T H E S I S

TEST OF HARBOR TUGBOAT.

SADIE ROSS

Submitted to the Department

of

Naval Architecture and Marine Engineering

by

Kenneth H. Campbell

May 1929

Professor A. L. Merrill,

Secretary of the Faculty,

Massachusetts Institute of Technology

Dear Sir-

The accompanying thesis on "Test of Harbor Tug Boat - Sadie Ross" is submitted in compliance with the requirements of the Massachusetts Institute of Technology for the degree of Bachelor of Science.

Respectfully yours,

INDEX

A C K N O W L E D G E M E N T

To Mr. Harry Ross owner of the boat on which the test was run, Professor Evers Burtner upon whose instigation the test was undertaken and who willingly offered assistance at all times, Mr. Nicholas Oresko who gave liberally of his time both in preparing for and during the trials, Mr. John Booth, Jr. who assisted on the run, Mr. Rad B. Clough engineer of the vessel whose cooperation helped materially and Professor J.J. Eames, who kindly lent apparatus and advised as to the use thereof; the author wishes to extend his thanks for assistance rendered.

Test of Harbor Tugboat
Sadie Ross

PURPOSE:-

The purpose of this test was to find the average water rate, and coal consumption of an ordinary harbor tug. The efficiency of the boiler and economizer was also secured as completely as possible with the means at hand.

UNIT TESTED:-

The boat in question is a typical harbor tug of the following dimensions, length 60.5 feet, breadth 18.6 feet, depth 7.7 feet Gross tons 49, net tons 27.

She is equipped with a main unit consisting of a Bertleson and Peterson steeple compound engine rated at 250 I. H. P. The engine was built with 11 inch high pressure and 22 inch low pressure cylinders and 15 inch stroke. Since then the engine had had the high pressure cylinder replaced by a 10 inch cylinder.

This has been bored once and is now 10-1/8 inches in diameter.

The boat was originally equipped with the ordinary Scotch boiler but this has since been replaced by an Almy boiler of the following dimensions.

Grate area 34.3 sq. ft. - Boiler heating surface 933 sq. ft. Economizer surface 165 sq. ft.

As nearly as could be ascertained the engine was built in 1904 and with the exceptions noted above and the addition of new air and circulating pump has been in constant service without any alterations except the usual maintainence since then.

The new boiler was built in 1926 and has been in service ever since.

In addition to the main unit the boat has the usual auxiliaries consisting of circulating pump, and air pump attached to the main engine, feed water pump, donkey pump, feed water heater and injector. She is fitted with a feed and filter tank. The boiler is equipped with an economizer.

The arrangement of the piping system is shown in figure one. The engine room layout is shown in figure two.

PROCEDURE:-

After making a preliminary trip of investigation measurements were taken and the main feed line was cut and a water meter placed therein. As the cylinders were not fitted with indicator cocks it was also necessary to make provisions for taking cards. Cocks were fitted and a reducing motion arranged off the air pump arm. An integrating counter was placed on the feed pump and another on the main engine. Thermometers were placed to secure the following temperatures, hot well, boiler room, feed line after meter, and stack. In addition readings were taken from time to time of sea temperature and overboard discharge. Coal was weighed by means of a spring balance and ash bucket. Owing to the difficult conditions under which the test was made, no attempt was made to weigh ashes. Orsatt readings were taken but proved worthless.

RESULTS:-

Following are the results of the tests. The graphs and diagrams are largely self explanatory. Results will be discussed in the pages which follow.

In plotting the curves time was taken as the abscissa and the various other readings as ordinates. Thus for any time during the run conditions may at once be found corresponding.

RESULTS OF ENGINE TEST.

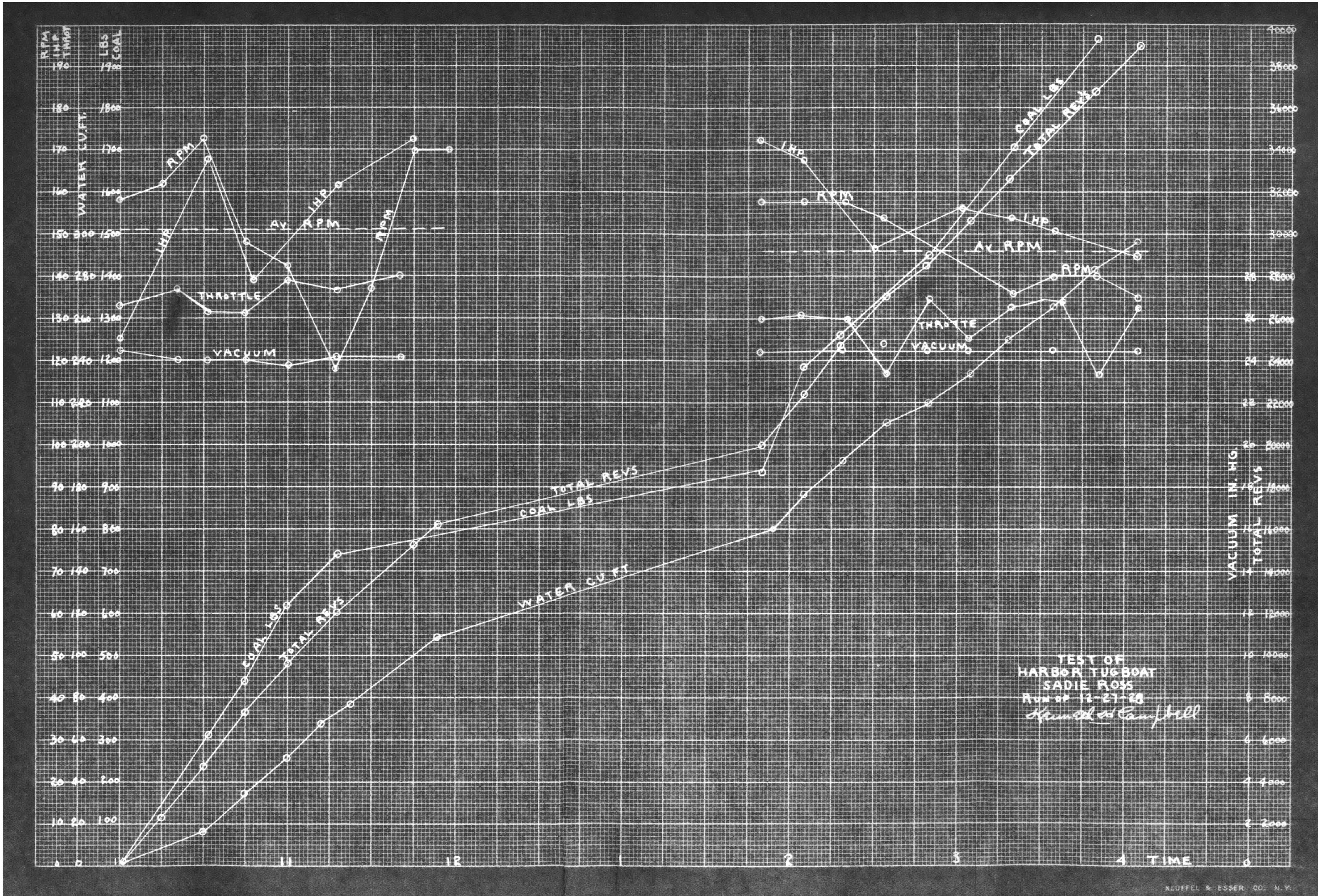
Type of engine	Steeple Compound		
Dimensions of cylinders	10" x 22" 15" stroke		
Date	12-27-28	12-29-28	(LONG RUN) 4-20-29
Duration hrs.	6	11	2.5
Press. in steam pipe near throttle lb/in² gage	130	125	130
Press. in receiver	17.8	11.45	13.8
Vacuum in Condenser in. Hg.	24.4	20.7	21.0
Quality of steam	.95	.95	.95
Net steam consumed/hr. (lb)	4640	6050	3650
M.E.P. each cylinder	H.P.: ce 90, he 88; L.P.: ce 19, he 19	H.P.: ce 90, he 88; L.P.: ce 19, he 19	H.P.: ce 99, he 100; L.P.: ce 19, h 18
R.P.M.	148.5	135	154.2
I.H.P.	153.8	137.8	166.3
Steam/IHP hr.	30.12	44.8	21.9
Lb. coal/I.H.P./hr.	3.19	6.85	3.3
B.T.U./I.H.P./hr.	45,800	97,400	46,800
Rankine Eff. %	27.3	25.1	25.3
Thermal Eff. %	7.83	5.32	10.85
Efficiency Ratio %	28.7	21.2	43.0
Over all Thermal Eff. boiler and engine	5.61	2.62	5.43

