

RESEARCH COMMITTEE ON MARINE-ENGINE TRIALS.

REPORT UPON TRIALS OF THREE STEAMERS,
"FUSI YAMA," "COLCHESTER," "TARTAR."BY PROFESSOR ALEXANDER B. W. KENNEDY, F.R.S., *Chairman.*

The Research Committee on Marine-Engine Trials, appointed some three years ago by this Institution, had the pleasure this time last year of presenting a report on the first of their trials, which was made upon a triple-expansion engine in the s.s. "Meteor" running between Leith and London (Proceedings 1889, page 235). The report now presented is on three more trials. The first of these was upon the "Fusi Yama," which may be taken as a fair specimen of the ordinary coasting steamer, with two-cylinder compound engine, working with a boiler pressure of 60 or 70 lbs. above the atmosphere. The engine was in reasonably good order and reasonably economical; and such engines are used by hundreds throughout the mercantile marine, and often on long voyages, without special pretensions to economy. It was tested under ordinary working conditions, as has been the case also with all the others tried. The second steamer tried, the "Colchester," is one of the latest belonging to the Great Eastern Railway, and has twin-screw two-cylinder compound engines. The third vessel was the "Tartar," a fine example of the triple-expansion engines used in large cargo steamers, working with 140 or 150 lbs. boiler pressure and fitted with steam-jackets. The engines are in every way finely designed. In the particular trial here reported it will be seen that these engines were considerably underworked, but this could not be helped, owing to the steamer being light on the occasion; no more power could be got out of the engines than they could be allowed to give under the circumstances of so light a load. All three of these trials were made at sea, and they were all made as nearly as possible on the same plan, and with the same apparatus.

1. TRIAL OF THE S.S. "FUSI YAMA."

Steamer.—This steamer was tested as a good example of an ordinary trading vessel working under the usual conditions. She belongs to Messrs. Gellatly, Hankey, Sewell and Co., to whom the Committee are much indebted for giving them every facility for making the experiments. She is a vessel of 214·3 feet length between perpendiculars, 29·3 feet beam, and 20·5 feet depth. Her registered tonnage is 632 net, and her gross tonnage 994, under deck 899 tons. Her displacement on the day of the trial, when the mean draft was 18 feet $11\frac{3}{4}$ inches, was 2,175 tons.

The trial was made upon the 14th and 15th November 1888, on a run from Gravesend to Portland. The ship left Gravesend, where her compasses had been adjusted, about six o'clock on the afternoon of the 14th November, and the trial started at 8.51 p.m. on that evening. It lasted until 11.0 a.m. on the 15th. The run was continuous, with the exception of stoppages amounting in all to 12 minutes between 3.10 and 3.25 a.m. when landing the pilot off Dover. In addition to this the engines were running slow for about 13 minutes between 3.0 and 3.30 a.m. The reading of the counter was entered at each change of speed or stoppage during this time.

Engines.—The "Fusi Yama" is fitted with compound surface-condensing engines, made by Mr. Martin Samuelson of Hull in 1874. They had been thoroughly overhauled by Messrs. Rait and Gardiner, under the superintendence of Mr. Frederick Edwards, immediately before the trial, and were in thoroughly good working order. The cylinder diameters are 27·35 inches and 50·3 inches, measured from gauges. Their common stroke is 33 inches. The diameter of both piston-rods is 4·9 inches. There are no tail-rods.

The cranks are at right-angles, the low-pressure leading.

The cylinders are not jacketed. The clearances of the high and low-pressure cylinders as measured on the drawings are respectively 8·5 and 5·0 per cent. Sections of the cylinders are shown in Plates 104 and 105.

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Each cylinder is provided with a single slide-valve worked by the ordinary link-motion gear. The throttle and stop valves, and the link-motion, were sealed up at starting. The link-motion however was opened out a little at 1.24 a.m., and remained in its new position during the rest of the run. The screw propeller is four-bladed, having a diameter of 13 feet, and a mean pitch of 16.37 feet.

Boiler.—Steam is supplied by one boiler 13 feet $3\frac{3}{4}$ inches mean diameter, 11 feet long, and containing three furnaces. The total grate area is 52 square feet, and the total heating surface 2,257 square feet, the ratio between the two being 1 to 43.4. The mean diameter of the flues is 2 feet $11\frac{1}{2}$ inches. The fire-bars are of the ordinary description; and there are 17 bars in the width of each furnace, and therefore 34 in each grate. There are 232 tubes of $3\frac{3}{4}$ inches external diameter, and 7 feet 5 inches long between plates, equivalent to a total tube surface of 1,689 square feet, which is 32.5 times the grate area. The internal diameter of the funnel is 4 feet $6\frac{1}{2}$ inches, and its total height is 43 feet 2 inches above the centre of the lowest furnace. Sections of the boiler are shown in Plate 106.

The total weight of the engines and boiler, including water in condenser, pipes, and boiler, and all mountings, is about 100 tons. The net volume of the boiler is about 1,681 cubic feet.

Duration of Trial.—The duration of the trial from start to finish was 14 hours 9 minutes. Deducting the 12 minutes of stoppage, the running time was therefore 13 hours 57 minutes, or 837 minutes.

Coal Measurement.—The same method was used for weighing the coal as was employed upon the “Meteor” trial (Proceedings 1889, page 237). About 70 lbs. of coal was weighed in each bucket, and about nine buckets were weighed on to the stoke-hold floor at one time. The trial was started with a clean floor. The time was noted at which each lot of weighed coal was put upon the fire, and no more coal was weighed out until the floor was again clear. The line of coal consumption plots out as shown in the diagram,

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Plate 88. The fires were not cleaned during the run. The ashes were weighed after the trial was over. The coal was West Hartley Tyne coal, costing 15s. 9d. per ton. It was somewhat irregular in quality, but a sample collected at different times during the run, and afterwards well mixed and pounded, gives the following analysis, which has been made by Mr. C. J. Wilson:—

	Coal as used.	Dry Coal.
Carbon	70·85 per cent.	77·52 per cent.
Hydrogen	4·71 " "	5·15 " "
Moisture	8·60 " "	0·00 " "
Ash	5·11 " "	5·59 " "
Nitrogen, Sulphur, Oxygen, &c., by difference	10·73 " "	11·74 " "
	<hr/> 100·00 <hr/>	<hr/> 100·00 <hr/>

The calculated calorific value of this fuel as used is 12,760 thermal units per lb., which is equivalent to the evaporation of 13·21 lbs. of water from and at 212° Fahr. The equivalent carbon-value of this fuel as used is 0·878 lbs. per lb. The total coal used was 13,768 lbs. in 849 minutes. As out of the whole time of running, the engines were stopped for 12 minutes, during which period of course the fires were more or less damped, it may be taken that the actual time of firing was equivalent to about 840 minutes; but in order not to confuse matters the boiler time will be taken as equal to the engine time, that is to say, to the time during which the engines were actually running, namely 837 minutes. The total coal was therefore 16·45 lbs. per minute, or 987 lbs. per hour. The weather was fair until reaching Dover, but became very rough during the last part of the trial, which was brought to an end somewhat sooner than was intended, because of the great difficulty of obtaining further accurate measurements. Up to the actual point of ceasing observations, however, the weather did not affect their accuracy, although it rendered difficult the estimation of the water-level in the boiler at the end of the trial. The roughness of the weather at the end of the trial prevented accurate measurements being made as to the amount of clinker obtained from cleaning the fires. The actual

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amount of ash weighed off from under the grates was only 278 lbs., or about 2 per cent. of the total weight of the fuel.

