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REPORT OF A BOARD OF NAVAL ENGINEERS ON THE TESTS OF A HERRESHOFF BOILER, NEW TYPE, FITTED ON THE LAUNCH "JERSEY LILY", AND OF A HERRESHOFF BOILER, OLD TYPE, FITTED ON THE LAUNCH "OUR MARY", AT BRISTOL, R. I., APRIL 19, 20, *AND* 24, 1888.

WASHINGTON, D. C., *May* 17, 1888.

SIR: In obedience to the Department's order of the 14th instant, and under instructions from the Bureau of Steam Engineering, letter No. 508, we proceeded to Bristol, R. I., to the works of the Herreshoff Manufacturing Company, for the purpose of testing a new design of boiler made by that company.

Our instructions contemplated two special tests of the boiler under maximum conditions of forced combustion, with measurements of the evaporation and quality of steam furnished, and an indication of the power of the engines. The Messrs. Herreshoff did not anticipate tests of this character, and, therefore, no provision had been made for making them. No indicator gear was fitted to the engines and, owing to the light hull of the boat, the rough water which prevailed, and the limited time before delivery to the owner, they were led to decline a full-power trial at the wharf. Facilities were, however, furnished for evaporative and calorimetric tests under natural draft, and for a full-power trial in free route, with the combustion forced by means of the steam-jet in the smoke-pipe.

DESCRIPTION OF THE BOILER.

The new design differs materially from any heretofore adopted by the Herreshoff Company. The boiler consists of a number of vertical elements, each composed of horizontal tubes (five tubes in the boiler tried) of equal lengths, with right and left hand threads, and connected by return bends. Two adjacent elements are connected at the back and lower ends, by short vertical tubes, to a Y-piece, which has a short connection to a mud-drum, situated below the grate-bars. At the upper ends, the same elements are similarly connected to a steam-drum situated just in front of the boiler casing. There are twenty-two of these tubular elements, the lower tubes being about thirteen inches above the grate-bars. At each side of the grate, there is a similar element having a longer connection to the steam-drum and a shorter one to the feed-water pipe near the mud-drum. These side elements and the vertical connecting pipes to the mud-drum serve like water-legs to protect the boiler-casing from the intense heat of the fire. Above the boiler proper and entirely within the casing, there are three horizontal elements forming a practically continuous pipe, the tubes of which are connected to each other as in the vertical elements. These elements serve as a feed-water heater and also protect the top of the casing by reducing the temperature of the gases of combustion.

In front and at the upper part of the boiler is the centrifugal separator, from the top of which the main steam-pipe leads to the engine, and at about the middle of which the steam-drum is connected. The upper element of the feed-water heater receives the main feed-pipe, the lower element being connected to the bottom of the separator. From each side of the separator and near its bottom, a tube leads the heated feed-water underneath the side element to the mud-drum. The ash-pan, mud-drum, grate-bars, furnace, and all tubes are inclosed in a rectangular double-shell casing of No. 16 iron, the 1¼-inch space between the shells being filled with mineral wool. The ash-pan is of No. 12 iron. The extreme dimensions of the casing are 3 feet 7½ inches by 3 feet 7½ inches, and 3 feet 10½ inches high. At the top, the casing slopes from the smoke-pipe to each side, making the height 6 inches less than in the middle. The steam-drum and separator project in front of the casing 14 inches. All tubes of the boiler and feed-water heater are of iron, 1 inch in inside diameter, and were separately tested, before they were put in the boiler, to a pressure of 1,000 pounds per square inch. The U-connections are of malleable cast-iron, carefully selected.

The accompanying drawings, which are on a scale of ⅙, clearly show the design of the boiler.

Before starting fires, water is pumped into the boiler until it shows in the glass on the separator, at the level indicated in the drawing. As steam is formed, water is fed to the upper part of and through the feed-water heater and thence to the bottom of the separator, from which the side tubes, before described, lead it, together with any water that may have come from the steam-drum, to the mud-drum. From the latter it circulates upwards through the tubes of the boiler proper. The design looks towards a complete, or nearly complete, conversion of the water into steam before it reaches the steam-drum.

The object of the present design is to produce a boiler which will not require, as did the original Herreshoff coil boiler, the close attention to the feed-water supply, or, at least, not more than is required in any quick-steaming boiler of the ordinary shell types.