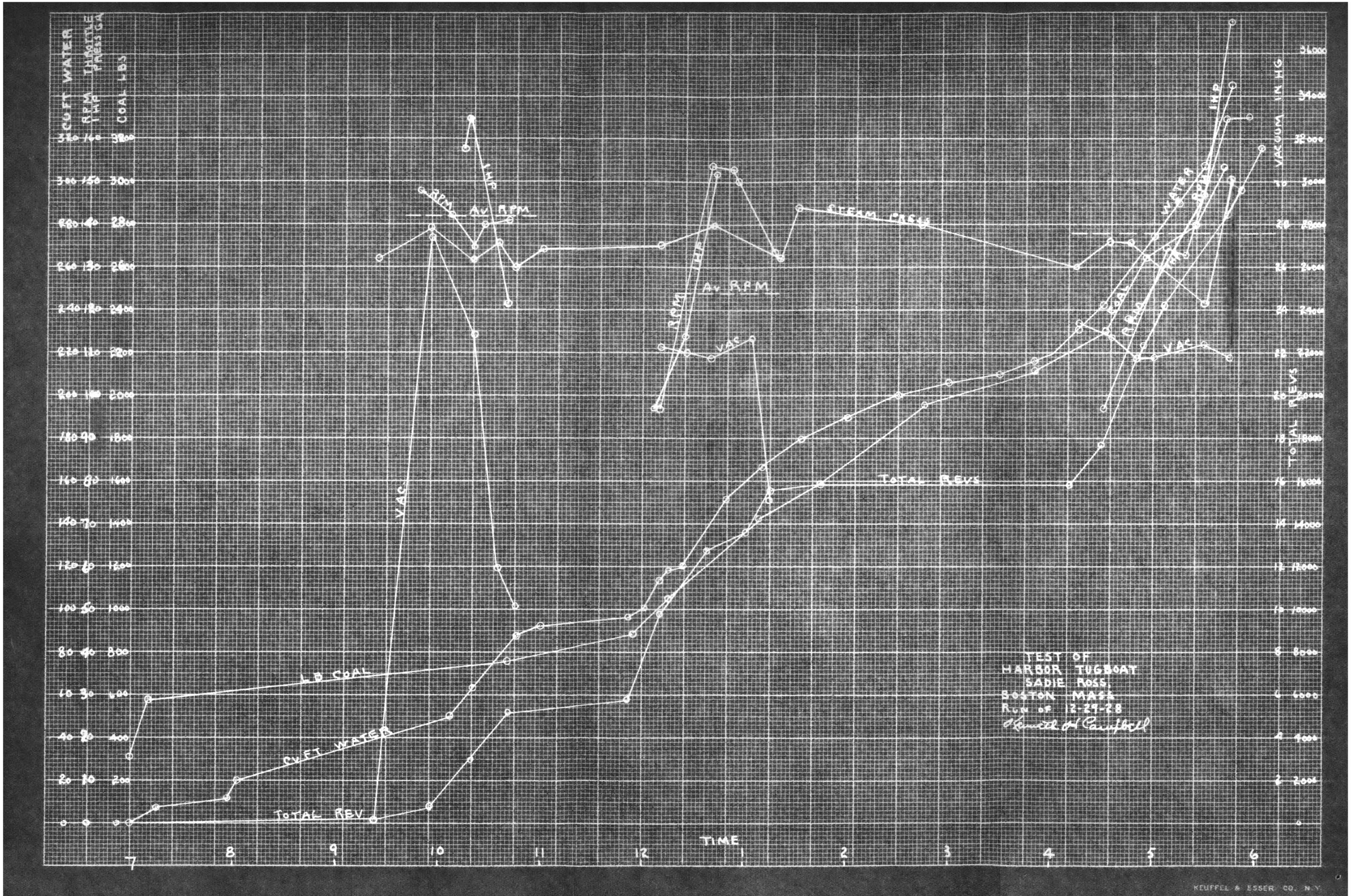
Note:-
Runs of 12-27-28 and 12-29-28 include standby losses and other items.
See Discussion.

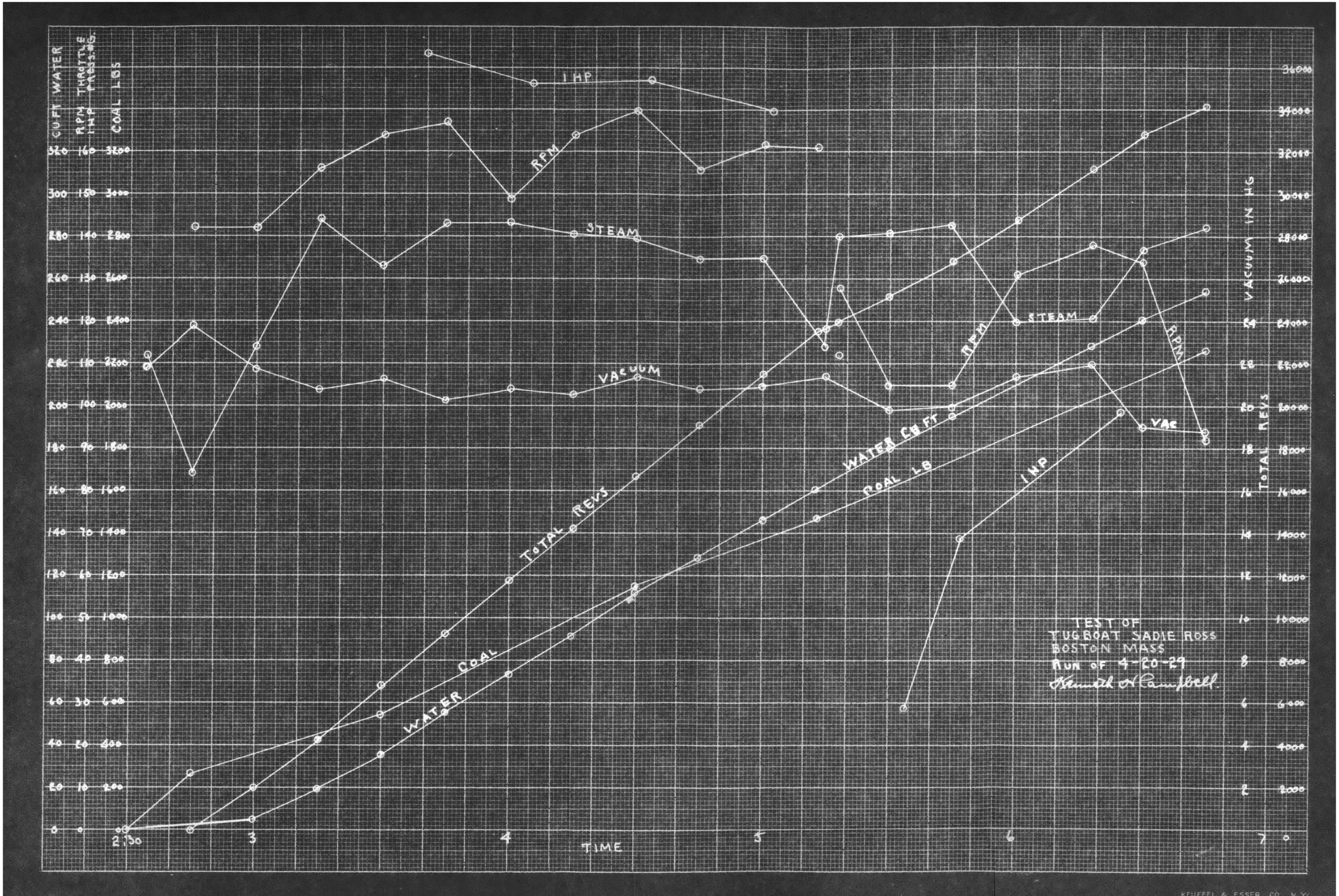
RESULTS OF BOILER TESTS.

Type	Almy Water Tube		
Date of Test	12 - 27 - 28	12 - 29 - 28	4- 20 - 29
Duration hrs.	water 6 hrs. coal 5.75	10.5	2.5
Length of boiler	95½"	95½"	95½"
No. of Furnaces	1	1	1
Length of grate	76"	76"	76"
Total heating surface sq. ft.	1098	1098	1098
Grate Surface	34.3	34.3	34.3
Ratio H.S. - G. S.	3.2	3.2	3.2
Boiler Press.	130	125	130
Lb. Coal / hr.	334	267	590
Lb. " / $ft.^2$ G.S.	9.74	7.80	17.2
B.T.U. / lb. coal	14,200	14,200	14,200
Lb. water / hr.	3,060	1800	3,650
Lb. water / lb. coal as fired	9.27	6.75	6.2
Lb. water F & A / lb. coal	10.05	7.4	6.75
Lb. water / $ft.^2$ H.S. / hr.	2.79	1.64	3.33
Quality Steam	.95	.95	.95
Temp. feed water	123	113.7	122.4
Temp. stack	640	------	606
Boiler Eff.	69.0	50.6	46.2
Type Draft		Natural	
Factor of Evap.	1.085	1.095	1.088
Eff. on Horse Power basis	70.4	49.2	49.5

Errata: Ratio H. S. - G. S. read 32.0 instead of 3.2


TEST OF
HARBOR TUGBOAT
SADIE ROSS
RUN OF 12-27-28
RPM
IHP
THROT
LBS COAL
WATER CU. FT.
VACUUM IN. HG.
TOTAL REVS
AV. RPM
THROTTLE
VACUUM
COAL LBS
WATER CU FT
TIME
KEUFFEL & ESSER CO. N.Y.


CU FT WATER
R.P.M.
I.H.P.
THROTTLE PRESS GA
COAL LBS
VACUUM IN HG
TOTAL REVS
TIME
7
8
9
10
11
12
1
2
3
4
5
6
LB COAL
CU FT WATER
TOTAL REV
VAC
I H P
RPM
AV RPM
STEAM PRESS
TOTAL REVS
WATER
COAL
TEST OF
HARBOR TUGBOAT
SADIE ROSS.
BOSTON MASS.
RUN OF 12-29-28
KEUFFEL & ESSER CO. N.Y.