Furnace Gases.—The temperature of the chimney gases was observed fifteen times during the trial, and its average value was 578° Fahr.; the highest reading being 617°, and the lowest (which was just after starting) 500°. The observations are plotted in Fig. 9, Plate 91. Two samples of furnace gases were collected and analysed; the analyses of these by weight and by volume are given in the following table:—

TABLE 3.—*Percentage Composition of Flue Gases.*

Constituent.	No. 1.		No. 2.		Mean.	
	By Volume.	By Weight.	By Volume.	By Weight.	By Volume.	By Weight.
Carbonic Acid .	6·93	10·30	8·14	12·04	7·53	11·17
Carbonic Oxide .	0·00	0·00	0·00	0·00	0·00	0·00
Oxygen . .	12·14	13·13	11·00	11·84	11·57	12·48
Nitrogen . .	80·93	76·57	80·86	76·12	80·90	76·35
	100·00	100·00	100·00	100·00	100·00	100·00

The mean chimney draft, which was measured by a U gauge-glass at the place where the furnace gases were collected, was 0·28 inch of water.

Feed-Water Measurement.—The feed-water was measured in the same way as for the "Meteor," on its way from the hot-well to the feed-pump of the engine. The tanks used for weighing it (which held about 260 lbs. each) were placed on the upper engine-room platform; their contents were carefully tested by weighing water into them, and they were at the same time ascertained to be free from any leakage. The necessary correction having been made for the

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temperature of the feed, the total water used amounted to 109,800 lbs. (its mean temperature being $129\cdot5^{\circ}$ Fahr.), over a total time of 850 minutes. The engine was actually running during 838* minutes of this time, so that the mean consumption of water per minute (engine time) was $131\cdot0$ lbs., or 7,860 lbs. per hour. The continuous consumption of feed-water is shown in Plate 88, and the temperature is plotted in Fig. 11, Plate 91.

All the steam made by the boilers went to the main engine, steam being kept up in the donkey boiler for any other purposes that were required.

Power Measurement.—Indicator diagrams were taken at about half-hourly intervals throughout the whole of the trial, 26 sets or 104 diagrams being taken in all. A pair of Darkes' indicators with 1–30th springs, were used on the high-pressure cylinder, and a pair of Richards' indicators with 1–10th springs on the low-pressure cylinder. The following are the mean effective pressures in the two cylinders in pounds per square inch :—

Cylinder.	Top.	Bottom.	Mean.
High-pressure .	31·06	30·41	30·74
Low-pressure . . .	10·43	11·30	10·87

These pressures correspond with the following indicated horse-powers :—

High-pressure cylinder	168·2
Low-pressure cylinder	203·1
Total Indicated Horse-Power	<u>371·3</u>

One set of diagrams was taken during the time when the engines were slowed down (13 minutes), and the proper allowance has been made for this in the preceding averages.

The maximum indicated horse-power given by any one set of diagrams was $402\cdot2$, which occurred at 5.30 a.m., with $57\cdot5$

* The last feed-tank was emptied at 11·1 a.m., or one minute after the last reading of the counter.

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revolutions per minute, and boiler pressure of 59·0 lbs. per square inch. The minimum indicated horse-power by any one set of diagrams at full speed was 313·0 at 11.0 p.m., with 53 revolutions per minute, and boiler pressure of 49 lbs. per square inch. In Plate 90 is given the set of diagrams nearest to the mean, taken at 9.30 p.m. with 55·9 revolutions per minute and boiler pressure of 57 lbs. per square inch. From the 104 diagrams which were taken during the trial a mean diagram has been plotted for each of the two cylinders, and these are given in Fig. 10, Plate 91. The continuous variations of boiler pressure and cylinder mean effective pressures are shown in Fig. 6, Plate 89; of horse-power in Fig. 4; and of speed in Fig. 5.

Speed.—The counter read 8,507 at 8.51 p.m. when the trial commenced, and 55,033 at 11.0 a.m. when the trial ended. The total number of revolutions made by the engines was therefore 46,526 in a total running time of 837 minutes, which gives an average rate of 55·59 revolutions per minute. The maximum number of revolutions per minute for any half-hour was 57·5, and the minimum number (except when slowed down) was 53·0. The continuous increase of total revolutions from the beginning of the trial is shown in Plate 88.

Pressures, &c.—The mean barometric pressure during the trial was 30·1 inches of mercury, or 14·8 lbs. per square inch. The mean boiler pressure was 56·84 lbs. per square inch above the atmosphere, measured on the gauge in the stoke-hold. On the engine-room gauge the mean pressure was 55·2 lbs. per square inch. It will be seen from the diagram, Fig. 6, Plate 89, that the boiler pressure was fairly constant, except during about two hours near the beginning of the run, and during the time when the engines were slowed down. The pressure-gauge in the stoke-hold was read every quarter of an hour during the trial, and the other gauges were read every half-hour alternately with the counter readings, and at the same time as that at which the indicator diagrams were taken. The mean reading of the vacuum-gauge was

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25·40 inches of mercury, or 12·48 lbs. per square inch below the atmosphere. The mean initial pressure in the high-pressure cylinder (from measurement of diagrams) was 50·3 lbs. per square inch above the atmosphere; and the mean back-pressure in the low-pressure cylinder was 10·9 lbs. per square inch below the atmosphere, which corresponds to an absolute back-pressure of 3·9 lbs. per square inch in the cylinder.

Boiler Efficiencies.—The rate of combustion in the furnaces was 18·98 lbs. of coal per square foot of grate surface per hour, or 0·437 lb. per square foot of total heating surface per hour. The evaporation was at the rate of 7·96 lbs. of water per lb. of coal. As the feed entered the boiler at a temperature of 129·5° Fahr., and as the temperature corresponding to the mean steam-pressure was 304° Fahr., each lb. of steam must have taken up 1,077 thermal units; so that the equivalent evaporation from and at 212° Fahr. was 8·87 lbs. of water per lb. of coal, or about 10·10 lbs. per lb. of carbon-value in the fuel. The equivalent amount of heat utilised per lb. of coal was 8,570 thermal units, or say 67·2 per cent. of the whole calorific value of the fuel; which percentage therefore represents the actual boiler efficiency.

