T.U.
Total Equivalent Evaporation from and at 212°F.	179,000 lbs.
Equivalent Evaporation per lb. of Coal	11.1 lbs
Equivalent Evaporation per sq. ft. of Heating Surface	6.06 lbs
Coal burned per sq. ft. of Grate	21.3 lbs
Boiler Horse Power (A.S.M.E. rating)	5,190
Heat absorbed by Water in Boiler per lb. of Coal	10,700 B.T.U.
Thermal Efficiency of Boilers	73.8%
Total Steam per Shaft H. P.	16.8 lbs
Steam through Turbines per Shaft H. P.	14.7 lbs
B. T. U. per Shaft H. P.	265
Coal per Shaft H. P.	1.61 lbs

Gauge Corrections.

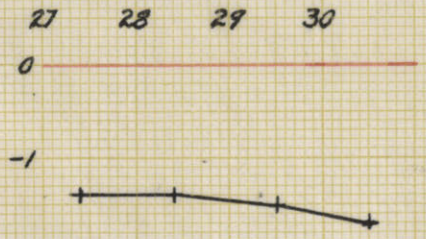
Boiler Gauge



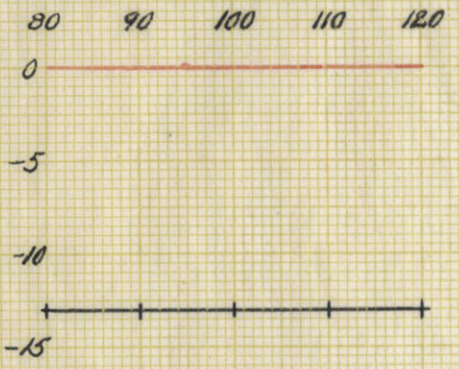