CU FT WATER
RPM THROTTLE
IHP PRESS #G.
COAL LBS
IHP
RPM
STEAM
VACUUM
TOTAL REVS
WATER CU FT
COAL LB
WATER
COAL
VAC
VACUUM IN HG
TOTAL REVS
TIME
2:30
3
4
5
6
7
TEST OF
TUGBOAT SADIE ROSS
BOSTON MASS
RUN OF 4-20-29
Kenneth N Campbell
KEUFFEL & ESSER CO. N.Y.

Hot Well and Feed Temperatures.

12 - 27 - 28		12 - 29 - 28		4 - 20 - 29	
Feed Water.	Hot Well	Feed Water	Hot Well	Feed Water	Hot Well
123	126	- -	89	104	112
127	-	- -	96	120	124
124	126	- -	111	124	121
126	-	- -	112	122	128
126	120	- -	118.5	131	131
124	-	- -	126	124	125
122	128	- -	100	124	121
125	127.5	122	139	-	129
127	113	120	-	122	125
121	-	120	126	122	-
119	124	122	123	-	109
123	116	-	111	126	131
120	125	-	125	122	120
126	128	109	85	-	116
120	123	-	85	118	-
121	-	105	135	123	131
		108	104	126	132
		-	80		
		105	86		
		110	111		
		-	116		
		-	116		
			121		
		116	-		
		-	115		
		-	118		

DISCUSSION:-

In considering the results of these tests, these facts should be borne in mind. The test was made by men inexperienced in the form of testing. Although all had done considerable stationary testing in the laboratory with the exception of Professor Burtner none of us had ever run an actual service test. This fact led to some slight but annoying inaccuracies such as failure to synchronize watches duplication of readings and the like on the first runs. On the later runs, however, these difficulties were largely overcome.

Next the test was made while the boat was in actual service. As all the test installations were made by members of the testing party and time was limited, the test being non commercial, it was not possible to install all the apparatus one might have wished. No deviations from regular operation were made for the benefit of the test data and hence it was extremely difficult to secure some readings such as power variations and constant power. Furthermore the engine room was rather lacking in space for extended observations in fact many of the readings were taken with some difficulty.

In evaluating results these errors were introduced. In weighing the coal the ash bucket and a spring balance were used. The swaying of the bucket introduced an error which was handled by estimating the mid point of the swing on the scale. The tare was taken at intervals and assumed to remain sensibly constant.

In the feed line also some error was introduced by the fact that the injector was used at times. As water from the injector did not pass through the meter it was impossible to ascertain the amount so used. However, it was quite small and it seems fair to neglect it.

In view of all the above it is not fair to assume results to be accurate to more than 5%. The carefulness with which readings were taken and the results worked up would seem however, to warrant confidence to that extent. This of course assumes all results to be free from numerical errors. As the last portion of the thesis work which includes practically all the computations was done by the author working alone and with the time limited; there are no doubt errors which a careful checking would have eliminated. The results would seem to indicate, however, that the numerical computations are substantially correct.

In considering the data sheets one is struck by the number of apparently unused reading. The principal one of these is the feed pump data. This was taken in order to provide a standby method of computing water rate if anything went wrong with the meter. The other readings might be of interest in a more extended study of the results of this test.

Before passing on to an analysis of the curves and figures the viewpoint from which this data is worked up must be considered. As the principal interest of the majority of parties concerned was in the economy of operation of a steam tug the results were worked up with this in mind. The whole basis of comparison used is that of horsepower hours of work actually done as compared with the amount of energy expended to produce the same. The runs of the 27th and 29th of December are particularly what is meant. In computing the steam and coal used on these days the average horsepower developed was multiplied by the number of hours during which the tug was actually running. The coal and water, however, were taken over the total time of the test. This means that all standby losses and manouvering losses are included in the results. In other words to take the run of December 29th as an example to get one indicated horsepower hour it was necessary to expend 44.8 pounds of steam. Probably 50% of this went into the condenser without doing any actual work during the time the tug was lying idle at the dock. The author feels that this method shows more clearly than the ordinarily accepted way of computing, the losses occasioned by enforced idleness.

Analysis of Results.

In considering the results of these tests and comparing the three sets of observations it should be borne in mind that they were taken under entirely different sets of operating conditions.

The run of December 27th represents an average day. The tug was fairly busy mostly on short runs. She ran to Lynn, South Boston, and the Atlantic works but there were periods of idleness. Different duties were undertaken the tug running both light and with a tow.

The run of December 29th represents a slack day. With the exception of two short runs the tug lay at the dock with fires banked all day. For purposes of comparison this may be considered a day of standby losses.

The run of April 20th represents the nearest possible approach to continuous full power operation it was possible to get. With the exception of a short run through the Annisquam River and canal the vessel was under full power from 2.30 A.M. when she left Boston until 5.15 when she arrived at Gloucester. She there entered the tidal river and proceeded to Essex. This part of the run is included in the chart as being of general interest and completing our test but is not worked up in the computations. On the whole it seems fair to consider this a representative full power run.

With all the points already discussed well in mind the tables of results require some further explanation. Under the condition taken we should expect the water and coal rates to be less on the longer run than on the harbor runs and the day of standby losses to show the greatest expenditure per horsepower. A reference to the engine test figures shows that while in general this holds true it is not strictly the case.

In the matter of steam consumption this holds very well. The day at the dock showing 44.8 pounds per horsepower developed per hour the day of harbor runs showing 30.12 and the period of continuous operation showing 21.9 pounds, a considerable reduction in each case.

In the matter of the coal however this does not hold. Here we have, speaking again on the basis of horsepower hours, for the day at the wharf 6.85 pounds , for the day of short runs 3.19 pounds and for the long run 3.3 pounds. In variance with our expectations we find that continuous operation requires .11 pound more coal per horsepower. This may be readily explained by the boiler results.

Boiler results were figured in two ways, on the horsepower basis as shown in the computations and in the usual manner. Both these methods check closely. For the sake of consistency we will consider only the horsepower figures. Here we note an amazing discrepancy. The efficiency of the tugs' boiler while engaged in harbor work was 70.4% while the efficiencies of the standby and full power day was practically the same about 49%.

Some explanation of this may be given on the grounds that the efficiency of the first day is too high. This is perhaps true as several different observers were engaged in the weighing of coal on that day. But even allowing for as great an error as 10% the efficiency would still be 60% or about 10% higher than that of the full power run which seemingly should show the best efficiency.

The author believes this to be due entirely to the firemen. On the day of Dec. 27th both firemen were experienced and one of them seemed to be particulary good. On the day of April 20th both firemen were green, [redacted] one of them had never fired before and the other had had but a few weeks experience. As an additional proof we may note the fact that the evaporation per pound of coal is the lowest on this day of any of the three 6.2 pounds of water per pound of coal as compared with 6.75 on the day spent banked and 9.27 on the day of short runs. The pounds of coal per square foot of grate surface is practically double that of the short run day being 17.2 as compared with 9.74.

The data on quality of the steam proved very unsatisfactory. For some reason it was impossible to build up a sufficient pressure in the calorimeter to superheat the steam. Saturated steam was, however, obtained on two occassions and used as the basis of computation.

The feed heater which was of the primary type operated by passing exhaust steam from the main engine and auxiliaries through it. It was open to the condenser. This means that for a 24 inch vacuum the temperature therein should be 137° F. This means that when the temperature in the hot well runs up over this figure or when the vacuum runs up a little, the device acts as a cooler not a heater. That this occurs at other times for some cause is clearly shown by the figures. Many of the cases where the temperature of the feed is higher than that of the hot well might be the reverse had the thermometer been left longer in the feed and filter tank.

Such a heater is injurious for the following reasons:- <u>first</u> it puts an undue load on the condenser. Some of the condenser cooling water is used for cooling this feed water which means that less may be devoted to the purpose for which it was intended. This means a loss in vacuum and hence in engine efficiency. Second the colder feed water increases the load on the economizer. This means that more heat is taken from the stack gas resulting in a reduction in draft. Thirdly the colder water entering the boiler means more heat required to raise it to the vaporization point resulting in a higher fuel bill.