The total nominal calorific value of the fuel burnt per minute was 209,900 thermal units. Assuming that the two samples of furnace gases analysed gave a fair average value, it appears that the weight of dry air per lb. of coal was about 22·8 lbs. The loss of heat in raising the temperature of the furnace gases from 55° Fahr., allowing for the steam due to the combustion of the hydrogen in the fuel, works out to 2,995 thermal units, or 23·5 per cent. of the whole calorific value of the fuel. There was no loss by formation of carbonic oxide. The loss due to evaporation of the moisture in the fuel would be 0·9 per cent. These quantities add up to 91·6 per cent. of the whole heat of combustion, the balance of 8·4 per cent. including all losses by radiation. The weight of water evaporated per square foot of total heating surface was 3·48 lbs. per hour. The average rate of transmission of heat through the material of the boiler

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was 3,750 thermal units per square foot of total heating surface per hour.

Coal Consumption.—The total coal burnt, namely 987 lbs. per hour, corresponds to 2·66 lbs. per indicated horse-power per hour. This is equivalent to 2·33 lbs. of carbon-value per indicated horse-power per hour.

Engine Efficiencies.—The measurement of feed-water shows that the quantity used per indicated horse-power was 21·17 lbs. per hour. The actual heat received by the feed-water per minute was 141,100 thermal units, or 380 thermal units per indicated horse-power per minute, which is 67·2 per cent. of the, whole heat of combustion. The absolute engine efficiency, or, ratio of the heat turned into work to the total heat received by the feed-water, was 11·25 per cent.

Total Efficiency.—The combined efficiency of the boiler and engines, or the ratio of the heat turned into work to the total heat of combustion of the fuel, was $0·672 \times 0·1125$, which is equivalent to 7·6 per cent.

Steam from Indicator Diagrams.—The following are the results of measurements made upon all the indicator diagrams taken, to ascertain the proportion of steam accounted for by them. The actual weight of feed-water used per revolution was 2·36 lbs. :—

Proportion of Steam accounted for by indicator diagrams.	Lbs. per Revolution.	Percentage of Total Feed.	Percentage present in cylinder as water.
Steam present in high-pressure cylinder after cut-off, when the pressure was 45·2 lbs. per square inch above the atmosphere	Lbs.	Per cent.	Per cent.
Steam present in low-pressure cylinder near end of expansion, when the pres- sure was 4·8 lbs. per square inch below the atmosphere	1·96	83·1	16·9
	1·67	70·8	29·2

2. TRIAL OF THE S.S. "COLCHESTER."

Steamer.—This vessel is the latest of those built for the Great Eastern Railway Co., for carrying their passenger traffic between Harwich and Antwerp. The Committee are very greatly indebted to the Great Eastern Railway Co., and especially to Mr. Holden, the locomotive superintendent of the line, and to Captain Howard, the Company's marine superintendent, for the facilities which they gave throughout for the carrying on of the trial. The "Colchester," which is driven by twin screws, is a vessel of 281 feet length, 31-foot beam, and 15·3 feet depth. Her gross registered tonnage is 1,160, while her net registered tonnage is only 517; the remainder of 643 tons representing space occupied by machinery, seamen, &c. Her draft at Harwich at the end of the trial was 13 feet 7 inches aft, and 10 feet 6 inches forward; corresponding to a displacement of 1,675 tons.

The trial was made upon the 9th November 1889, on a run from the Humber to Harwich. The ship had been lying in the Humber, where her machinery had received a thorough overhauling by the makers, Messrs. Earle's Shipbuilding and Engineering Company, Hull. Steam was got up on the morning of the 8th November, and the engines were turned round about 3 p.m. on that day. The steamer left her moorings about 3 a.m. on the 9th November, and the trial started at 5 a.m. on that morning. It lasted until 4 p.m. exactly, the boat being taken a little south of the Stour estuary in order somewhat to prolong the trial. The furthest point south was reached at 3 p.m. The engines were stopped about 7 minutes during this time to allow the pilot to leave the ship, and they were also slowed down for 5 minutes about the same time. The counter was read at each of these changes of speed, all of which occurred before 5.40 a.m.

Engines.—The "Colchester" is fitted with two compound surface-condensing engines, driving the two screw shafts. The engines are entirely separate, and are placed slightly inclining from the vertical, the space between them being taken up by a condenser which is

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common to the two. They were built by Messrs. Earle's Shipbuilding and Engineering Co. in 1888-89. The vessel had been on her station running to Antwerp and back twice every week from the end of February to the middle of September 1889, and had run a total distance of about 16,530 miles during that time; and had undergone her first overhaul at the makers, as already mentioned, during the week before the trial. The engines and boilers therefore were in thoroughly good order. The diameters of the cylinders are 30 inches and 57 inches respectively. An opportunity has not occurred to gauge them. Their common stroke is 36 inches. The diameter of all piston-rods is 6·0 inches, and of all tail-rods 4·5 inches. The cranks of each engine are at right-angles, and the high-pressure cranks lead. The cylinders are not jacketed. The clearances of the high and low-pressure cylinders as given by the owners are 9·39 and 6·23 per cent. Sections of the cylinders are shown in Plates 107 and 108.

The valve-gear is of the ordinary link-motion type. The surface-condenser contains 3,000 square feet of tube surface in 1,176 tubes, 1 inch external diameter, and 9 feet $9\frac{3}{4}$ inches long between plates. The screw propellers have cast-steel blades and boss; each is 11 feet 6 inches diameter, and 20 feet $4\frac{1}{2}$ inches pitch, with a surface of $45\frac{1}{2}$ square feet.

Boilers.—There are two iron boilers, each double-ended, 13 feet mean diameter, and 18 feet 3 inches long; each boiler having six furnaces of 3 feet 4 inches internal diameter. The total grate surface is 220 square feet; the length of each surface on bars being 5 feet 6 inches. The total heating surface is 5,820 square feet, of which 4,770 square feet is tube surface. There are 784 tubes, $3\frac{1}{2}$ inches external diameter, and 6 feet $7\frac{5}{8}$ inches long between plates. The total heating surface is therefore 26·5 times, and the tube surface 21·7 times the grate surface. The boilers have been designed to work safely with a pressure of 90 lbs. of steam, but are ordinarily worked, as during the trial, with a pressure from 5 to 10 lbs. less. There are two double funnels, one for each stoke-hold; the internal diameters of their outer and inner shells

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are respectively 6 feet 7 inches, and 5 feet 5 inches, and the total height of each funnel is 47 feet above the centre of the wing furnaces. Sections of one of the boilers are shown in Plate 109.

The total weight of the engines and boilers, including water in condenser, pipes, and boilers, and all mountings, is about 395 tons. The net volume of the boilers is about 4,980 cubic feet.

Duration of Trial.—The duration of trial from start to finish was 11 hours exactly. Deducting the 7 minutes of stoppage, the running time was therefore 10 hours 53 minutes, or 653 minutes.