The first boiler built on this design, and the one tested by us, is placed on board of a large launch, the *Jersey Lily*, which is intended for special excursions and arranged to carry the largest possible number of passengers. The hull is very light, finished inside and out in mahogany, with iron strengthening frames. There is a light canopy and a small pilot-house forward.

The engines are of the vertical, inverted, direct acting, triple-expansion type, exceedingly light, but of the best materials and highest class of workmanship. All cylinders are fitted with piston-valves, worked by eccentrics on a counter-shaft which is geared to the main shaft. There is only one eccentric and rod for each valve. The reversing is effected by means of spiral feathers, pinion and rack, the latter being concentric and revolving with the shaft. There is an outside keel condenser. The air and feed pumps are vertical, and are worked by beams and links from the cross-heads of the low and high-pressure piston-rods, respectively.

The following are the principal dimensions of the hull:

	Ft.	In.
Length over all	65	0
Length on water-line	63	5
Beam	10	8
Draught, amidship (light)		33
Draught at stem and stern (light)		0

Weight of hull, boiler, and machinery complete, without coal or water, and two men on board, 7.81 tons.

The principal dimensions of the engine are as follows:

	Inches.
Diameter of high-pressure cylinder	4
Diameter of intermediate-pressure cylinder	$6\frac{1}{4}$
Diameter of low-pressure cylinder	10
Stroke of pistons	8
Diameter of high-pressure valve	2
Stroke of high-pressure valve	$1\frac{3}{8}$
Diameter of intermediate-pressure valve	$2\frac{3}{4}$
Stroke of intermediate-pressure valve	$1\frac{3}{8}$
Diameter of low-pressure valve	$3\frac{1}{4}$
Stroke of low-pressure valve	$1\frac{1}{2}$
Steam-ports, high-pressure and intermediate-pressure cylinders	$\frac{3}{8}$
Steam-ports, low-pressure cylinder	$\frac{1}{2}$
Cut-off, in all three cylinders, from commencement	$\frac{3}{4}$

The condenser is a copper tube 39 feet 6 inches long, $\frac{1}{16}$ thick, and tapering nearly uniformly from $3\frac{1}{4}$ to 1 inches.

The air-pump is single-acting, $3\frac{1}{2}$ inches in diameter and has a stroke of $3\frac{1}{4}$ inches.

There are two feed-pumps, each $\frac{7}{8}$ inch in diameter and a stroke of $3\frac{1}{4}$ inches.

NOTE.—Two feed-pumps are required with the coil boiler, one to draw from the hot-well and the other from the separator. With the new boiler, only one pump is required, as the water from the separator falls by gravity to the lower part of the boiler.

Weight of engines, complete, including crank-shaft, 831 pounds.

No particulars of the propeller were furnished.

The principal dimensions of the boiler are as follows:

Grate surface, 3 by 3 feet	square feet..	9.0
Heating surface above grates, in boiler proper	do....	134.52
Heating surface above grates, in feed-water heater	do....	70.76
Heating surface, total	do....	205.28
Ratio of grate to heating surface		1 to 22.81
Weight of empty boiler, including attachments	pounds..	2,945
Weight of water in boiler to steaming level	do...	105
Total weight of boiler and water	do...	3,050

Under the Bureau's modified instructions (Letter No. 520) the tests mentioned on page 1 of this report were made. In addition, we made a short evaporative and calorimetric test of a rectangular coil boiler. This boiler was of the same outside dimensions of casing as the other and was in the launch *Our Mary*, a duplicate of the *Jersey Lily*.

In each of the three tests, the boiler was first pumped up to the steaming level and then a wood fire started, steam being raised in from five to ten minutes. A fire was then started with 30 pounds of white pine, a quantity considered just sufficient to ignite the coal, which was thereafter so supplied as to keep the fire in a uniform condition. The height of the water in the gauge was marked and the trial considered as having commenced.

In the first trial, firing was stopped at the end of six hours, the coal then in the furnace burning out in one hour and twenty minutes.

The following table gives the results of the first trial:

Evaporative test of the boiler of the Jersey Lily, at Bristol, R. I., April 19, 1888.

[All weights are in pounds and all temperatures in degrees Fahrenheit.]

Totals.

Duration of trial, in hours	6.0
Coal consumed	497.0
Refuse from coal	126.0
Combustible consumed	371.0
Water evaporated, by tank measurement	3,165.2

Averages.