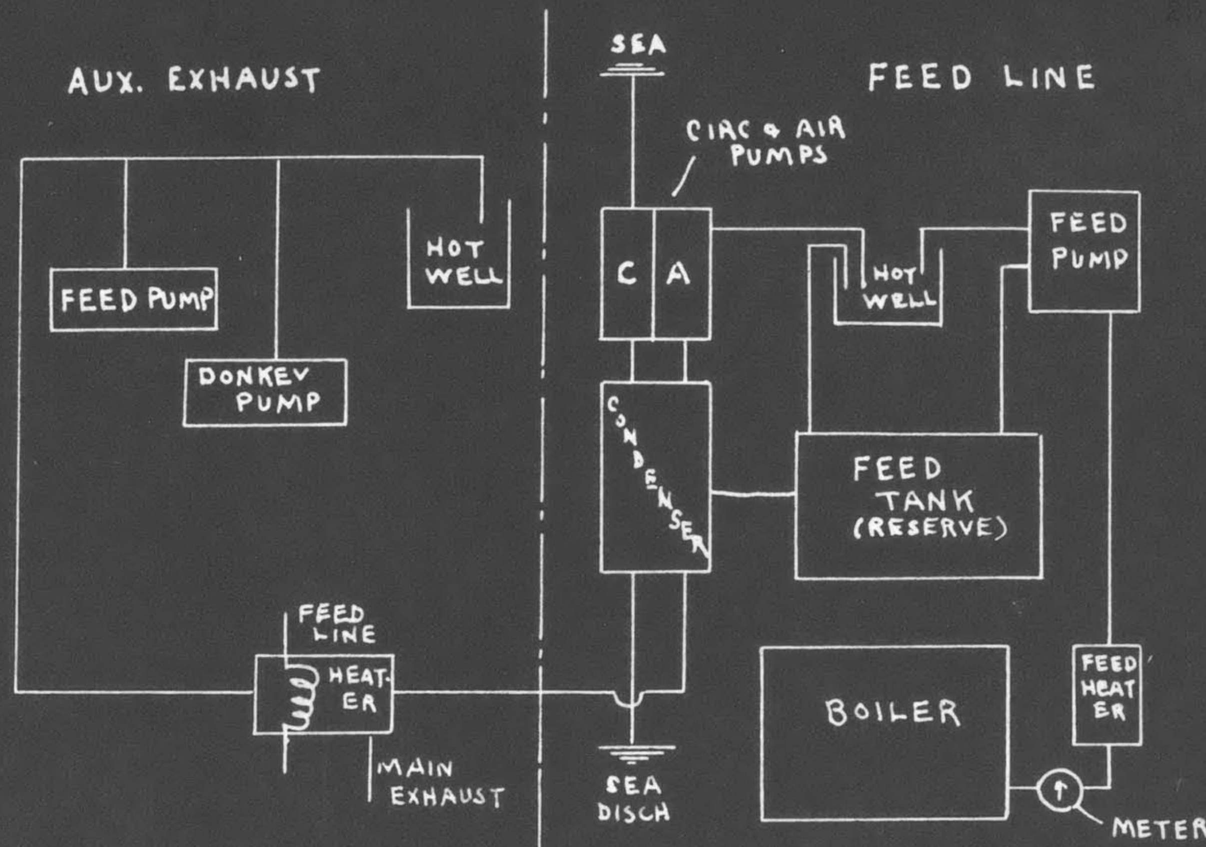
CONCLUSIONS.

As regards the boiler and economizer we may say that with proper firing the efficiency of the boiler is quite satisfactory. Sterling "Marine Engineers Handbook" gives values ranging from 62% to 76.4% efficiency. If this boiler can be made to average 65% it would seem to be in accordance with usual practice. To do this, however, the firing must be carefully watched. It would be interesting to ascertain just what the economizer is doing. To do this a thermometer well must be inserted between the economizer and boiler proper. As this well would be under full boiler pressure it was impossible for such an insert to be made with facilities provided. The efficiency and steaming of the boiler could be considerably unproved by the use of higher temperature feed water. At 150# gage pressure the temperature of the water leaving the economizer could well be 365° or 366°F.

The coal consumption is excessive, viewed from modern practice. Of course allowance must be made for the type of installation and conditions of operation. A first class feed heater of the closed type should, however, reduce this consumption considerably. With careful fireing and the use of such a feed heater it does not seem impossible to reduce the consumption by one third, as two pounds per I.H.P. per hour is not especially a high efficiency figure.

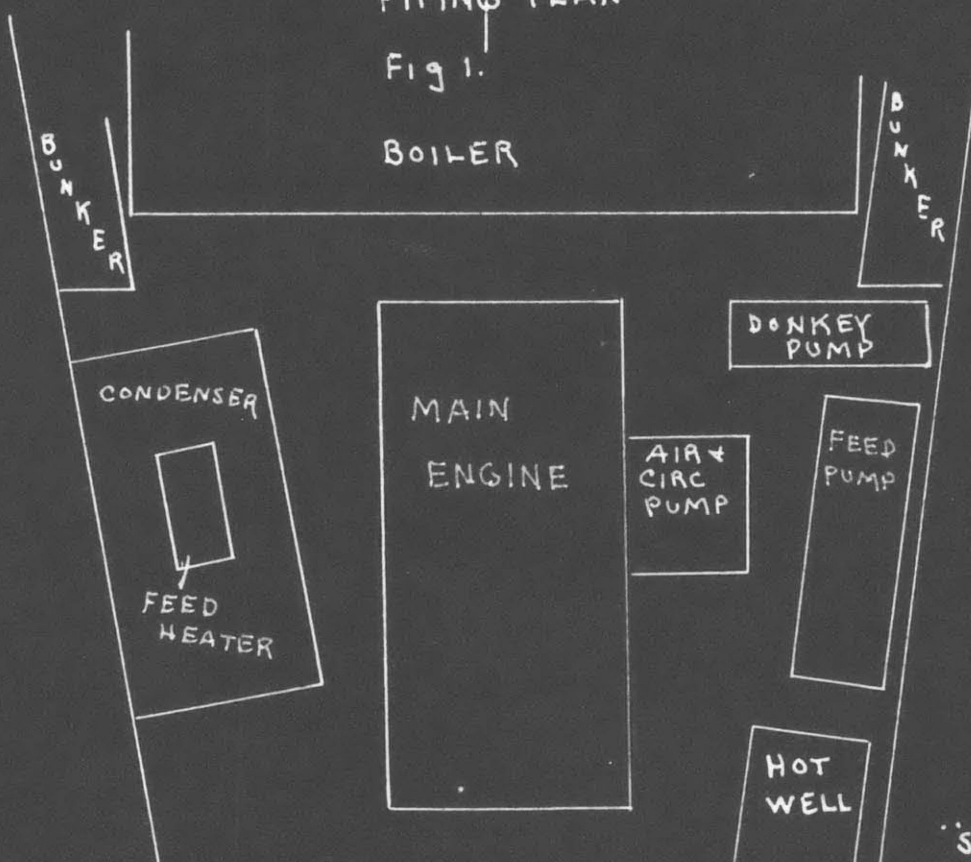
As regards the engine the steam consumption would seem to be quite good for this type of an installation. On the day of continuous running it was only 21.9 pounds per I.H.P. per hour and on the day of harbor runs 30.12. It is difficult to see how this could be materially improved with the existing installation although a higher vacuum would certainly help some. Sterling "Marine Engineers Handbook" gives values for compound engines, most of them larger than this, ranging from 18.4 to 29.8 # / I.H.P./ hr. In view of these figures the consumption of this tug would seem reasonable.

A P P E N D I X



PIPING PLAN

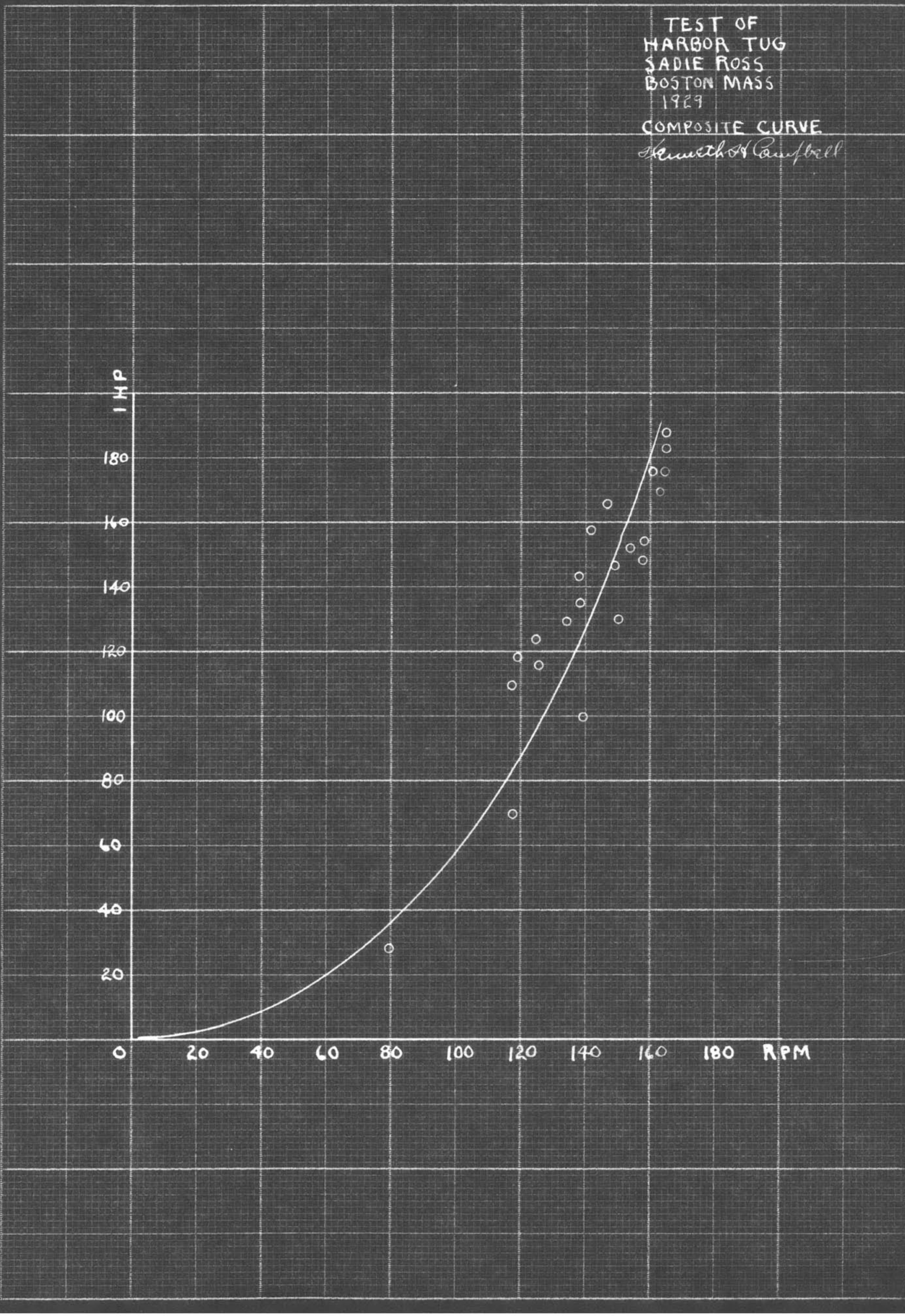
Fig 1.