Blower Orifice Gauge



Starboard Vacuum Gauge

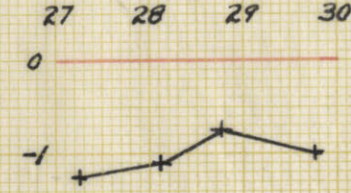


Auxiliary Orifice Gauge



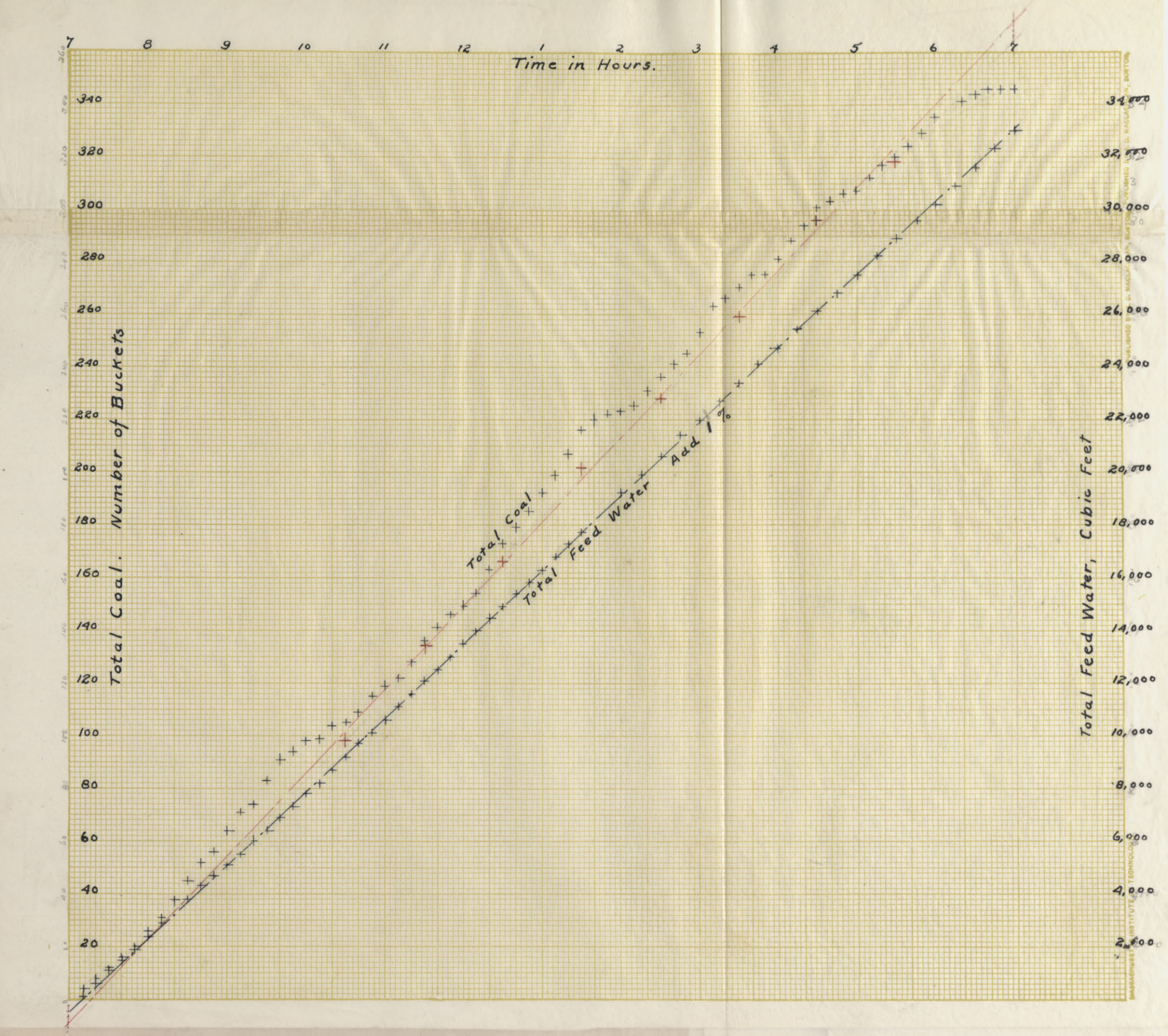
Calorimeter Gauge

Port Vacuum Gauge



Curve of Total Coal.

Curve of Total Feed Water. (uncorrected)

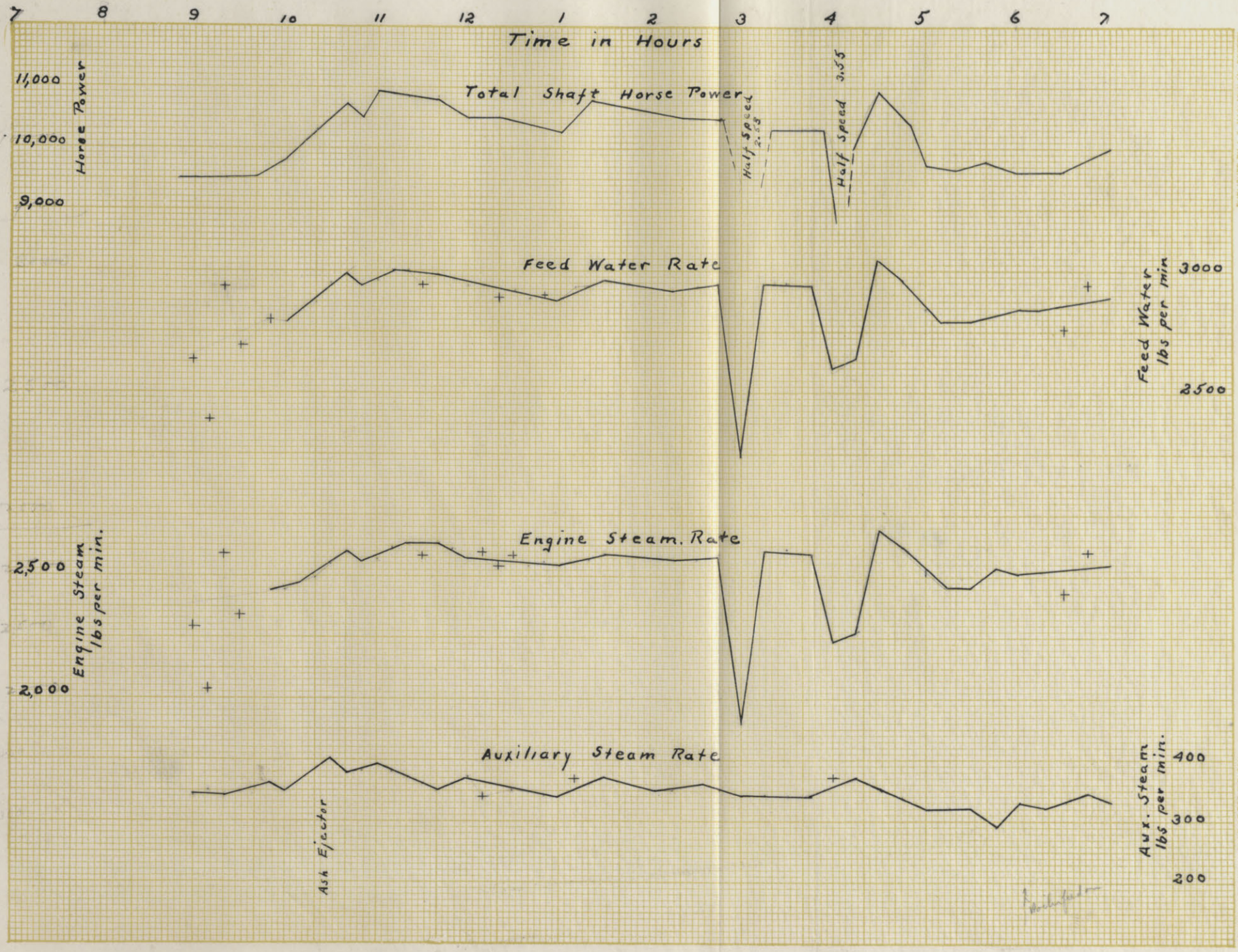

Time in Hours.
7
8
9
10
11
12
1
2
3
4
5
6
7
Total Coal. Number of Buckets
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
Total Feed Water, Cubic Feet
34,000
32,000
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
Total Coal
Total Feed Water
Add 1%

Curve of Total Shaft Horse Power.