Coal Measurement.—The coal was weighed in each stoke-hold by spring balances as before. From 500 to 700 lbs. of coal was put down at one time on each side of each stoke-hold. The trial was started with clean floors in each stoke-hold. The time was noted at which each lot of weighed coal was put upon the fire, and no more coal was weighed out until the floor was again clear. The line of coal consumption plots out as shown in Plate 92. The fires were not cleaned during the run. The ashes were weighed after the trial was over; but the weight of the ashes given below includes the ash formed while steam was being raised during the time the fires were banked up before the start, and during the two hours' run before the trial actually commenced. The fire-grates were fitted with Henderson's fire-bars, with the object mainly of rendering possible a somewhat larger rate of combustion, so as to get the greatest possible duty out of the boilers. The coal used in the forward stoke-hold, and during the first half of the run in the after stoke-hold, was Monk Bretton (Yorkshire) coal. For the second half of the run a mixed coal, chiefly Hucknall and Shireoaks (Nottinghamshire), was used in the after stoke-hold. Coal samples were taken from both stoke-holds frequently during the run, and were mixed together, and finally pounded, so as to obtain as representative a sample as possible for analysis. The analysis was made as before by Mr. C. J. Wilson, who gives it as follows:—

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	Coal as used.	Dry Coal.
Carbon	71·89 per cent.	75·08 per cent.
Hydrogen	5·42 " "	5·66 " "
Moisture	4·25 " "	0·00 " "
Ash	4·08 " "	4·26 " "
Nitrogen, Sulphur, Oxygen, &c., by difference	14·36 " "	15·00 " "
	<hr/> 100·00 <hr/>	<hr/> 100·00 <hr/>

The following is an analysis made by Mr. Wilson of a sample of the clinker and ash :—

Loss on ignition (=Carbon)	43·73 per cent.
Mineral matter	56·27 " "
	<hr/> 100·00 <hr/>

The ash therefore contained about 43·7 per cent. of carbon.

The calculated calorific value of the fuel as used is 13,280 thermal units, which corresponds to the evaporation of 13·75 lbs. of water from and at 212° Fahr. The equivalent carbon-value of 1 lb. of the fuel as used is 0·913 lbs. The total coal used was as follows :—

After stoke-hold, port side	16,020 lbs.
" " starboard side	15,426 "
Forward " port side	15,509 "
" " starboard side	15,536 "
	<hr/> 62,491 lbs. <hr/>

This amounts to 95·7 lbs. per minute, or 5,742 lbs. per hour, taking the running time of 653 minutes. As a check upon the coal consumption it has also been worked out from a time after the stoppage, at about 5.40 a.m., to the end of the trial; and over this period it comes to 95·9 lbs. per minute, that is to say the same as before within the limits of measurement.

The weather was very fine during the whole of the trial, but a little foggy towards the end; which made the captain of the steamer

TABLE 4 (*continued on opposite page*).

COLCHESTER TRIAL.

Analyses of Funnel Gases by Volume.

	No. of Sample.	Carbonic Acid.	Carbonic Oxide.	Oxygen.	Nitrogen.
		Per cent.	Per cent.	Per cent.	Per cent.
FORWARD FUNNEL.	1	8.13	0.00	11.20	80.67
	3	10.55	1.84	6.59	81.02
	5	12.47	0.00	6.43	81.10
	7	7.98	0.00	11.79	80.23
	9	12.37	1.64	5.39	80.60
	11	9.89	0.00	9.72	80.39
	13	11.18	0.00	8.30	80.52
	15	10.60	0.00	9.17	80.23
	17	11.80	0.00	6.45	81.75
	19	11.27	0.00	7.67	81.06
	Mean	10.62	0.35	8.27	80.76
AFTER FUNNEL.	2	7.75	0.00	11.27	80.98
	4	8.93	0.00	10.66	80.41
	6	8.72	0.00	11.21	80.07
	8	6.18	0.00	13.46	80.36
	10	6.33	0.00	13.69	79.98
	12	3.01	0.00	17.66	79.33
	14	9.97	0.00	9.72	80.31
	16	12.08	1.15	5.90	80.87
	18	9.90	0.00	10.37	79.73
	20	5.94	0.00	14.09	79.97
	Mean	7.88	0.12	11.80	80.20
Mean of Both Funnels		} 9.25	0.23	10.04	80.48

(continued from opposite page) TABLE 4.

COLCHESTER TRIAL.

Analyses of Funnel Gases by Weight.

No. of Sample.	Carbonic Acid.	Carbonic Oxide.	Oxygen.	Nitrogen.	Time of Collecting.
	Per cent.	Per cent.	Per cent.	Per cent.	
1	12.02	0.00	12.05	75.93	5.20 a.m.
3	15.50	1.72	7.04	75.74	6.20 "
5	18.14	0.00	6.80	75.06	7.20 "
7	11.80	0.00	12.68	75.52	8.25 "
9	18.03	1.52	5.71	74.74	9.40 "
11	14.52	0.00	10.38	75.10	10.40 "
13	16.33	0.00	8.82	74.85	11.40 "
15	15.52	0.00	9.76	74.72	12.40 p.m.
17	17.22	0.00	6.85	75.93	2.5 "
19	16.47	0.00	8.15	75.38	3.5 "
Mean	15.56	0.32	8.82	75.30	
2	11.48	0.00	12.15	76.37	5.50 a.m.
4	13.16	0.00	11.43	75.41	6.50 "
6	12.86	0.00	12.02	75.12	7.55 "
8	9.21	0.00	14.59	76.20	9.10 "
10	9.42	0.00	14.82	75.76	10.10 "
12	4.54	0.00	19.36	76.10	11.10 "
14	14.63	0.00	10.37	75.00	12.10 p.m.
16	17.62	1.07	6.26	75.05	1.35 "
18	14.52	0.00	11.06	74.42	2.35 "
20	8.85	0.00	15.28	75.87	3.35 "
Mean	11.63	0.11	12.73	75.53	
Mean of Both Funnels	13.59	0.22	10.78	75.41	

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reluctant to continue the run longer, as it was originally intended to do.

The actual amount of clinker and ash weighed off under the conditions already mentioned (page 214) was 2,890 lbs. It may be taken roughly that of this quantity 2,200 lbs., or 200 lbs. per hour, was made during the actual run, which is about 3·5 per cent. of the total quantity of coal.

Furnace Gases.—A sample of the furnace gases was collected over mercury by Mr. Wilson each hour from each funnel, there being twenty samples in all. The analyses of these samples are given in Table 4, pages 216–217. This set of analyses and the corresponding set for the “Tartar” trial are perhaps the most important and complete which have ever been made under such conditions, and merit close examination. The “mean” figures in the table (page 217) show that 3·8 per cent. by weight of the dry furnace gases is carbon: from which it follows that, allowing for the combustion of the hydrogen of the fuel, 18·5 lbs. of dry air passed through the furnace per pound of coal burnt.