'TWEEN DECKS PLAN

Fig 2.

TEST OF "SADIE ROSS"
BOSTON MASS
5-10-29.
Kenneth N Campbell.

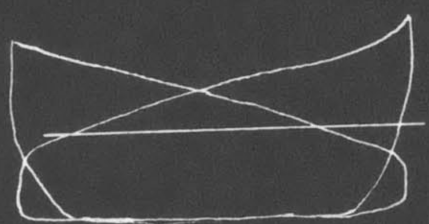

TEST OF
HARBOR TUG
SADIE ROSS
BOSTON MASS
1929
COMPOSITE CURVE
Kenneth H Campbell
I HP
180
160
140
120
100
80
60
40
20
0
20
40
60
80
100
120
140
160
180
RPM

TEST OF
TUGBOAT SADIE ROSS
BOSTON MASS
1929
Kenneth H Campbell

SAMPLE CARDS

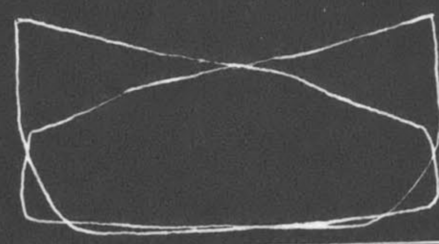
L.P. | H.P.

H.E. C.E. | H.E. C.E.



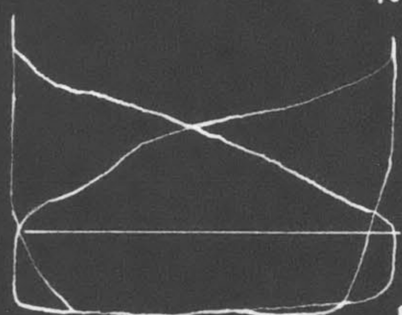
LENGTH 2.2 SPRING 30#
MEP 11.7 12.2
IHP 22.2 22.9
CYCL HP 45.1

RPM 139



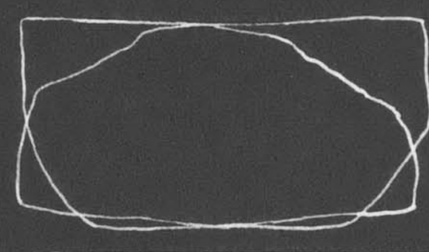
LENGTH 2.2 SPRING 100
MEP 77.8 78.2
IHP 24.6 29.7
CYCL HP 54.3

TOTAL HP
99.4



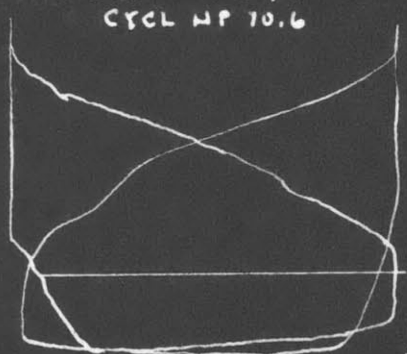
LENGTH 2.05 SPRING 20
MEP 16.75 16.75
IHP 35.3 35.3
CYCL HP 70.6

RPM 155



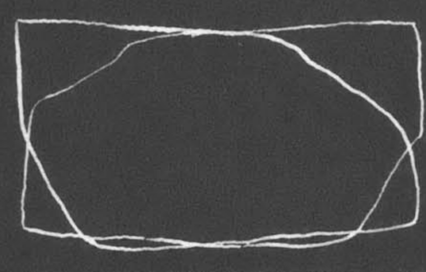
LENGTH 2.15 SPRING 100
MEP 84 92
IHP 37 38.9
CYCL HP 75.9

TOTAL HP
146.5



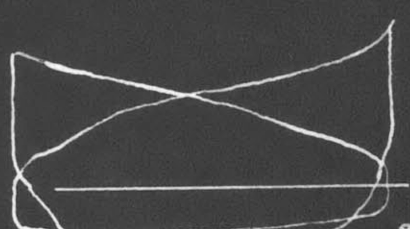
LENGTH 2.05 SPRING 20
MEP 19.1 19.8
IHP 41 42.5
CYCL HP 83.5

RPM 158



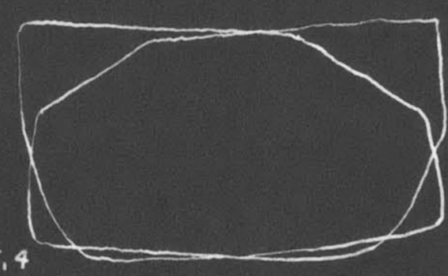
LENGTH 2.12 SPRING 100
MEP 96.5 94.0
IHP 43.3 40.6
CYCL HP 83.9

TOTAL HP
167.4



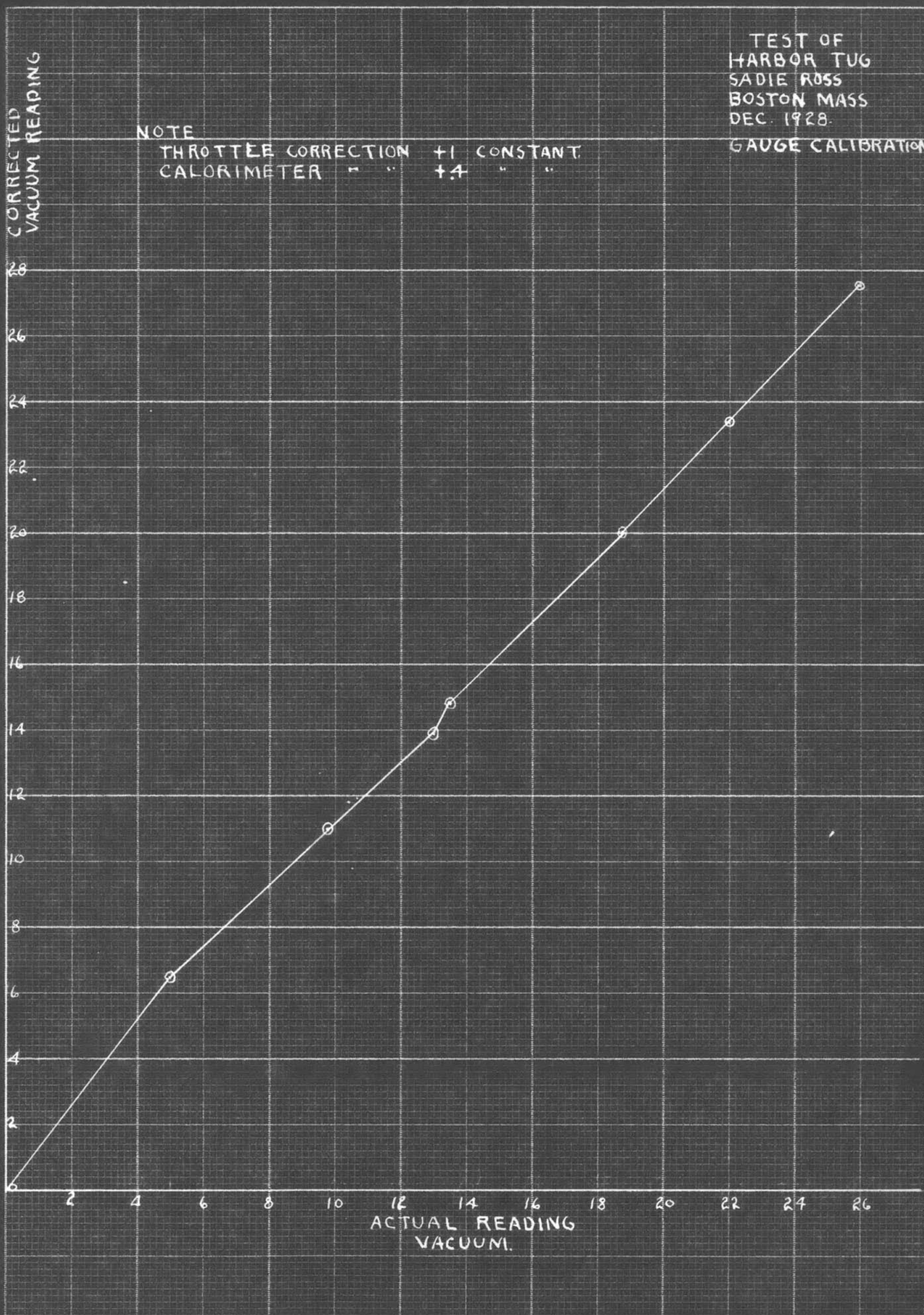
RPM 165.4

LENGTH 2.0 SPRING 30
MEP 18 20.4
IHP 40.5 46.0
CYCL HP 86.5



LENGTH 2.2 SPRING 100
MEP 106 103
IHP 50 46.5
CYCL HP 96.5

TOTAL HP
183.0



TEST OF
HARBOR TUG
SADIE ROSS
BOSTON MASS
DEC. 1928.
GAUGE CALIBRATION
NOTE
THROTTLE CORRECTION +1 CONSTANT
CALORIMETER " " +.4 " "
CORRECTED VACUUM READING
ACTUAL READING VACUUM.
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28

COMPUTATIONS

Engine Constants.