Curve of Feed Water Rate.

Curve of Steam for Turbines.

Curve of Total Auxiliary Steam.


7
8
9
10
11
12
1
2
3
4
5
6
7
Time in Hours
Total Shaft Horse Power
Horse Power
11,000
10,000
9,000
Half Speed 2.53
Half Speed 3.55
Feed Water Rate
Feed Water lbs per min
3000
2500
Engine Steam. Rate
Engine Steam lbs per min.
2,500
2,000
Auxiliary Steam Rate
Aux. Steam lbs per min.
400
300
200
Ash Ejector

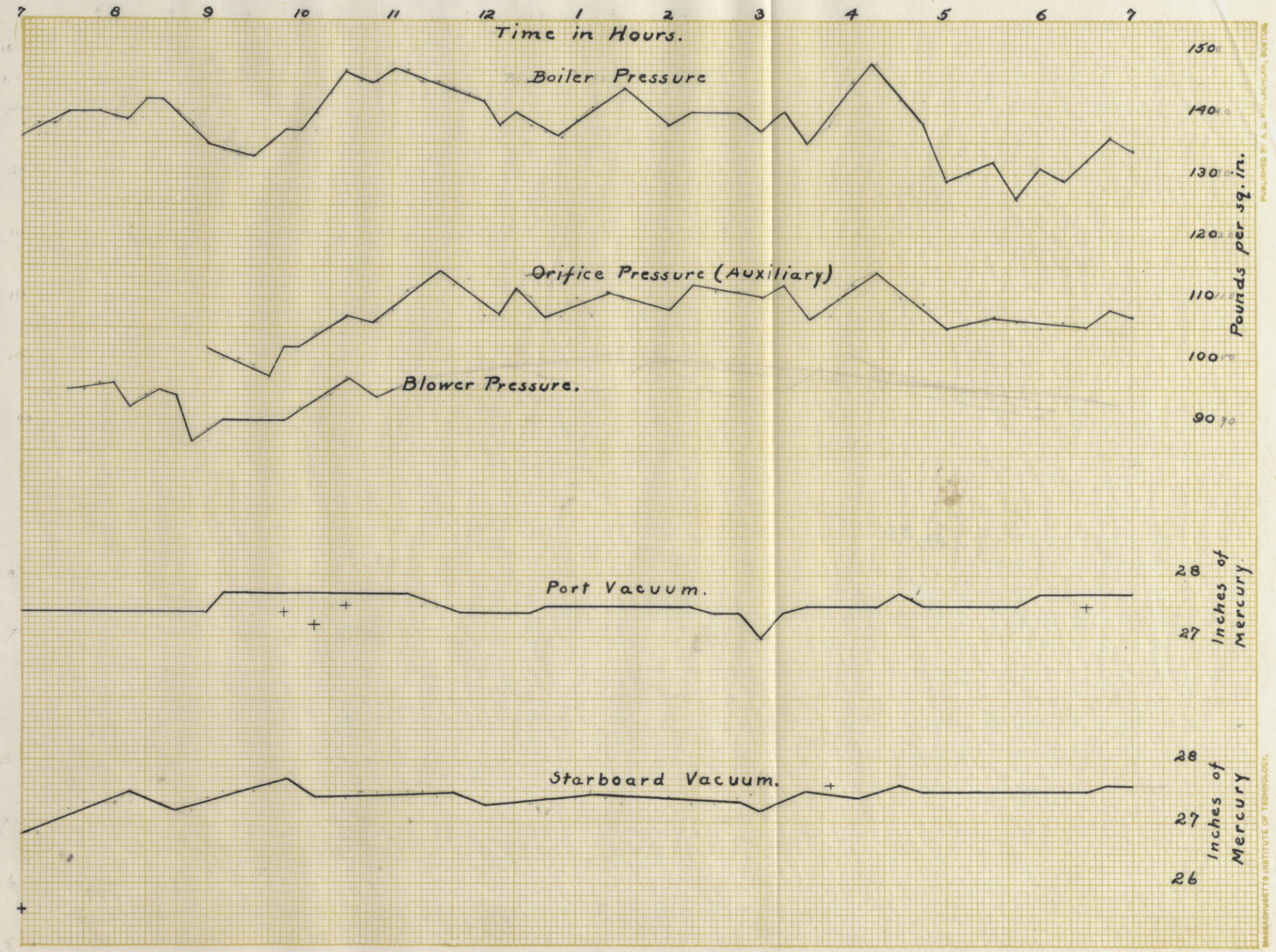
Curve of Boiler Pressure.

Curve of Back Pressure on Auxiliary Orifice.

Curve of Back Pressure on Blower Orifice.

Curve of Vacuum in Starboard Condenser.