Temperature of feed-water	62.0
Temperature of uptake	427.5
Temperature of atmosphere	50.0
Temperature of steam, by thermometer	340.0
Pressure of steam, by gauge	120.4

Ratios.

Coal per square foot of grate, per hour	9.33
Combustible per square foot of grate, per hour	6.89
Water evaporated from 62 degrees, per pound of coal	6.37
Water evaporated from 62 degrees, per pound of combustible	8.53
Water evaporated, equivalent to, from and at 212 degrees	10.23

The coal was "red ash" anthracite, egg size, and of good quality.

During the trial, six calorimetric tests were made, the quality of the steam being computed by the formula.

$$Q=\frac{1}{l}\left(\frac{W}{w}(h'-h)-(T-h')\right)$$

Q=quality of steam, dry saturated steam being unity.
W=weight of water originally in calorimeter.
w=weight of water added to W by condensed steam.
T=total heat of water, due to observed pressure of steam.
l=latent heat of steam at observed pressure.
h=total heat of water of initial temperature, in calorimeter.
h′=total heat of water of final temperature, in calorimeter.

The observed data and computed results are given in the following table:

Calorimeter tests of Herreshoff boiler (new type) in launch Jersey Lily, at Bristol, R. I., April 19, 1888.

No. of test.	Time. At beginning of test.	Time. At end.	Steam pressure by gauge. At beginning.	Steam pressure by gauge. At end.	Weight of empty barrel. *b*.	W + *b*.	W.	W + *b* + *w*.	*w*.	Temperatures. Final. *t′*.	Temperatures. Initial. *t*.
1	A. M. 11.13	A. M. 11.35	115	120	39.9	196	156.1	205.1	9.1	111.3	48.4
2	A. M. 11.57	P. M. 12.17	125	116	39.3	196	156.7	205.4	9.4	111.0	47.7
3	P. M. 12.47	P. M. 1.09	122.5	115	39.5	196	156.5	206.2	10.2	111.5	46.3
4	1.32	1.56	122	122	39.3	196	156.7	205.4	9.4	111.2	46.1
5	2.07	2.40	120	120	39.6	196	156.4	205.5	9.5	110.7	45.9
6	3.11	3.33	123	121	39.9	196	156.1	205.25	9.25	110.6	46.5

Calorimeter tests of Herreshoff boiler (new type) in launch Jersey Lily, etc.—**Continued.**

No. of test.	Units of heat.						Q.
	h'.	h.	$h'-h$.	l.	T.	$T-h'$.	
1	79.4009	16.4015	62.9994	867.7412	320.4620	241.0611	.966
2	79.0998	15.7010	63.3988	866.4778	322.2531	243.1533	.969
3	79.6016	14.3007	65.3009	867.2365	321.1773	241.5762	.962
4	79.3005	14.1009	65.1996	865.8555	323.1361	243.8356	.974
5	78.7988	13.9010	64.8978	866.6859	321.9580	243.1692	.962
6	78.6985	14.5006	64.1979	865.8555	323.1361	244.4376	.960
					Average Q		.965

From the average value of Q it will be seen that the moisture was 1.0—0.965=0.035, or 3½ per cent.

To determine the equivalent evaporation, had all the heat absorbed by the water in the boiler been utilized in producing dry steam, we have the following data and the computations therefrom:

Average steam pressure, absolute (p)	135.1
Temperature corresponding to this pressure (t)	350.077
Units of heat in 1 pound of steam at pressure p, from 32°	1188.7135
Units of heat in 1 pound of water at pressure p, from 32°	322.1943
Total weight of feed-water of a temperature of 62°	3165.19
Units of heat in 1 pound of water of a temperature of 62°	30.0075

1188.7135—30.0075=1158.706=units of heat required to convert 1 pound of water at 62° to steam at pressure p.

322.1943—30.0075=292.1868=units of heat required to raise 1 pound of water from 62° to temperature t.

But only 0.965 of the water fed to the boiler was converted into steam, the remainder, 0.035, passing over as moisture of a temperature t.

Therefore, 3165.19×0.965=3054.408=pounds of water converted into steam. This required an expenditure of 3054.408×1158.706=3539160.876 units of heat.

To raise the remaining water from 62° to the temperature t required (3165.19—3054.408)×292.1868=32369.038 units of heat.