Area H. P. Cylinder piston (10-1/8" dia.)	=	80.52 square inches
Area H. P. piston rod (2" dia.)	=	3.14 square inches
Area of crank end	=	77.38 square inches
Area L.P. Cylinder piston ($22\frac{1}{4}$" dia.)	=	388.8 square inches
Area L.P. piston rod (2-3/8" dia.)	=	4.43 square inches
Area crank end of piston	=	384.37 square inches
Area L.P. Cylinder piston	=	388.8 square inches
Area H.E. Piston Rod	=	3.14 square inches
Area H.E. of piston	=	385.66 square inches

$$\text{I. H. P.} = \frac{plan}{33{,}000} = \frac{la}{33{,}000}\ p.n.$$

where p = mean effective pressure

l = stroke in feet

a = area of piston (net) in square inches

n = number of R.P.M.

Horse Power Constants

High Pressure Cylinder

$$\text{H E}\ \frac{la}{33000} = \frac{14}{12} \times \frac{80.52}{33{,}000} = .00284$$

C E $\frac{la}{33000} = \frac{14}{12} \times \frac{77.38}{33000} = .00273$

Low Pressure Cylinder

H.E. $\frac{la}{33000} = \frac{14}{12} \times \frac{385.6}{33000} = .0136$

C.E. $\frac{la}{33000} = \frac{14}{12} \times \frac{384.37}{33000} = .0136$

COMPUTATIONS

Average M.e.p. and I.H.P.

Run of Dec. 27, 1928

	High Pressure		Low Pressure	
	Head End	Crank End	Head End	Crank End
	55	60.5	17.8	19
	40.6	39.5	22.0	20.8
	91.5	95.0	23.2	21.4
	98.7	103.0	19.1	18.5
	103.5	98.7	21	21.5
	100.5	103.	19	19.9
	96.5	94	19.1	19.8
	84.0	92	16.75	16.75
	96.8	98.1	19.7	19.95
	100	94.0	20.5	21.5
	98	97.7	19.4	20.5
	97.7	98	19.8	20.1
	95	99	19.5	19.5
Sum	1157.8	1173.4	256.85	258.2
Ave.	88.0	90.0	19.92	19.93

Time 6 hours. I.H.P. (Average R.P.M. = 148.5)

37.	35.9	40.6	40.3

Total I. H. P. = 153.8

$$\text{Water Rate} = \frac{296 \times 62.5}{153.8 \times 4} = 30.12 \text{ \# water / I. H. P. / hr.}$$

$$\text{Coal Rate} = \frac{1960}{153.8 \times 4} = 3.19 \text{ \# coal / I. H. P. / hr.}$$

COMPUTATIONS

Average M.e.p. and I.H.P.

Run of Dec. 29, 1928.

M.E.P.

	High Pressure		Low Pressure	
	Head End	Crank End	Head End	Crank End
	102	106	19.7	19.3
	103	101	20.7	21.1
	80.6	80	14.3	16.6
	91	90	17.6	17.4
	86.7	88.8	17.6	18.3
	87	89.4	17.8	18.7
	79.5	88.6	20.4	17.6
	76.0	73.5	20.5	21.2
	89.5	93.0	23.2	23.4
Sum	795.3	810.3	171.8	173.6
Ave.	88.37	90.03	19.09	19.29
I.H.P., at 135 R.P.M.				
	33.9	33.2	35.3	35.4

Time 11 hours. Total I. H. P. 137.8

$$\text{Water rate} = \frac{\text{Cu. ft. water} \times \#/\text{ cu. ft}}{\text{time} \times \text{horse power}} = \#/\text{I.H.P.}/\text{ hr.}$$

$$\text{Coal rate} = \frac{\#\text{ coal}}{\text{time} \times \text{H.P.}} = \# / \text{I.H.P./hr.}$$

$$\text{Water Rate} = \frac{345 \times 62.5}{3.5 \times 137.8} = 44.80 \ \# / \text{I. H. P.} / \text{hr.}$$

$$\text{Coal Rate} = \frac{3300}{3.5 \times 137.8} = 6.85 \ \# / \text{I. H. P.} / \text{hr.}$$

Run of April 20,1929

M.E.P.

	High Pressure Head End	High Pressure Crank End	Low Pressure. Head End	Low Pressure. Crank End.
	106	103	18	20.4
	98	100	18.9	20.70
	98.8	100	19.3	19.85
	99	94	17.4	19.0
Sum.	401.8	397	73.6	79.95
Av.	100.4	99.2	18.4	19.99

I.H.P. at 154.2 R.P.M.

I.H.P.

43.8	41.8	38.7	42.

Total I.H.P. 166.3 over $2\frac{1}{2}$ hours.

$$\text{Water rate} = \frac{146 \times 62.5}{166.3 \times 2.5} = 21.9 \text{ \# / I.H.P./ hr.}$$

$$\text{Coal rate} = \frac{1370}{166.3 \times 2.5} = 3.3\text{\# / I.H.P./hr.}$$

Equivalent Evaporation.

From and At 212°

Run of 12-27-28

Evaporation as is 30.12# from average feed temperature of 123° F and average pressure of 130# / in.^{2} gage.

130 x 15 = 145 at 145# $q = 327.4$

$L = 865.4$

From calorimeter reading quality = 95%.

Total heat B.T.U. at our conditions then

$xL + (q - f) = H.$

$865.4 \times .95 + (327.4 - 91) = H$

or 822 - 236.4 = 1058.4.

Then factor of equivalent evaporation is

$$\frac{1058.4}{970.4} = 1.085$$

$$\text{Eff.} = \frac{\#\ \text{water F \& A} \times 970.4}{\#\ \text{fuel} \times \text{heating value per }\#.}$$

$$= \frac{30.12 \times 1.085\ .\ 970.4}{3.19 \times 14,200}$$

$$= 70.4\%$$

Equivalent Evaporation
and
Boiler Efficiency

Run of 12-29-28.

Average Pressure 125# gage

Average Temperature feed water 113.7

Total heat

$$H = (q. - f) + x_1 r$$

$$= (324.6 - 81.7) + 867.6\ (95)$$

$$= 1067.9$$

Factor of equivalent evaporation

$$= \frac{1067.9}{970.4} = 1.095$$

$$\text{Eff.} = \frac{44.80 \times 1.095 \times 970.4}{6.85 \times 14,200}$$

$$= 49.2\%$$

Equivalent Evaporation and Boiler Efficiency

Run of 4 - 20 - 29

130 # pressure 122.4° F feed temperature average.

$$H = x_1 r_1 + (q - f)$$

$$= 95. (865.4) + (327.4 - 90)$$

$$= 1059.4$$

Factor of equivalent evaporation $= \frac{1059}{970.4} = 1.088.$

Boiler Efficiency.

$$\text{Eff.} = \frac{\#\ \text{water F \& A} \times 970.4}{\#\ \text{fuel} \times \text{heating value.}}$$

$$= \frac{21.9 \times 1.088 \times 970.4}{3.3 \times 14{,}200}$$

$$= 49.5\%$$

Rankine Efficiency

Run of 12-27-28

$$\text{Rankine Efficiency} = \frac{H_1 - H_2}{H_1 - Q_2}$$

$$= \frac{1192.9 - 896.2}{1192.9 - 104.87}$$

$$= 27.3\%$$

Run of 12 - 29 - 28.

$$\text{Rankine Efficiency} = \frac{1192.2 - 923.7}{1192.2 - 125.86}$$

$$= 25.1\%$$

Run of 4 - 20 - 29

$$\text{Rankine Efficiency} = \frac{1192.9 - 921.1}{1192.9 - 123.86}$$

$$= 25.3\%$$

Thermal Efficiency

of Engine.

Thermal Efficiency $= \dfrac{\text{B T U equivalent of horsepower}}{\text{\# Steam (Total heat - heat liquid at exhaust}}$

$= \dfrac{2545}{Wa\ (H_1 - q_2)}$

Run of 12 - 27 - 28

T. E. $= \dfrac{2545}{30.12\ (1088)}$

$= 7.83\%$

Run of 12 - 29 - 28

T. E. $= \dfrac{2545}{44.8\ (1066)}$

$= 5.32\%$

Run of 4 - 20 - 29

T. E. $= \dfrac{2545}{21.9\ (1074)}$

$= 10.85\%$

Overall Efficiency of Boiler and Engine

$$\text{Efficiency} = \frac{\text{Output in B.T.U.}}{\text{Input in B.T.U.}}$$

$$= \frac{\text{B.T.U. equivalent of one horsepower}}{\text{\# coal x heating value of coal.}}$$

Run of 12 - 27 - 28

$$\text{Efficiency} = \frac{2545}{3.19\ (14,200)}$$

$$= 5.61\%$$

Run of 12 - 29 - 28

$$\text{Efficiency} = \frac{2545}{6.85\ (14,200)\#}$$

$$= 2.62\%$$

Run of 4 - 20 - 29

$$\text{Efficiency} = \frac{2545}{3.3\ (14,200)}$$

$$= 5.43\ \%$$

Calorimeter.