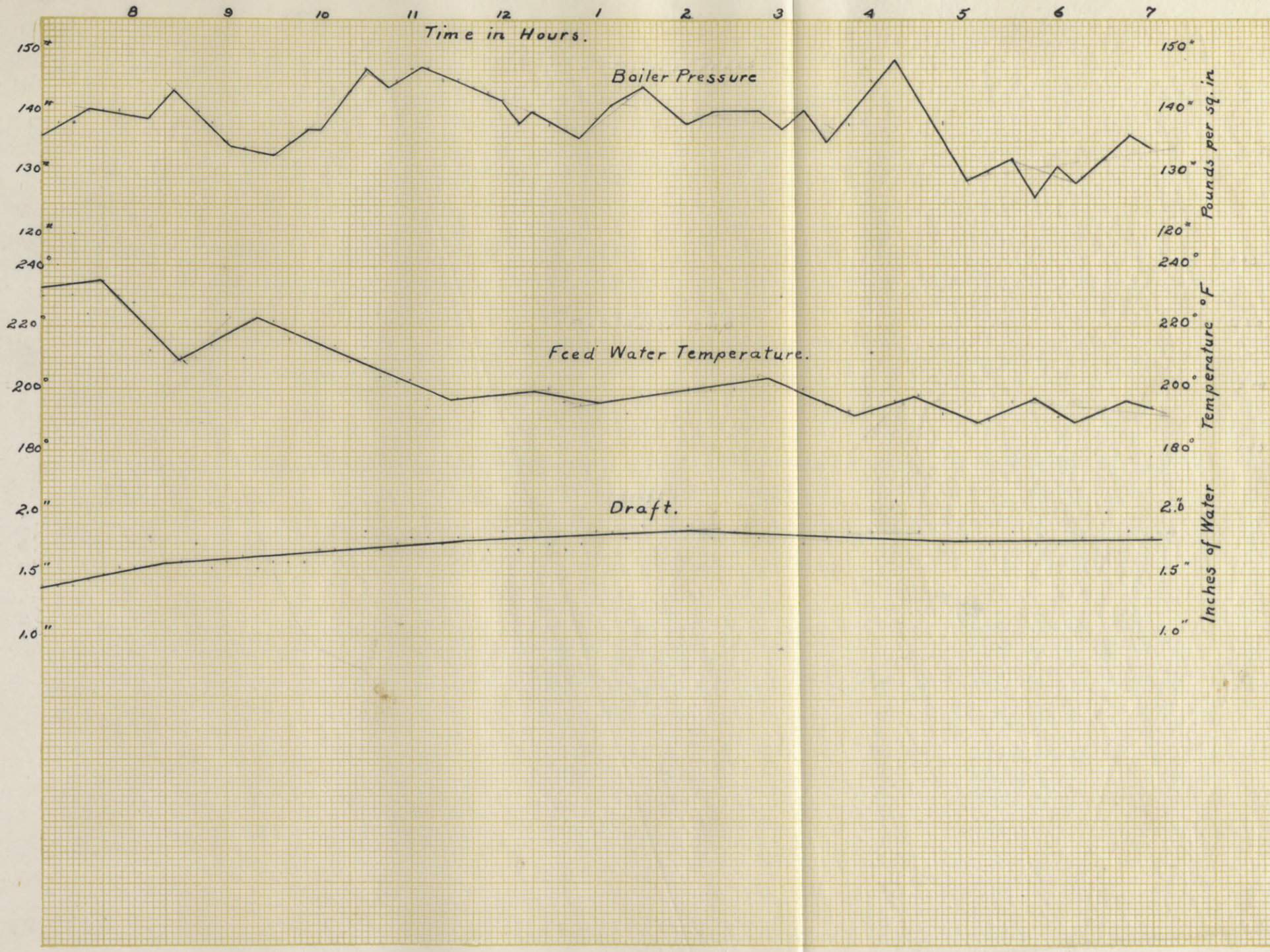
Curve of Vacuum in Port Condenser.


7
8
9
10
11
12
1
2
3
4
5
6
7
Time in Hours.
Boiler Pressure
Orifice Pressure (Auxiliary)
Blower Pressure.
150
140
130
120
110
100
90
Pounds per sq. in.
Port Vacuum.
28
27
Inches of Mercury
Starboard Vacuum.
28
27
26
Inches of Mercury

Curve of Boiler Pressure.

Curve of Feed Water Temperature.

Curve of Draft.


8
9
10
11
12
1
2
3
4
5
6
7
Time in Hours.
Boiler Pressure
Feed Water Temperature.
Draft.
150#
140#
130#
120#
240°
220°
200°
180°
2.0"
1.5"
1.0"
Pounds per sq. in
Temperature °F
Inches of Water
PUBLISHED BY A. G. MACLACHLAN, BOSTON
MASSACHUSETTS INSTITUTE OF TECHNOLOGY.

Tables of Readings.