Therefore, there was absorbed by the 3165.19 pounds of water fed into the boiler a number of units of heat equal to 3539160.876+32369.038=3571529.914, and hence, $\frac{3571529.914}{371 \times 1158.706}$=8.31=equivalent evaporation per pound of combustible from 62° and under an absolute pressure of 135.1 pounds.

And (8.31×1158.706)÷965.7=9.97=equivalent evaporation from and at 212°.

During the trial there was at no time any evidence of priming, no difficulty was experienced in manipulating the boiler, and the engines were not slowed for any purpose.

FREE-ROUTE TRIAL OF THE LAUNCH "JERSEY LILY", APRIL 20, 1888.

Steam was raised in nine minutes. Eight minutes after starting the coal fire the engines were started and the launch put under way. At 10.11 a. m., when the steam-gauge showed 145 pounds pressure, the jet was put on and continued in use until the end of firing, except when the safety-valve, which had been set at 200 pounds, lifted. The water from the condenser was measured into the hot well, as was also that supplied to the auxiliary pump, the waste of steam by the jet and safety-valve being supplied from a barrel of fresh water carried on board.

Five hundred and thirty-five pounds of coal, of the same quality and size as that used in the trial at the wharf, were put on board and burned, the last coal being fired at 12.25 p. m. From this time the fire continued to burn for 56 minutes more. The amount of refuse remaining, when the furnace was cleaned, was much smaller than that in the previous trial, owing to the use of forced draft.

The engine data, which were taken every seven and one-half minutes during two and one-half hours of the greatest performance, are averaged below:

Steam-pressure, by guage, in pounds per square inch	195
Vacuum, in inches	24.5
Revolutions per minute	471.7
Lowest number of revolutions per minute	426
Highest number of revolutions per minute	488

Total weights, in pounds:	
Coal consumed	535
Dry refuse from coal (no allowance for coal and ashes carried out of smoke-pipe)	94.5
Combustible consumed (apparent)	440.5
Water pumped into boiler from hot well	2,713.02
Water pumped into boiler from auxiliary tank	444.00
Total water pumped into boiler	3,157.02
Evaporation:	
Per pound of coal, from 62°	5.901
Per pound of combustible, from 62°	7.17
Per pound of combustible, from and at 212°	8.68
Total time of firing, in hours	$2\frac{18}{60}$
Coal consumed per hour, in pounds	232.62
Coal consumed per hour per square foot of grate, in pounds	25.85

Soon after starting on the run, the gauge-glass burst, the automatic valves closing immediately, and during the rest of the trial the water-level was regulated by the gauge-cocks.

Ten runs were made over the measured mile, five with and five against the wind and tide, and then two, over a measured course of 3 nautical miles, one with and one against the wind and tide, the speed increasing from 13 to 15 statute miles per hour. The engines were not slowed at any time between the runs, nor in turning. There was no evidence of priming, nor was any water carried over to the engines, although there must have been considerable variation in the height of water in the boiler.

Steam blown through the gauge-cocks appeared to be dry. At 11.24½ a. m., the gauge indicating then 190 pounds, the engines were stopped, the fire burning actively. The auxiliary pump was put on, the jet closed, and the furnace door opened; the steam-pressure fell so rapidly, however, with the bleeder-pipe open, that the door was closed very soon after. There was no lifting of the water or other evidence in the behavior of the boiler that would indicate any more tendency to disastrous results of any kind than in the ordinary shell boiler. Apparently dry steam only was blown through the gauge-cocks, which were frequently opened during the stoppage.

At 11.34½, the engines were again started and the jet put on, the steam-pressure beginning to rise immediately from 185 pounds. At 11.35½, went ahead at full speed. From 12.25, when the last coal was put in the furnace, until 1 p. m., the average pressure maintained was 195 pounds.

At 1.04 the valves were reversed from full speed ahead to full speed astern, the engines backing in 15 seconds, with steam at 150 pounds. Several other trials in backing and also in turning were made, the boat beginning to back from full speed ahead in little more than half her length. The diameters of the turning circles were about twice the length of the boat. She was easily handled, being light; the engines worked without a hitch, the bearings ran cool and required little attention. At 1.21 p. m., the launch was brought alongside the wharf, the steam-gauge showing 70 pounds. The water was left at the bottom of the gauge, apparently. The dry ashes were weighed, the furnace having been well cleaned.