Cal. Press.	Cal. Tempt.	Sat. Temp.	Superheat	Total Heat.
20.1	216	228	0	
20.1	215	228	0	
20.1	225	228	0	
20.1	228	228	0	1156.2
20.1	225.5	228	0	
20.1	225	228	0	
23.1	232	235.5	0	
25.1	240	240	0	1160.4
22.7	232	235	0	

$$H_2 = x_1 r_1 + q$$

$$1160.4 = x_1 r_1 + 331.4$$

$$x_1 r_1 = 829.0 \qquad r = 862.3$$

$$x_1 = \frac{829.0}{862.3} = 96\%$$

$$1156 = 320.5 + x\ (870.9)$$

$$x = \frac{835.5}{870.9} = .95 \text{ or } 95\%$$

Heating Value of Coal
by Bomb Calorimeter
Computations.

Calories expected 6,666 x .850 = 5,650

Theoretical expected rise $\frac{5650}{2356}$ = 2.40

(2356 = equivalent weight of water)

60% of expected rise = 2.4 x .6 = 1.44

Temp. at 60% = 1.44 + 26.30 = 27.74

$r_1 = \frac{t_2 - t_1}{n}$ $\qquad$ $r_1 = \frac{26.30 - 26.30}{5}$

where

r_1 = rate of rise $\qquad$ n = time firing to start.

t_1 = temperature at start

t_2 = temperature at firing point

Hence r_1 = 0 no rise correction.

$r_2 = \frac{t_3 - t_4}{p} = \frac{29.10 - 28.85}{9}$

where.

r_2 = rate of cooling

t_3 = maximum temperature

t_4 = final temperature

p = time from maximum to finish

r_2 = .028 and as b - c = 2 minutes

Then final temp. corrected.

$(2 \times .028) + 29.1 = 29.15$

Then

total rise = $29.15 - 26.30 = 2.85^{\circ}$

Total calories = $2356 \times 2.85 = 6{,}720$

Calories per gram = $6{,}720 \div .85 = 7900$

B T U per lbs. = $7900 \times 1.8 = 14{,}200$

Hence heating value = 14,200

Heating Value of Coal
by Bomb Calorimeter.

DATA

	Minutes	Temp.° C.		Minutes	Temp.° C.
	0	26.30		9	29.10
	1	26.30		10	29.00
	2	26.30		11	28.99
	3	26.30		12	28.99
a.	4	26.30	Fired	13	28.90
	4.5	26.60		14	28.90
b.	5.0	27.70		15	28.88
	5.5	28.40		16	28.85
	6.0	28.90			
	6.5	29.00			
c.	7	29.10			
	7.5	29.10			
	8	29.10			

Weight of sample .850 gram.

Weight of water 1900 grams

Water equivalent of calorimeter 456 grams

Assume heating value of coal 6,666 Cal per gram.

Gauge Calibration Data

200# Gauge

Actual	Corrected	Actual	Corrected
99	100	134	135
104	105	139	140
109	110	144	145
114	115	149	150
119	120	154	155
124	125	159	160
129	130		

30# gauge.

Reading	Corrected Reading.
5.4	5
10.4	10
15.1	15

Vacuum guage

Reading	Corrected Reading
5	6.5
9.8	11
13	13.95
13.5	14.8
18.8	20
22	23.4
26	27.6

Date 12-27-28

ENGINE AND BOILER ROOM DATA

Run Number	Time	Pressures: Main Steam	Throttle	First Receiver	Vacuum	Corrected Vacuum	Temperatures °F: Feed Water	F & F Tank	Cooling Disch.	Sea Water	Boiler Room	STACK	Misc.	MAIN ENGINE TOTAL REVS
I	10:00	130	132	18	23	24.5	123	126			101	635		0
	10:20	137.5	136	19	22.5	24	127							2385
	10:32	135	130	18	22.5	24	124	126	66		101	645		4809
	10:45	130.5	130	18	22.5	24	126		66	42				7406
	11:00	138.0	138	19	22.25	23.8	126	120	71	39	102	665		9627
	11:18	138	136	15.5	22.75	24.2	124							12195
	11:40		139	20	22.75	24.2								15390
														16240
	1:50	130	129	18	23	24.5	122	128			91		RUNNING FREE	30084
	2:05	125	130	18	23	24.5	125	127.5			93	680		22405
	2:20	122	129	18	23	24.5	127	113			95	635		24848
	2:35	140	116	15	23.25	24.8	121	—			106			27158
III	2:50	133	134	18	23	24.5	119	124			93	620	TOWING SAND & GRAVEL SCOW LIGHT	28635
	3:05	124	125	17	23	24.5	123	116			91	625		30716
	3:20	132.5	133	18	23	24.5	120	125			95	655		32761
	3:35	135	136	19.5	23	24.5	126	128			94	625		34872
	3:50	110	116	15	23.25	24.8	120	123			91	640		36976
	4:05	127	132	18	23	24.5	121	—	66	40	—	620		
	4:19													

ENGINE AND BOILER ROOM DATA

Run Number	Time	Counters and R.P.M.: Main Engine Counter	Main Engine Counter Diff.	R.P.M.	Feed Pump Counter	Feed Pump Counter Diff.	R.P.M.	Coal and Meter: Coal as Weighed	Net Coal	Total Coal	Meter Time	Meter Reading	(Cu.ft.)/10	(Cu.ft.Total)/10	Gage Glass
	10	67710			1417				320		10	1060			1/2
	10:15	70095	2385	158.5	1725	308	20.5				10:15	1130	70	70	
	10:30	72519	2424	162.0	2066	341	22.7			320	10:30	1310	180	180	1/2
	10:45	75116	2597	173	2398	332	22.1		123.5	443.5	10:45	1490	180	360	3/8
FEED PUMP TIME	11:00	77337	2221	148	2704	306	20.4		183	626.5	10:60	1650	160	520	DOWN
11.13	11:18	79905	2568	143	3007	303	20.2	150	120	746.5	11:13	1820	170	690	3/8
11:20	11:45	83100	3195	118.5	3180	183	18.3				11:23	1910	90	780	
11:53	11:50	83950	850	170	3737	557	18.6				11:53	2230	320	1100	
											SAME AS AT LEFT				
1	1:50	87794	3844		3851			233	188	934.5		2740	510	1610	5/8
	2:05	90175	2381	158	4145	294	19.6	315	255	1189.5		2900	160	1770	1/2
	2:20	92558	2383	158	4435	290	19.3					3060	160	1930	1/3
	2:35	94868	2310	154	4738	303	20.2					3240	180	2110	3/4
	2:50	96345	1477		4940			322	262	14515		3332	92	2202	1/2
	3:05	98426	2081	138.5	52110	271	18.05					3474	142	2344	Down
	3:20	100471	2045	136.3	5508	297	19.8	312	252	1703.5		3640	166	2510	1/2
	3:35	12582	2111	140.6	5792	284	18.9					3790	150	2660	1/4
	3:50	4686	2104	140.2	6101	309	20.6	320	260	1963.5		3960	170	2830	5/8
	4:05	6712	2026	135	6357	256	17.05					4098	138	2968	1/2

ARRIVE S. BOSTON 11:23
ATLANTIC W 11:53
T WHARF 12:10

ENGINE AND BOILER ROOM DATA

Run Number	Time	Pressures: Main Steam	Throttle	First Receiver	Vacuum	Corrected Vacuum	Temperatures: Feed Water	F & F Tank	Cooling Disch.	Sea Water	Boiler Room		Misc.: Time	Total Revs
	7:55							89			90		7:00	0
	8:10							96					7:15 9:54	95 826
	9:20	128											10:20	3189
	9:25	128	132	3	0	0		111			99		10:21	3324
	9.50		139	9	26	27.6		112			97		10:23	3665
	10:20	128	132	18	21	22.4		118.5			95		10:24	3805
	10:35	115	136	3	11	12.0		126			98		10:33	4932
	10:45		130	-1	9	10.2		100			95		10:38	5041
	11:00	115	134	3	0	0							10:40	5323
	11:30	120					122	139			103		11:53	5949
	11:53	125											1201	7461
	12:10	135	135	17	21	22.4	120						1209	8239
	12:20	135	131	13	21	22.4	120	126			95		12:10	9800
	12:40	138	140	17	20.5	21.8	122	123			88		12:30	11311
	1:05	120	132	13	21.5	22.8							12:40	12856
	1:15	140	144	4	14	15.4		111			99		1:03	13934
	1:40							125			107		1:04	14087
	2:00	135					109	85			101		1:09	14839
	2:15							85			105		1:15	15644
	2:30	140					105	135			107		1:32	15858
													4:10	15858