Boiler Pressure

Time	Reading	Corrected	Time	Reading	Corrected
7.00	141	136	10.20	148	143
7.10	143	138	10.30	152	147
7.20	143	138	10.40	150	145
7.30	145	140	10.50	150	145
7.40	145	140	11.00	152	147
7.50	145	140	11.10	152	147
8.00	144	139	11.20	150	145
8.10	144	139	11.30	150	145
8.20	147	142	11.40	149	144
8.30	147	142	11.50	148	143
8.40	145	140	12.00	147	142
8.50	143	138	12.10	143	138
9.00	140	135	12.20	145	140
9.10	139	134	12.30	143	138
9.20	138	133	12.40	142	137
9.30	138	133	12.50	141	136
9.40	140	135	1.00	144	139
9.50	142	137	1.10	146	141
10.00	142	137	1.20	147	142
10.10	145	140	1.30	149	144

Boiler Pressure (con)

Time	Reading	Corrected
1.45	——	——
2.00	143	138
2.15	145	140
2.30	145	140
2.45	145	140
3.00	142	137
3.15	145	140
3.30	140	135
3.45	143	138
4.00	150	145
4.15	153	148
4.30	147	142
4.45	143	138
5.00	135	129
5.15	136	130
5.30	138	132
5.45	132	126
6.00	137	131
6.15	135	129
6.30	138	132
6.45	141	136
7.00	139	134

Coal.

Time	Total Buckets	Time	Total Buckets	Time	Total Buckets
7.00	0	10.20	104	1.40	220
7.10	1	10.30	105	1.50	222
7.20	6	10.40	109	2.00	223
7.30	11	10.50	115	2.10	225
7.40	17	11.00	119	2.20	231
7.50	19	11.10	122	2.30	236
8.00	26	11.20	128	2.40	241
8.10	31	11.30	136	2.50	245
8.20	38	11.40	141	3.00	253
8.30	45	11.50	146	3.10	263
8.40	52	12.00	149	3.20	266
8.50	56	12.10	154	3.30	270
9.00	64	12.20	163	3.40	275
9.10	71	12.30	173	3.50	275
9.20	74	12.40	179	4.00	281
9.30	83	12.50	185	4.10	288
9.40	91	1.00	192	4.20	294
9.50	94	1.10	199	4.30	301
10.00	98	1.20	207	4.40	303
10.10	99	1.30	216	4.50	306

Coal (Con.)

Time	Total Buckets	Time	Total Buckets	Time	Total Buckets
5.00	307	5.50	329	6.40	346
5.10	312	6.00	335	6.50	346
5.20	317	6.10	341	7.00	346
5.30	320	6.20	341		
5.40	324	6.30	344		

Estimated Coal on Floor.

Time	No. of Buckets
7.00	36
10.30	43
11.30	37
12.30	42
1.30	50
2.30	44
3.30	47
4.30	41
5.30	37
7.00	36

Weights of Buckets

	Full	Empty
	660	159
	670	159
	670	159
	660	159
Total	2660	636
Av.	665	159

Weight of Coal per Bucket 506 lbs.

Water Meter Readings cu. ft.
Uncorrected

Time	Reading	Total	Time	Reading	Total
7.00	4870	—	10.30	14054	9184
7.10	5291	421	10.40	14536	9666
7.20	5690	820	10.50	15012	10142
7.30	6055	1185	11.00	15490	10620
7.40	6440	1570	11.10	15975	11105
7.50	6900	2030	11.20	16460	11590
8.00	7290	2420	11.30	16935	12065
8.10	7810	2940	11.40	17418	12548
8.20	—	—	11.50	17899	13029
8.30	8675	3805	12.00	18375	13505
8.40	9125	4255	12.10	18851	13981
8.50	9590	4720	12.20	19318	14448
9:00	10015	5145	12.30	19789	14919
9.10	10400	5530	12.40	20255	15385
9.20	10875	6005	12.50	20723	15853
9.30	11310	6440	1.00	21188	16318
9.40	11753	6883	1.10	21661	16791
9.50	12205	7335	1.20	22135	17265
10.00	12657	7787	1.30	22614	17744
10.10	13114	8244	1.45	—	—
10.20	13577	8707	2.00	24060	19190

Water Meter Readings (con.)

Time	Reading	Total
2.15	24767	19897
2.30	25478	20608
2.45	26290	21420
3.00	26831	21961
3.15	27544	22674
3.30	28260	23390
3.45	28970	24100
4.00	29599	24729
4.15	30240	25370
4.30	30978	26108
4.45	31701	26831
5.00	32388	27518
5.15	33064	28194
5.30	33740	28870
5.45	34422	29552
6.00	35105	30235
6.15	35793	30923
6.30	36461	31591
6.45	37173	32303
7.00	37870	33000

Hot Well Temperature F°

Time	Temp	Time	Temp
7.00	106	10.20	111
7.10	109	10.30	111
7.20	108	10.40	109
7.30	109	10.50	108
7.40	113	11.00	108
7.50	113	11.10	109
8.00	115	11.20	111
8.10	111	11.30	109
8.20	—	11.40	115
8.30	120	11.50	117
8.40	120	12.00	117
8.50	118	12.10	113
9.00	118	12.20	113
9.10	115	12.30	115
9.20	124	12.40	111
9.30	115	12.50	108
9.40	111	1.00	107
9.50	111	1.10	109
10.00	117	1.20	109
10.10	109	1.30	115