The chimney temperatures were read in each funnel every quarter of an hour during the whole of the trial, from a mercury thermometer containing compressed nitrogen over the mercury. This thermometer reads up to 860° Fahr.; but in a large number of cases (about 37 per cent. of the whole) the temperature rose somewhat above the maximum reading of the thermometer. It was obvious from the motion of the mercury that the true temperature was not much above the limit of the thermometer, but of course its exact value is unknown. Assuming that the mean value of these excess readings was 20° Fahr. above the limit of the thermometer, or 880° Fahr. (which is probably true within an error of 10° either way), the mean temperature in the forward funnel was 828° Fahr., and in the after funnel 842° Fahr., the mean of both being therefore 835° Fahr. The variations in temperature of the chimney gases are shown in Fig. 22, Plate 96.

The mean chimney-draft measured by U gauges was 0·38 inch of water in the forward, and 0·34 inch in the after funnel.

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Feed-Water Measurement.—The feed-water was measured in the two tanks, of which details of construction are shown in Plate 87. These tanks have been made specially for feed measurement in a form as adaptable as possible to the conditions of various steamers; and in parts of such a size that they can be readily got down into the engine-room of a steamer, and erected and jointed there. It was found possible to put them together in an extremely confined space in the "Colchester," and again in the "Tartar" at a somewhat later date; and it is thought that the details of their construction may therefore be interesting. Each tank held about 2,200 lbs. of water at 64° Fahr., between the upper and the lower cocks. Their contents were carefully tested by weighing water into them when jointed and connected, before placing them on board the steamer. The water in each tank lasted in the "Colchester" about three minutes. The total weight of water used was 468,845 lbs., over a total running time of 654 minutes.* This amounts to 717 lbs. per minute, or 43,020 lbs. per hour, the mean temperature of the feed being 113° Fahr. The continuous consumption of feed-water is shown in Plate 92, and the variations of its temperature in Fig. 24, Plate 96. The feed-pump of one of the engines only was employed to pump throughout, the other pump not being used.

All the steam made by the boilers went to the main engines; the steam for the circulating-pump engine, the steering engine, and the dynamo engine, and any steam that was required for heating, was all taken from the donkey boiler, to which special steam connections were made for the purpose. The water-level was practically the same at the beginning and the end of the trial.

Power Measurement.—Indicator diagrams were taken every half-hour from each engine. There were thus 22 sets of diagrams, or 176 single diagrams, taken in all. The eight indicators used were all made by Messrs. T. S. M'Innes and Cairns of Glasgow, by whom six of them were kindly lent to the Committee. These indicators are very simple in construction and handy in use, and their vulcanite sheathing is attended, at sea especially, with much convenience in

* The last feed-tank was finished at 4.1 p.m. instead of 4 p.m.

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manipulation. The following are the mean effective pressures in the cylinders in pounds per square inch :—

Cylinder.	Top.	Bottom.	Mean.
Port ; high-pressure	43·34	47·96	45·65
„ low-pressure	13·25	13·58	13·42
Starboard ; high-pressure	38·45	45·68	42·07
„ low-pressure	11·68	13·15	12·42

These pressures correspond with the following indicated horse-powers :—

Port engine ; high-pressure cylinder . . .	490·3	
„ „ low-pressure cylinder . . .	532·2	1,022·5
Starboard engine ; high-pressure cylinder . . .	457·9	
„ „ low-pressure cylinder . . .	499·3	957·2
Total Indicated Horse-Power		<u>1,979·7</u>

The maximum indicated horse-power given by any one set of diagrams was 2,194·2, which occurred at 10.15 a.m., with a mean speed of 88·6 revolutions per minute, and boiler pressure of 86 lbs. per square inch. The minimum indicated horse-power by any one set of diagrams was 1,699·6, at 5.45 a.m., with a mean speed of 83·2 revolutions per minute, and boiler pressure of 73 lbs. per square inch. In Plates 94 and 95 is given the set of diagrams nearest to the mean, taken at 7.45 a.m. with 86·3 and 87·2 revolutions per minute and boiler pressure of 81·5 lbs. per square inch. From the 176 diagrams which were taken during the trial, two mean diagrams have been plotted, one for the two high-pressure and one for the two low-pressure cylinders, and these are given in Fig. 23, Plate 96. The continuous variations of boiler pressure are shown in Fig. 16, Plate 93 ; of cylinder mean effective pressures in Fig. 17 ; of horse-powers in Figs. 13 and 15 ; and of speed in Fig. 14.

Speed.—The counters for the two engines were entirely separate. The total number of revolutions made by the port engine was 56,136, and by the starboard engine 56,857 ; which correspond respectively to 86·0 and 87·1 revolutions per minute. The maximum number of revolutions per minute during any half hour was 89·9 for the port, and 91·7 for the starboard engine ; and the minimum

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number, except when slowed down, was 82·9 for the port, and 84·0 for the starboard engine. The continuous increase of total mean revolutions from the beginning of the trial is shown in Plate 92.

Pressures, &c.—The mean barometric pressure during the trial was 30·6 inches of mercury, or 15·0 lbs. per square inch. The mean boiler-pressure was 80·5 lbs. per square inch by the pressure-gauge in the stoke-hold, and 78·2 lbs. per square inch by the pressure-gauge in the engine-room. It will be noticed from the diagram, Fig. 16, Plate 93, that the pressure was falling both at the commencement and at the end of the trial. The mean vacuum by gauge was 25·4 inches of mercury, corresponding to 2·5 lbs. per square inch of absolute back-pressure. The mean pressure in the receiver of the starboard engine was 8·0 lbs. per square inch above the atmosphere, and in that of the port engine 8·8 lbs. per square inch above the atmosphere. The mean initial pressures in the high-pressure cylinders were 64·3 lbs. per square inch above the atmosphere in the port engine, and 59·4 lbs. in the starboard engine. The mean back-pressures in the low-pressure cylinders were respectively 4·4 and 4·5 lbs. per square inch absolute.

Boiler Efficiencies.—The mean rate of combustion in the furnaces was 26·1 lbs. of coal per square foot of grate surface per hour, or 0·987 lbs. per square foot of total heating surface per hour. The evaporation was at the rate of 7·49 lbs. of water per lb. of coal. The feed entered the boiler at a temperature of 113° Fahr., and the temperature corresponding to the mean boiler-pressure was 324° Fahr., so that each lb. of steam must have taken up 1,100 thermal units; hence the equivalent evaporation from and at 212° Fahr. was 8·53 lbs. of water per lb. of coal, or about 9·34 lbs. per lb. of carbon-value in fuel. The equivalent amount of heat utilised per lb. of coal was 8,240 thermal units, or say 62·0 per cent. of the whole calorific value of the fuel, which percentage therefore represents the actual boiler efficiency.

The total calculated calorific value of the fuel burnt per minute was 1,271,000 thermal units.