ENGINE AND BOILER ROOM DATA

Run Number	Time	Pressures					Temperatures						Misc.	
		Main Steam	Throttle	First Receiver	Vacuum.	Corrected Vacuum	Feed Water	F & F Tank	Cooling Disch.	Sea Water	Boiler Room		Time	Total Revs
	2:40		140	2	0	0							4:30	17696
	3:05	100	103	2	0	0							5:06	22455
	3:45						108	104			108		5:12	23577
	4:05	150						80			101		5:18	24377
	4:15	140	130	16	22	23.4	105	86			90		5:43	28502
	4:35	135	136	7	21.5	22.8	110	111			95		5:50	29661
	4:45		136	22	20.5	21.8		116			93		6:03	31687
	5:00	120	117	19	20.5	21.8		116			99			
	5:20							121			100			
	5:30	125	112	19	21	22.4	116							
	5:40							115			103			
	5:45	142	142	20	20.5	21.8								
	6:00							118			91			

Date 12-29-28

ENGINE AND BOILER ROOM DATA

		Counters and R.P.M.						Coal and Meter							
Run Number	Time	Main Engine Counter	Main Engine Counter Diff.	R.P.M.	Feed Pump Counter	Feed Pump Counter Diff.	R.P.M.	Coal as Weighted	Net Coal	Total Coal	Meter Time	Meter Reading	(Cu.ft)/10 min.	(Cu.ft.Total)/10	[illegible]
	7:00							389	319	319				0	
	7:06	10113													
	7.10							307	251	570	7:09	04460			
	7:15	10208	95	9.5	6952						7:15	4540	80	80	
	7:55				6992						7:55	4548	48	128	Bot
	8:02				7218						8:02	4636	88	216	
	9:07				7427										
	9:20	10208	000		7501										Bot
	9:50			148											1/2
	9:54	10939	731												
	10:08			142	7883						10:08	4930	294	510	
	10:20	13302	2363	91.5											
	10:21	13437	135	135	8113						10:21	5074	144	654	
	10:23	13778	341	170.5											
	10:24	13918	140	140											
	10:33	15045	1127		8346										Bot
	10:38	15154	109												
	10:40	15436	282	141				293	227	797					
	10:45				8492						10:45	5237	163	817	
	11:00				8628						11:00	5309	72	889	3/5
	11:30				8778						11:30	5350	41	930	1/2
	11:53	16062	626		8895						11:53	5389	39	969	Full

Date 12-29-28

ENGINE AND BOILER ROOM DATA

Run Number	Time	Counters and R.P.M. Main Engine Counter	Main Engine Counter Diff.	R.P.M.	Feed Pump Counter	Feed Pump Counter Diff.	R.P.M.	Coal and Meter Coal as Weighed	Net Coal	Total Coal	Meter Time	Meter Reading	(Cu.ft.)/10	(Cu.ft.Total)/10	Gage Glass
	11:55							124	96	893					
	12:01	17574	1512		9007						12:01	5433	44	1013	
	12:09	18352	778	97											
	12:10	19913	1561								12:10	5564	131	1144	1/5
	12:15							227	165	1058	12:15	5610	46	1190	
	12:25				9525						12:25	5726	116	1206	1/5
	12:30	21424	1511	75.5				134	92	1150					
	12:40	22969	1545	154.5	9788						12:40	5910	184	1390	
	12:50				10047							6042	132	1522	
	1:03	24047	1078	47											
	1:04	24200	153	153											
	1:07							351	281	1431					
	1:09	24952	752	150											
	1:10				519						1:10	6190	148	1670	2/5
	1:15	25757	805	134											
	1:32	25971	214		606						1:32	6325	135	1805	Bot
	1:45							210	168	1599					
	2:00	25971	0		858						2:00	6420	95	1900	
	2:30	25971			1177						2:30	6533	113	2013	4/5
	2:45							430	360	1959					
	3:00				1311						3:00	6590	57	2070	1/5
	3:30				1430							6630	40	2110	Bot

Date 12-29-28

ENGINE AND BOILER ROOM DATA

Run Number	Time	Counters and R.P.M.: Main Engine Counter	Main Engine Counter Diff.	R.P.M.	Feed Pump Counter	Feed Pump Counter Diff.	R.P.M.	Coal and Meter: Coal as Weighed	Net Coal	Total Coal	Meter Time	Meter Reading	(Cu.ft.)/10.	(Cu.ft. Total)/10	
	3:50				1576			220	164	2123	3:50	6690	60	2170	
	4:00	25971			1686						4:00	6720	30	2200	
	4:10	25971	00												
	4:15				1883						4:15	7837	117	2317	4/5
	4:30	27809	1838	97	2123						4:30	7940	103	2420	
	4:32							230	188	2311					
	4:55							414	344	2655					
	5:00				2716						5:00	8266	326	2746	1/5
	5:06	32568	4759	135											
	5:12	33690	1122	185.2											
	5:15				2982						5:15	8420	154	2900	1/5
	5:18	34490	800	133.3											
	5:25							200	144	2799					
	5:30				3274						5:30	8600	180	3080	
	5:40							346	276	3075					
	5:43	38615	4125	165											
	5:46				3565						5:46	8770	170	3250	
	5:50	39774	1159	165.5											
	6:03	41800	2026												

Date:- 12-29-28

STACK and QUALITY DATA

Run Number	Time	Flue Gas Analysis							Combustion				Calorimeter		
		$\% \, CO_2$	[illegible]	O_2	Volume	% CO	$\% \, N_2$		Stack Temp.	Smoke - %	Draft, In. H_2O		Steam Pres.	Cal. Pres.	Cal. Temp.
	9:10												133	5	216
													133	5	215
	10:25												133	5	225
													133	5	228
	11:30												133	5	225,5
													133	5	225
	2:00												135	8	232
	4:40												137	10	240
	5:10												116	7.6	232

Date 4-20-29

ENGINE AND BOILER ROOM DATA

Run Number	Time	Pressures: Main Steam	Throttle	First Receiver	Vacuum	Corrected Vacuum	Temperatures: Feed Water	F & F Tank	Cooling Disch.	Sea Water	Boiler Room	Stack.	Misc.: Total Rev's	
	2:30	112	—	—	—									0
	2:34	—	112	12	20.5	21.8								0
	2:45	—	84	9	22.0	23.4					76			0
	3:00	120	114	15	20.5	21.8	104	112			80	510	2	035
	3:15	145	144	20	19.5	20.8	120	124			90	530	4	382
	3:30	130	133	18.5	19.8	21.2	124	121			88	585	6	846
	3:45	142	143	2.4	19	20.3	122	128			84	545	9	348
	4:00	140	143	20	19.5	20.8	131	131			82	620	11	742
	4:15	141	140.5	21	19.3	20.5	124	125			87	622	14	204
	4:30	140	139.5	20	20	21.4	124	121			85	625	16	726
	4:45	132	135	19	19.5	20.8	—	129			84	620	19	067
	5:00	138	135	19	19.6	20.9	122	125			84	625	21	492
	5:13	145	—	—	—	—	122	—			—	647	23	576
	5:15		114	16	20	21.4	—	109			89	—	23	656
	5:18	140	140	9	21	22.4	—	—			—	—	24	040
	5:30	142	141	11	18.5	19.8	126	131			95	635	25	266
	5:45	135	143	5	18.8	20	122	120			99	665	26	836
	6:00	140	120	14.5	20.0	21.4	—	—			—	—	28	800
	6:15	—	—	—	—	—	—	116			98	—	—	—

Date 4-20-29

ENGINE AND BOILER ROOM DATA

Run Number	Time	Pressures					Temperatures						Misc.	
		Main Steam	Throttle	First Receiver	Vacuum	CORRECTED VACUUM	Feed Water	F & F Tank	Cooling Disch.	Sea Water	Boiler Room	STACK	TOTAL REVS	
	6:18	135	121	9	20.7	22	118					595	31	280
	6:30	140	137	13	17.7	19.0	123	131			96	645	32	890
	6:45	145	142	8.5	17.5	18.8	126	132			99	620	34	274

ENGINE AND BOILER ROOM DATA

Run Number	Time	Counters and R.P.M.						Coal and Meter							[illegible]
		Main Engine Counter	Main Engine Counter Diff.	R.P.M.	Feed Pump Counter	Feed Pump Counter Diff.	R.P.M.	Coal as Weighted	Net Coal	Total Coal	Meter Time	Meter Reading	Cu.ft./min.	Cu.ft.Total	
	2:30				4045							874			
	2:34														
	2:45	56524		142				344	264	264					
	3:00	58559	2035	142	4325	280						879	5	5	
	3:15	60906	2347	156	4583	258						894	15	20	
	3:30	63370	2464	164	4894	311		359.5	279.5	543.5		912	18	38	
	3:45	65872	2502	167	5144	250						930	18	56	
	4:00	68266	2394	159	5436	292						948	18	74	
	4:15	70728	2462	164	5711	275					SAME AS OTHER READINGS	966	18	92	
	4:30	73250	2522	170	6023	312		791.5	611.5	1155		985	19	111	
	4:45	75591	2341	156	6317	294						1003	18	129	
	5:00	78016	2425	162	6594	277						1020	17	146	
	5:13	80100	2084	161	6864	270		419	319	1474		1035	15	161	
	5:15	80180	80	40											
	5:18	80564	384	128											
	5:30	81790	1226	105	7123	259						1054	19	180	
	5:45	83360	1570	105	7370	253						1069	15	195	
	6:00	85324	1964	131											
	6:18	87804	2480	138								1101	32	227	
	6:30	89414	1610	134	8113	743						1115	14	241	
	6:45	90798	1384	92	8334	221		1047	787	2261		1128	13	254	