Hot Well Temp. (con)

Time	Temp.	Time	Temp.
1.45	—	4.30	109
2.00	115	4.45	108
2.15	113	5.00	106
2.30	118	5.15	103
2.45	117	5.30	108
3.00	106	5.45	108
3.15	109	6.00	106
3.30	109	6.15	108
3.45	108	6.30	107
4.00	99	6.45	106
4.15	104	7.00	104

Feed Water Temperature F°

Time	Temp.	Time	Temp.	Time	Temp.
7.00	230	10.30	210	2.15	200
7.10	240	10.40	204	2.30	200
7.20	230	10.50	202	2.45	204
7.30	224	11.00	203	3.00	230
7.40	235	11.10	194	3.15	200
7.50	230	11.20	198	3.30	195
8.00	228	11.30	197	3.45	193
8.10	212	11.40	196	4.00	212
8.20	—	11.50	198	4.15	196
8.30	210	12.00	198	4.30	198
8.40	210	12.10	199	4.45	192
8.50	214	12.20	199	5.00	191
9.00	224	12.30	200	5.15	190
9.10	210	12.40	196	5.30	196
9.20	223	12.50	195	5.45	197
9.30	222	12.	196	6.00	191
9.40	216	1.10	196	6.15	190
9.50	218	1.20	192	6.30	194
10.00	214	1.30	198	6.45	196
10.10	214	1.45	—	7.00	194
10.20	209	2.00	200		

Back Pressure on Auxiliary Orifice lbs. per sq. in.

Time	Reading	Corrected	Time	Reading	Corrected
7.00	—	—	10.20	118	105
7.10	—	—	10.30	120	107
7.20	—	—	10.40	119	106
7.30	—	—	10.50	119	106
7.40	—	—	11.00	121	108
7.50	—	—	11.10	124	111
8.00	—	—	11.20	125	112
8.10	—	—	11.30	127	114
8.20	—	—	11.40	125	112
8.30	—	—	11.50	126	113
8.40	—	—	12.00	120	107
8.50	—	—	12.10	120	107
9.00	115	102	12.20	124	111
9.10	113	100	12.30	123	110
9.20	113	100	12.40	120	107
9.30	112	99	12.50	120	107
9.40	110	97	1.00	123	110
9.50	115	102	1.10	120	107
10.00	115	102	1.20	124	111
10.10	117	104	1.30	123	110

Auxiliary Orifice (con.)

Time	Reading	Corrected
1.45	—	—
2.00	121	108
2.15	125	112
2.30	124	111
2.45	124	111
3.00	123	110
3.15	124	111
3.30	120	107
3.45	120	107
4.00	125	112
4.15	126	113
4.30	123	110
4.45	122	109
5.00	118	105
5.15	119	106
5.30	120	107
5.45	119	106
6.00	118	105
6.15	119	106
6.30	118	105
6.45	121	108
7.00	120	107

Back Pressure on Blower Orifice lbs. per sq. in.

Time	Reading	Corrected	Time	Reading	Corrected
7.00	—	—	10.20	92	94
7.10	—	—	10.30	95	97
7.20	—	—	10.40	—	—
7.30	93	95	10.50	92	94
7.40	93	95	11.00	93	95
7.50	94	96			
8.00	94	96			
8.10	90	92			
8.20	92	94			
8.30	92	95			
8.40	93	94			
8.50	92	87			
9.00	85	89			
9.10	87	90			
9.20	88	90			
9.30	88	90			
9.40	—	—			
9.50	88	90			
10.00	90	92			
10.10	—	—			

Table Showing Steam Distribution

Rate in pounds per min.

Time	Auxiliary Steam	Blower Steam	Total Aux. Steam	Engine Steam	Total Steam
7.00	—	74	—	—	—
7.10	—	—	—	—	—
7.20	—	—	—	—	—
7.30	—	—	—	—	—
7.40	—	74	—	—	—
7.50	—	73	—	—	—
8.00	—	72	—	—	—
8.10	—	74	—	—	—
8.20	—	76	—	—	—
8.30	—	76	—	—	—
8.40	—	74	—	—	—
8.50	—	—	—	—	—
9.00	270	70	340	2290	2630
9.10	280	70	350	2030	2380
9.20	270	71	340	2590	2930
9.30	280	70	350	2340	2690
9.40	—	—	—	—	—
9.50	290	73	360	2440	2800
10.00	280	73	350	2440	2790
10.10	—	—	—	—	—
10.20	300	76	380	2490	2870

Steam Distribution (con.)

Time	Auxiliary Steam	Blower Steam	Total Aux. Steam	Engine Steam	Total Steam
10.30	320	78	400	2550	2950
10.40	300	78	380	2600	2980
10.50	300	79	380	2560	2940
11.00	310	80*	390	2570	2960
11.10	300	80	380	2620	3000
11.20	290	80	370	2630	3000
11.30	280	80	360	2580	2940
11.40	270	80	350	2630	2980
11.50	280	80	360	2610	2970
12.00	290	80	370	2570	2940
12.10	260	80	340	2600	2940
12.20	270	80	350	2540	2890
12.30	260	80	340	2580	2920
12.40	260	80	340	2540	2880
12.50	260	80	340	2900	2560
1.00	260	80	340	2540	2880
1.10	280	90	370	2560	2930
1.20	270	90	360	2570	2930
1.30	280	90	370	2590	2960
1.45	—	—	—	—	—
2.00	260	90	350	—	—

* See page 16

Steam Distribution (con.)