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The weight of dry air per lb. of coal, calculated from the furnace gas analyses, works out to 18.5 lbs., so that the total weight of furnace gases per pound of coal would be about 19.4 lbs. Their specific heat may be taken as 0.238, and they have been raised in temperature from say 55° Fahr., the temperature of the outer air, to 835° Fahr., the temperature of the chimney gases. This corresponds to a loss of 3,714 thermal units per lb. of coal, or 28.0 per cent. of the whole calorific value of the fuel, inclusive of raising through the same range of temperature the steam formed by the combustion of the hydrogen in the fuel. The loss due to evaporation of the moisture in the fuel works out to 0.4 per cent., and that due to imperfect combustion to 1.3 per cent. These quantities add up to 91.7 per cent. of the whole heat of combustion, leaving a balance of 8.3 per cent., which includes all losses by radiation unaccounted for. The weight of water evaporated from and at 212° Fahr. per square foot of total heating surface was 8.42 lbs. per hour.

The average rate of heat transmission through the material of the boiler was 8,130 thermal units per sq. foot of heating surface per hour.

Coal Consumption.—The total coal burnt, namely 5,742 lbs. per hour, corresponds to 2.90 lbs. per indicated horse-power per hour. This is equivalent to 2.65 lbs. of carbon-value per indicated horse-power per hour.

Engine Efficiencies.—The total indicated horse-power being 1,979.7, and the total feed-water used per hour being 43,020 lbs., the feed-water used per indicated horse-power per hour was 21.73 lbs. The actual heat received by the feed-water per minute was 788,700 thermal units, or 398.4 thermal units per indicated horse-power per minute; which is 62 per cent. of the whole heat of combustion. The absolute engine efficiency, or ratio of the heat turned into work to the heat given to the feed-water, was 10.7 per cent.

Total Efficiency.—The combined efficiency of the boilers and engines, or ratio of the heat turned into work to the total heat of combustion of the fuel, was 0.62×0.107 , which is equivalent to 6.6 per cent.

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Steam from Indicator Diagrams.—The following are the results of measurements made upon the indicator diagrams taken, to ascertain the proportion of steam accounted for by them. The actual weight of feed-water used per revolution was 8·28 lbs. :—

Proportion of Steam accounted for by indicator diagrams.	Lbs. per Revolution.	Percentage of Total Feed.	Percentage present in cylinder as water.
Steam present in high-pressure cylinder, port engine, after cut-off, when the pressure was 51 lbs. per square inch above the atmosphere . . .	3·13	72·0	28·0
Steam present in high-pressure cylinder, starboard engine, after cut-off, when the pressure was 51 lbs. per square inch above the atmosphere . . .	2·83		
Steam present in low-pressure cylinder, port engine, near end of expansion, when the pressure was 7 lbs. per square inch below the atmosphere . .	2·18	52·7	47·3
Steam present in low-pressure cylinder, starboard engine, near end of expansion, when the pressure was 7 lbs. per square inch below the atmosphere .	2·18		

Speed of Vessel.—The following notes from the log book of the ship may be of interest :—

	Time.	Distance in Nautical miles.
Left Hull Roads	3·15 a.m.	0
Spurn Light	4·40	24
Dudgeon „	7·45	54
Cromer „	9·5	75½
Cockle „	10·35	97
Corten „	11·15	108
Shipwash „	1·25 p.m.	140
Sunk „	2·20	151
Long Sand Head Light . . .	2·40	158½
Cork Light	4·0	173
Parkeston Quay	4·35	178½

The mean speed between Dudgeon and Cork Lights, which includes nearly the whole of the trial except that portion when the vessel was slowed down and stopped, was therefore 14·4 knots.

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The “Colchester” is a vessel built to attain a maximum of power and speed over a short journey rather than a maximum of economy. Looked at from this point of view, it may be interesting to compare the relation between power developed and size of the machinery in her case, and in those of the other steamers tested. The net volume of her boilers is about 4,980 cubic feet, or at a rate of 2·52 cubic feet per indicated horse-power. This rate in the case of the “Meteor,” “Fusi Yama,” and “Tartar,” is respectively 2·72 and 4·53 and 4·33 cubic feet per I.H.P.

3. TRIAL OF THE S.S. “TARTAR.”

Steamer.—This steam-ship is owned by Messrs. Gellatly, Hankey, Sewell and Co., and is an excellent example of a cargo-carrying steamer with modern economical engines. She was built in 1887 by Messrs. R. Dixon and Co. of Middlesbrough, and engined by Messrs. Thomas Richardson and Sons of Hartlepool with triple-expansion engines, working a single screw. She is a vessel of 332 feet length, 38 feet breadth, and 27 feet depth (moulded). Her gross registered tonnage is 2,389, and she is classed at Lloyd's 100 A 1. Her draft during the trial was 8 feet 6 inches forward, and 15 feet 6 inches aft, or 12 feet mean; and her displacement at this draft was 2,250 tons. She was practically without cargo, carrying nothing but water ballast.

The trial was made upon the 27th November 1889, on a run from the Thames to Portland. The vessel had arrived in London on the 21st November, after a voyage from Australia; and the boilers were cleaned, and the engines opened out and overhauled before the trial, while the ship was unloading in the docks. Steam was got up on the evening of the 26th November, and the vessel went out of dock about 5 a.m. on the 27th. The trial started at 8.25 a.m., as soon as the vessel was far enough down the Thames to run at full speed, and lasted until 6.30 p.m. The weather during the last part of the run was sufficiently rough to cause the engines to race a little, in consequence of the light draft of the ship. At 6.30 p.m. the weather had

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become sufficiently bad to make the taking of accurate observations a matter of considerable difficulty; and it was therefore decided to end the trial, rather than to run any risk of having it spoilt by inaccuracies. In consequence of snowstorms met with going down the Channel, the engines were slowed from 9.52 a.m. to 10.56 a.m., and again for 11 minutes between 12 and 1 o'clock. During these periods the speed was about 64 revolutions per minute, the full speed at other times being about 71 revolutions per minute. Diagrams were taken at the slower speeds, so that they are properly allowed for in the averages. The engines were not stopped at all during the trial; and, with the exception of the intervals named, ran under constant conditions as to position of valve-gear &c., namely with the main stop-valve and the throttle-valve fully open, and the link-motion slightly linked up.

Engines.—The "Tartar" is fitted with triple-expansion surface-condensing engines, the cylinders being placed in the order—high, low, intermediate, going from forward to aft. The cranks rotate in the sequence—high, low, intermediate. The diameters of the cylinders are 26.03 inches, 42.03 inches, and 68.95 inches, by gauges. The piston-rods are all 5.5 inches diameter. There are no tail-rods. The stroke of all three cylinders is 3 feet 6 inches. The cylinders are jacketed, and there is a separate steam-admission pipe to each jacket. The clearances of the cylinders are given by the makers as 14.51, and 9.25, and 5.10 per cent. Sections of the three cylinders are shown in Plates 110 to 112.

The valve-gear is Wyllie's elliptical gear, with an independent adjustment for the cut-off. The surface condenser contains 2,250 square feet of tube surface, in 876 tubes of $\frac{3}{4}$ inch external diameter and of 13 feet $0\frac{7}{8}$ inch length between tube-plates. The screw propeller has four blades, and is 16 feet 6 inches diameter, with a pitch of 18 feet.