In the *Jersey Lily* the top of the boiler-casing is easily removable, so that by disconnecting the separator and pipes in front, the whole boiler can be readily lifted out (a space above equal to the height of vertical tubular elements being required to do this) and any tube removed.

In the larger boiler, arranged for higher power, while the principle is the same in every respect, there are some differences in the details of construction. The steam-drum is placed within the rectangular casing and the separator at the back of the boiler, so as to leave the front of the casing free for removal. There are four horizontal elements in the feed-water heater, instead of three, and seven tubes in each vertical element, instead of five. All tubes are 2 inches in internal diameter, and are joined to U's and elbows by right and left hand threads. The vertical elements connect directly (without the interposition of Y's) to short tubes in the steam and mud drums, being secured to them by heavy union-couplings, the nuts of which are fitted with lugs on top for spanners. The joint is made with asbestos washers. The holes in the drums are zigzagged. The casing is a single shell, with inside T-irons securing a lining, 2½ inches thick, of "Magnesia" bricks.

A boiler of this kind, designed to develop from seven to eight hundred horse-power, is being put in the yacht *Say When*, launched by the Herreshoff Company on April 24. Its grate-surface is 58 square feet, and the casing rectangular, about 8½ by 8½ by 8½ feet high. The construction in all details seems to be substantial. Owing to the large number of joints in contact with the fire, the liability to leakage is increased, but, on account of the facility with which any one element can be removed, the force of any objection on this score is reduced to a minimum. In case one or several of the elements are removed, the holes can be closed by caps and the rest of the boiler continued in use.

The computed weight of this boiler, with its attachments, is between 11 and 12 tons net. The space required in front for removal of the elements would be only 7 feet, or less than the usual width of fire-rooms.

We are of the opinion that this type of boiler is well adapted for large powers, and see no reason why any number of boilers, each complete in itself as described, with regulating check-valves for the control of the feed-water supply, should not be successfully arranged in batteries and in separate compartments. It is not yet certain whether it will operate satisfactorily with a powerful forced draft and highest rate of combustion, but its performance in the *Jersey Lily*, when in free route, indicated that even a higher rate of combustion than was secured would not have caused prejudicial results. When the *Say When* is completed, there will be an excellent opportunity to further test this question, as a powerful blower is supplied to force the combustion to the high rate that is expected, and which, in fact, will be necessary to produce the horse-power anticipated.

The class of skilled labor required for the proper care of the boiler when in use, and for repair and renewal of parts when found defective, can be generally found, in our opinion, on board our naval steamers, the character of the work being mainly pipe-fitting.

On April 24, in accordance with the expectations and wishes of the Messrs. Herreshoff, we made the trial with the old type of boiler in *Our Mary*. This trial was mainly for the purpose of observing the general working of the boiler in order to institute a comparison of the care and attention required in the two types; but, as before described, an evaporative and four calorimetric tests were also made. The trial lasted four hours, the fire burning for forty-five minutes after the last coal was put in the furnace.

The following table gives the results:

EVAPORATIVE TEST OF THE BOILER OF "OUR MARY", AT BRISTOL, R. I., APRIL 24, 1888.

[All weights are in pounds and all temperatures in degrees Fahrenheit.]

Totals.	
Duration of trial, in hours	4.00
Coal consumed	324.00
Refuse from coal	63.35
Combustible consumed	260.65
Water evaporated, by tank measurement	2,310.00
Averages.	
Temperature of feed-water	64.6
Temperature of atmosphere	49.6
Pressure of steam by gauge	112.0
Ratios.	
Coal per square foot of grate, per hour	9.00
Combustible per square foot of grate, per hour	7.22
Water evaporated from 64.6°, per pound of coal	7.13
Water evaporated from 64.6°, per pound of combustible	8.[illegible]6
Water evaporated, equivalent to, from and at 212°	10.59