Time	Auxiliary Steam	Blower Steam	Total Aux. Steam	Engine Steam	Total Steam
2.15	260	90	350	2570	2920
2.30	270	90	360	2570	2930
2.45	270	80	350	2590	2940
3.00	260	80	340	1900	2240
3.15	260	80	340	2600	2940
3.30	260	80	340	2610	2950
3.45	260	80	340	2590	2930
4.00	290	80	370	2230	2600
4.15	290	80	370	2270	2640
4.30	270	80	350	2690	3040
4.45	264	80	340	2620	2960
5.00	240	80	320	2520	2840
5.15	240	80	320	2460	2780
5.30	240	80	320	2460	2780
5.45	210	80	290	2530	2820
6.00	250	80	330	2510	2840
6.15	240	80	320	2520	2840
6.30	250	80	330	2430	2760
6.45	260	80	340	2600	2940
7.00	250	80	330	2550	2880

Vacuum in Inches of Mercury

Time	Port	Corrected	Starboard	Corrected
7.00	28.4	27.4	27.0	25.6
7.10	28.4	27.4	28.2	26.8
7.20	28.4	27.4	28.4	27.0
7.30	28.4	27.4	28.6	27.2
7.40	28.4	27.4	28.7	27.3
7.50	28.4	27.4	28.7	27.3
8.00	28.4	27.4	28.7	27.3
8.10	28.4	27.4	29.0	27.5
8.20	28.4	27.4	28.8	27.4
8.30	28.4	27.4	28.7	27.3
8.40	28.4	27.4	28.6	27.2
8.50	28.4	27.4	28.6	27.2
9.00	28.4	27.4	28.8	27.4
9.10	28.6	27.7	29.0	27.5
9.20	28.6	27.7	29.0	27.5
9.30	28.6	27.7	29.0	27.5
9.40	28.6	27.7	29.1	27.6
9.50	28.5	27.5	29.2	27.7
10.00	28.6	27.7	29.1	27.6
10.10	28.3	27.2	28.8	27.4
10.20	28.6	27.7	28.8	27.4

Vacuum (con)

Time	Port	Corrected	Starboard	Corrected
10.30	28.5	27.5	28.8	27.4
10.40	28.6	27.7	28.9	27.5
10.50	28.6	27.7	29.0	27.5
11.00	28.6	27.7	28.9	27.5
11.10	28.6	27.7	28.9	27.5
11.20	28.5	27.5	28.9	27.5
11.30	28.5	27.5	28.8	27.4
11.40	28.5	27.5	28.9	27.5
11.50	28.4	27.4	28.8	27.4
12.00	28.4	27.4	28.7	27.3
12.10	28.4	27.4	28.7	27.3
12.20	28.4	27.4	28.7	27.3
12.30	28.4	27.4	28.7	27.3
12.40	28.5	27.5	28.8	27.4
12.50	28.5	27.5	28.8	27.4
1.00	28.5	27.5	28.8	27.4
1.10	28.5	27.5	28.9	27.5
1.20	28.5	27.5	28.8	27.4
1.30	28.5	27.5	28.7	27.3
1.45	—	—	—	—
2.00	28.5	27.5	28.8	27.4

Vacuum (con)

Time	Port	Correction	Starboard	Correction
2.15	28.5	27.5	28.7	27.3
2.30	28.4	27.4	28.7	27.3
2.45	28.4	27.4	28.8	27.4
3.00	28.2	27.0	28.6	27.2
3.15	28.4	27.4	28.8	27.4
3.30	28.5	27.5	29.0	27.5
3.45	28.5	27.5	29.1	27.6
4.00	28.5	27.5	28.8	27.4
4.15	28.5	27.5	29.0	27.5
4.30	28.6	27.7	29.1	27.6
4.45	28.5	27.5	29.0	27.5
5.00	28.5	27.5	29.0	27.5
5.15	28.5	27.5	29.0	27.5
5.30	28.5	27.5	29.0	27.5
5.45	28.5	27.5	29.0	27.5
6.00	28.6	27.7	29.0	27.5
6.15	28.6	27.7	29.0	27.5
6.30	28.5	27.5	29.0	27.5
6.45	28.6	27.7	29.1	27.6
7.00	28.6	27.7	29.1	27.6