Boilers.—Steam is supplied by two double-ended steel boilers with Fox's corrugated flues, designed to work at a pressure of 150 lbs. per square inch. The boilers are 13 feet in mean diameter, and 14 feet

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9 inches long, each with two furnaces at each end, there being eight furnaces in all. The total grate area is 161 square feet, each grate being 5 feet 6 inches in length, and 3 feet 8 inches broad. The total heating surface is 5,226 square feet, of which 4,366 square feet is tube surface. The total heating surface is therefore 32·5 times, and the tube surface 27·1 times the grate area. There are 992 tubes, 3 inches diameter outside, and 5 feet 7¼ inches long between plates. The internal diameter of the funnel is 7 feet, and its total height 57 feet above the centre of the furnaces. Sections of one of the boilers are shown in Plate 113.

The total weight of the engines and boilers, including water in condenser, pipes, and boilers, and all mountings, is about 291 tons. The net volume of the boilers is about 4,710 cubic feet.

Duration of Trial.—The duration of the trial from start to finish was 10 hours 5 minutes, or 605 minutes.

Coal Measurement.—The coal was weighed as in the other cases, from 500 to 600 lbs. at a time being put down on each side of each stoke-hold. The trial was started with clean floors, and the time of first stoking from each weighed lot of coal was noted, as well as the time when the whole of the weighed coal was finished. The line of coal consumption plots out as shown in Plate 97. The fires were not cleaned during the run. The ashes were weighed after the trial was over, the ash-pits having been cleaned a little time after it commenced. The coal used throughout was Welsh from Penrikyber (Glamorganshire). Coal samples were taken from both stoke-holds frequently during the run; and the final analysis, after a thorough mixture of all these samples, is as follows:—

	Coal as used.	Dry Coal.
Carbon	87·98 per cent.	88·92 per cent.
Hydrogen	4·22 ” ”	4·26 ” ”
Moisture	1·07 ” ”	0·00 ” ”
Ash	3·42 ” ”	3·46 ” ”
Nitrogen, Sulphur, Oxygen, &c., by difference	3·31 ” ”	3·35 ” ”
	<hr/> 100·00 <hr/>	<hr/> 100·00 <hr/>

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A sample of the ash was also collected, and has been analysed by Mr. Wilson as follows:—

Loss on ignition (=Carbon) . . .	65·53 per cent.
Mineral matter	34·47 „ „
	<hr/>
	100·00
	<hr/>

The calculated calorific value of the fuel is 14,995 thermal units, which corresponds to the evaporation of 15·52 lbs. of water from and at 212° Fahr., and to an equivalent carbon-value of 1·031 lbs. per lb. The total coal used was as follows:—

After stoke-hold, port side . . .	5,322 lbs.
„ „ starboard side . . .	5,052 lbs.
Forward „ port side . . .	4,701 lbs.
„ „ starboard side . . .	4,162 lbs.
	<hr/>
	19,237 lbs.
	<hr/>

This amounts to 31·8 lbs. per minute, or 1,908 lbs. per hour. As a check upon this consumption, and in order to see how far it might be affected by any irregularities in measurement at the end of the trial, the consumption has also been worked out over a time (in average 560 minutes), at the beginning and end of which the condition of the stoke-hold floors, and of the fires, was identical, and for this interval the coal consumption works out to 32·08 lbs. per minute. It has been thought wise to assume therefore that the actual coal consumption was 32·0 lbs. per minute, or 1,920 lbs. per hour; the small difference between this and the foregoing figures was probably caused by the increasing difficulty of measurement at the very end of the trial. The total amount of ash taken from the two stoke-holds at the end of the trial was 291 lbs., but the ash-pits were not cleaned out until some little time after the trial commenced, so that this weight corresponds to a period of only 6 hours 53 minutes. The ash was therefore equivalent to 0·70 lbs. per minute, or 42 lbs. per hour; which is 2·2 per cent. of the total weight of the fuel put on the bars.

TABLE 5 (*continued on opposite page*).

TARTAR TRIAL.

Analyses of Funnel Gases by Volume.

No. of Sample.	Carbonic Acid.	Carbonic Oxide.	Oxygen.	Nitrogen.	Time of Collecting.
	Per cent.	Per cent.	Per cent.	Per cent.	
1	7.28	0.00	12.45	80.27	8.30 a.m.
2	7.61	0.00	11.88	80.51	9.0 "
3	8.22	0.00	11.38	80.40	9.30 "
4	6.97	0.00	13.20	79.83	10.0 "
5	5.91	0.00	14.32	79.77	10.30 "
6	6.24	0.00	13.38	80.38	11.0 "
7	6.94	0.00	13.10	79.96	11.30 "
8	6.44	0.00	13.80	79.76	12.0 noon
9	7.70	0.00	12.10	80.20	12.30 p.m.
10	6.21	0.00	13.57	80.22	1.0 "
11	8.24	0.00	12.00	79.76	1.30 "
12	5.62	0.00	14.40	79.98	2.0 "
13	6.29	0.00	13.15	80.56	2.30 "
14	6.79	0.00	12.78	80.43	3.0 "
15	6.80	0.00	13.30	79.90	3.30 "
16	6.54	0.00	12.71	80.75	4.0 "
17	6.95	0.00	13.10	79.95	4.30 "
18	6.03	0.00	13.08	80.89	5.0 "
19	6.67	0.00	13.17	80.16	5.30 "
20	6.61	0.00	13.52	79.87	6.0 "
21	5.00	0.00	15.27	79.73	6.30 "
Mean	6.72	0.00	13.12	80.16	

(continued from opposite page) TABLE 5.

TARTAR TRIAL.

Analyses of Funnel Gases by Weight.

No. of Sample.	Carbonic Acid.	Carbonic Oxide.	Oxygen.	Nitrogen.	Mean Funnel Temperature
	Per cent.	Per cent.	Per cent.	Per cent.	Fahr.
1	10.80	0.00	13.43	75.77	500°
2	11.28	0.00	12.80	75.92	512°
3	12.15	0.00	12.23	75.62	503°
4	10.34	0.00	14.25	75.41	420°
5	8.81	0.00	15.52	75.67	447°
6	9.30	0.00	14.50	76.20	478°
7	10.30	0.00	14.15	75.55	511°
8	9.58	0.00	14.93	75.49	486°
9	11.40	0.00	13.03	75.57	488°
10	9.25	0.00	14.70	76.05	514°
11	12.17	0.00	12.89	74.94	504°
12	8.39	0.00	15.63	75.98	480°
13	9.37	0.00	14.25	76.38	474°
14	10.09	0.00	13.82	76.09	496°
15	10.10	0.00	14.37	75.53	464°
16	9.74	0.00	13.76	76.50	471°
17	10.32	0.00	14.14	75.54	478°
18	9.00	0.00	14.19	76.81	458°
19	9.92	0.00	14.24	75.84	440°
20	9.83	0.00	14.61	75.56	436°
21	7.48	0.00	16.61	75.91	456°
Mean	9.98	0.00	14.19	75.83	477°

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Furnace Gases.—A very complete series of furnace-gas samples was obtained, a sample being collected over mercury by Mr. Wilson every half-hour. The analyses of these samples are given in Table 5, pages 228–229.