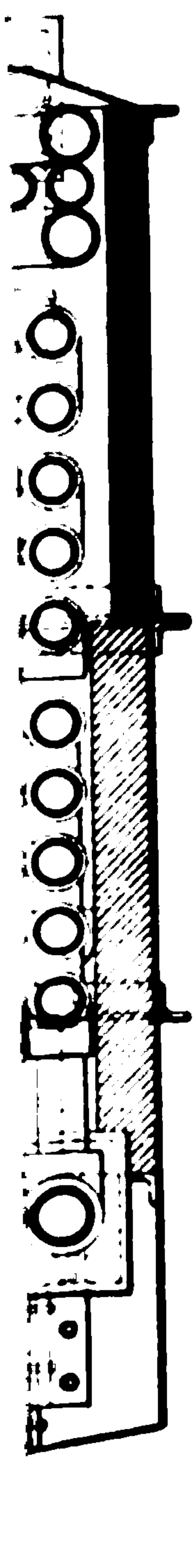
The observed data and computed results of the calorimetric tests are given in the following table:

Calorimeter tests of Herreshoff boiler (old type) in launch Our Mary, at Bristol, R. I., April 24, 1888.

Number of test.	Time.		Steam pressure by gauge.		Weight of empty barrel.	W + b.	W.	W + b + w.	w.	Temperatures.	
	At beginning of test.	At end.	At beginning.	At end.	b.					Final. t'.	Initial. t.
1*	A. M. 11.02	A. M. 11.29	97	130	39.7	196	156.3	206.2	10.2	111.1	44.0
2	A. M. 11.50	P. M. 12.11	155	125	39.8	196	156.2	205.75	9.75	111.3	45.4
3	P. M. 1.26	1.51	115	115	39.8	195	155.2	204.6	9.6	111.3	46.9
4	2.08	2.31	105	112	39.8	195	155.2	204.8	9.8	112.0	45.7

* Slowed engines during test owing to water in cylinder.

Note: Original report contained drawings which are omitted in this version.



Calorimeter tests of Herreshoff boiler (old type) in launch Our Mary, etc.—Continued.

No. of test.	Units of heat.						Q.
	h'.	*h*.	*h'*-*h*.	*l*.	T.	T-*h'*.	
1	79.2001	12.0006	67.1995	869.4661	318.0155	238.8154	.9095
2	79.4008	13.4009	65.9999	859.7610	332.1875	252.7867	.9358
3	79.4008	14.9003	64.5005	868.8159	318.9377	239.5369	.9245
4	80.1032	13.7009	66.4023	871.6488	314.9190	234.8158	.9371
					Average Q		.927

From the average value of Q, it will be seen that the moisture was 1.0—0.927=0.073, or 7.3 per cent., which is more than twice the amount found in the boiler of the *Jersey Lily*.

To determine the equivalent evaporation, had all the heat absorbed by the water in the boiler been utilized in producing dry steam, we have the following data and the computations therefrom:

Average steam pressure, absolute (p)	126.7
Temperature corresponding to this pressure (t)	345.15
Units of heat in 1 pound of steam at pressure p, from 32°	1187.2107
Units of heat in 1 pound of water at pressure p, from 32°	317.0975
Units of heat in 1 pound of water at temperature of 64.6°	32.6091
Total weight of feed-water of a temperature of 64.6°	2310.0

1187.2107—32.6091=1154.6016=units of heat required to convert 1 pound of water at 64.6° into steam at pressure p; 317.0975—32.6091=284.4884=units of heat required to raise 1 pound of water from 64.6° to temperature t.

But only 0.927 of the water fed to the boiler was converted into steam, the remainder 0.073, passing over as moisture of a temperature t.

Therefore 2310×0.927=2141.37 pounds of water converted into steam. This required an expenditure of 2141.37×1154.6016=2472428.5858 units of heat.

To raise the remaining water from 64.6° to the temperature t, required (2310—2147.37)×284.4884=47973.2283 units of heat.

Therefore there was absorbed by the 2310 pounds of water fed into the boiler a number of units of heat equal to 2472428.5858+47973.2283=2520401.8141, and hence (2520401.8141×260.65)÷1154.6016=8.83=equivalent evaporation per pound of combustible from 64.6° and under an absolute pressure of 126.7 pounds.

And (8.83×1154.6016)÷965.7=10.557=equivalent evaporation from and at 212°.

The excessive moisture shown by the calorimetric tests in the above case was plainly evident from the working of the engines during the trial, as these had to be slowed several times on account of water in the cylinder. This excess was, no doubt, due to slight variations in the water-level, although the closest attention was given to its regulation. It is in this particular, as well as in facility for repairs, that the new type is superior to the old one.

Very respectfully,

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C. W. RAE,
Passed Assistant Engineer, U. S. Navy.
F. C. BIEG,
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