Draft in Inches of Water

Time	Reading	Time	Reading	Time	Reading
7.00	1.40	10.30	1.85	2.15	1.80
7.10	1.40	10.40	1.70	2.30	1.85
7.20	1.40	10.50	1.75	2.45	1.80
7.30	1.45	11.00	1.80	3.00	0.90
7.40	1.50	11.10	1.80	3.15	1.75
7.50	1.55	11.20	1.75	3.30	1.80
8.00	1.55	11.30	1.80	3.45	1.85
8.10	1.80	11.40	1.80	4.00	1.85
8.20	—	11.50	1.70	4.15	2.10
8.30	1.60	12.00	1.85	4.30	1.85
8.40	1.75	12.10	1.70	4.45	1.75
8.50	1.55	12.20	1.80	5.00	1.80
9.00	1.60	12.30	1.75	5.15	1.75
9.10	1.65	12.40	1.70	5.30	1.85
9.20	1.55	12.50	1.75	5.45	1.75
9.30	1.60	1.00	1.85	6.00	1.75
9.40	1.60	1.10	1.85	6.15	1.80
9.50	1.60	1.20	1.80	6.30	2.00
10.00	1.70	1.30	1.90	6.45	1.85
10.10	1.70	1.45	—	7.00	1.80
10.20	1.70	2.00	1.90		

Calorimeter Data

	Temp. in Cal.	Cal. Pressure	Boiler Press.
	115.0	7.0	145
	114.7	7.0	143
	113.8	7.0	136
Total	343.5	21.0	424
Average	114.5	7.0	141.3
	114.0	7.0	135
	114.0	7.0	135
Total	228.0	14.0	270
Average	114.0	7.0	135
	120.0	5.0	145
	120.3	4.9	145
	119.2	5.0	—
	118.1	—	—
	117.3	—	—
	113.2	—	—
	113.2	—	—
	113.5	—	—
	114.2	—	—
	115.0	—	—
Total	1164.0	14.9	290
Average	116.4	5.0	145

CALCULATION

Equivalent Evaporation

Boiler Pressure	140.2 lbs.
Barometer	14.7 lbs.
Absolute Boiler Pressure	154.9 lbs.
Quality of Steam	96.0 %
Q+XR at 154.9 lbs.	1,157.6 B.T.U.
Q at 202.7°F.	170.9 B.T.U.
Heat to vaporize 1 lb. of feed water (4% priming)	986.7 B.T.U.
Q at vacuum	77.7 B.T.U.

$$\text{Equivalent Evaporation} = \frac{175{,}000 \times 986.7}{966.3}$$

$$= 179{,}000 \text{ lbs.}$$

$$\text{Equivalent Evaporation per lb. of coal} = \frac{179{,}000}{16{,}000}$$

$$= 11.1 \text{ lbs.}$$

Equivalent Evaporation per sq. ft. of Heating Surface

$$\frac{179{,}000}{29{,}500} = 6.06 \text{ lbs.}$$

Coal burned per sq. ft. of Grate Surface per Hour

$$\frac{16{,}000}{756} = 21.3 \text{ lbs.}$$

CALCULATION (con.)

Boiler Horse Power (A.S.M.E. Rating)

$$\frac{175{,}000 \times 986.7}{33{,}320} = 5180$$

Heat absorbed by Water in Boiler per lb. of Coal

$$\frac{175{,}000 \times 986.7}{16{,}100} = 10{,}700 \text{ B. T. U.}$$

Thermal Efficiency

$$\frac{986.7 \times 175{,}000 \times 100}{14{,}510 \times 16{,}100} = 73.8\ \%$$

Total Steam per Shaft Horse Power

$$\frac{175{,}000}{10{,}400} = 16.8 \text{ lbs.}$$

Engine Steam per Shaft Horse Power

$$\frac{153{,}000}{10{,}400} = 14.7 \text{ lbs.}$$

B. T. U. per Shaft Horse Power

$$\frac{1080 \times 153{,}000}{60 \times 10{,}400} = 265 \text{ B. T. U.}$$

Coal per Shaft Horse Power

$$\frac{16{,}100}{10{,}400} = 1.55 \text{ lbs.}$$

DISCUSSION OF RESULTS.

From previous statements it is evident that errors of more than 2% in the coal rate and 1% in the feed water rate are unlikely. A possible error of 10% in the auxiliary steam could not affect the engine steam to more than 1.2%. An error of 1% in the feed water will affect the engine steam by about 1%, so that the total error in the engine steam is not likely to be greater than 2%.

The equivalent evaporation is affected by five factors---the boiler pressure, the quality of the steam, the temperature of the feed water, the feed water rate, and the coal rate. Any errors which are likely to occur in the first three of these are so small as compared with the probable errors in the last two as to be negligible, so that the error introduced into the equivalent evaporation per pound of coal is not greater than 2.5%.

With probable errors of 3% in the shaft horse power and 1% in the feed water rate, the total error in the steam per shaft horse power would not be more than 3.5%.

The error in the engine steam and the coal per shaft horse power cannot be more than 3.5% as can be seen by the above figures.

CONCLUSION.

This test was run under favorable conditions as regards weather and sea and the results given here are average results obtained in regular service between Boston and New York. From a consideration of all the errors entering into this work the results are seen to be certainly accurate within 3.5% and the probable error is smaller.

We hereby express our thanks to all who have in any way aided us in this work.

Respectfully submitted:

Signature redacted

Signature redacted