The chimney temperatures were read every quarter of an hour throughout the trial from a mercury thermometer as before. The average reading was 477° Fahr. It remained very fairly constant during the whole trial. The variations of temperature are shown in Plate 97, and the mean temperatures for each half-hour are given in Table 5, page 229.

The chimney draft was read on a U gauge at the same time that the temperature was taken, and varied from $\frac{3}{16}$ inch to $\frac{1}{4}$ inch of water.

Feed-Water Measurement.—The feed-water was measured in the same tanks used for the "Colchester," and already described (page 219, and Plate 87). Each tank lasted in this case from five to six minutes. The total amount of water used was 217,430 lbs., over a total time of 605 minutes. This amounts to 359.4 lbs. per minute, or 21,564 lbs. per hour; but reasons are given later on (page 233) for supposing that a considerable percentage of this quantity was not actually turned into steam. The continuous supply of feed-water and the variations of its temperature are shown in Plate 97. At first pumping was carried out by one of the feed-pumps of the engine; but for the last four hours a donkey-pump was used, as it was found to give much less trouble, and to be much more conveniently under control. The steam for this donkey-pump was supplied from the main boilers.

The steam made by the boilers all went to the main engines, steam being kept up in the donkey boiler for all auxiliary engines; and the pipes and connections were all carefully examined, in order to see that no unintentional communications existed. The water-level in the boilers averaged $1\frac{1}{4}$ inch lower at the finish than at the start of the trial. This corresponds to a total of 1,874 lbs. of water, or about 0.86 per cent. of the whole feed; this amount has been added to the quantities given above. It may be interesting to notice

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that an error of half an inch in reading the level in one boiler in a case like this would make a difference of about 375 lbs., or less than 0·2 per cent. of the water used.

Power Measurement.—Indicator diagrams were taken every half-hour from each end of each cylinder as before. There were thus 21 complete sets of diagrams, or 126 single diagrams, taken in all. The indicators used were those lent by Messrs. McInnes and Cairns, which had been used also for the "Colchester." The following are the mean effective pressures in the cylinders in pounds per square inch :—

Cylinder.	Top.	Bottom.	Mean.
High-pressure	35·74	38·04	36·89
Intermediate	19·92	20·23	20·07
Low-pressure	7·19	7·18	7·18

These pressures correspond with the following indicated horse-powers :—

High-pressure cylinder	283·7
Intermediate cylinder	408·5
Low-pressure cylinder	395·2
Total Indicated Horse-Power	<u>1,087·4</u>

The maximum indicated horse-power given by any one set of diagrams was 1,296·7, which occurred at 8.45 a.m., with 73·2 revolutions per minute, and boiler pressure of 146 lbs. per square inch. The minimum indicated horse-power by any one set of diagrams was 719·3, at 10.10 a.m., with 61·4 revolutions per minute, and boiler pressure of 135 lbs. per square inch. In Plate 99 is given the set of diagrams nearest to the mean, taken at 11.15 a.m. with 66 revolutions per minute and boiler pressure of 141·4 lbs. per square inch. From the 126 diagrams which were taken during the trial a mean diagram has been plotted for each of the three cylinders, and these are given in Plate 100. The continuous variations of boiler pressure are shown in Fig. 27, Plate 98; of cylinder mean effective pressures in Fig. 29; of horse-power in Fig. 26; and of speed in Fig. 28.

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Speed.—The counter was read every quarter of an hour. The total number of revolutions made was 42,350 in 605 minutes, or exactly 70 revolutions per minute. The maximum number of revolutions per minute for any quarter of an hour at full speed was 73·8; and the minimum, 70·3 revolutions per minute; while the average speed during the time that the engine was slowed down was 63·7 revolutions per minute. The continuous increase of total revolutions from the beginning of the trial is shown in Plate 97.

Steam-Jackets.—As has been already mentioned, each jacket received steam through a separate valve. The connections from the jacket-drains to the hot-well were broken, and all three jackets were made to drain into a small tank placed at the back of the engine; and the rate at which the jacket-water was collected in this tank was measured fourteen times during the trial, on most occasions for a quarter of an hour continuously. The water collected in this way amounted in all to 2,476 lbs. in 175 minutes, or 14·15 lbs. per minute, which is 3·94 per cent. of the total feed. This quantity is of course included in the total feed measured through the tanks. It was not possible to jacket the high-pressure cylinder with steam of full boiler-pressure; and under these circumstances it did not appear advisable to allow any steam to pass into that jacket, which was accordingly shut off. The quantity of water given is therefore from the intermediate and low-pressure cylinder jackets only.

Pressures, &c.—The mean barometric pressure during the trial was 29·6 inches of mercury, or 14·6 lbs. per square inch. The mean boiler pressure was 143·6 lbs. per square inch by the pressure-gauge in the stoke-hold, and 140·4 by that at the engine. The pressures in the high-pressure, intermediate, and low-pressure valve-chests, were respectively 131·4 and 46·1 and 3·8 lbs. per square inch above the atmosphere. The pressures in the steam-jackets of the intermediate and low-pressure cylinders were 52·5 and 14·0 lbs. per square inch respectively. The cock admitting steam into the high-pressure jacket, although nominally shut, allowed enough steam to leak through to enable the gauge to show pressures varying from 0

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to over 50 lbs. per square inch. The actual amount of water coming from the high-pressure jacket-drain however was too small to affect appreciably the quantities given in the preceding paragraph. The mean vacuum was 26·2 inches of mercury by gauge, which corresponds to a mean absolute back-pressure in the condenser of 1·7 lbs. per square inch. The mean initial pressure in the high-pressure cylinder was 121·4 lbs. per square inch above the atmosphere; and the mean back-pressure in the low-pressure cylinder was 10·5 lbs. per square inch below the atmosphere, which corresponds to an absolute back-pressure of 4·1 lbs. per square inch in the cylinder.

Boiler Efficiencies.—The mean rate of combustion in the furnaces was 11·93 lbs. of coal per square foot of grate surface per hour, or 0·367 lb. per square foot of total heating surface per hour. The total amount of feed-water pumped into the boilers was at the rate of 11·23 lbs. per lb. of coal. As the feed entered the boiler at an average temperature of 101° Fahr., and the temperature corresponding to the mean boiler-pressure was 362° Fahr., each lb. of steam would have taken up 1,123 thermal units; and the equivalent evaporation from and at 212° Fahr., had the whole of the feed-water been turned into steam, would therefore have reached the very high figure of 13·06 lbs. of water per lb. of coal. The equivalent amount of heat utilised per lb. of coal would be 12,610 thermal units, or say 84·1 per cent. of the whole calorific value of the fuel. Such a figure, although unusually high, is of course not in the nature of things impossible; but if it really represented the evaporation in this case, it would follow (as will be seen from the figures below) that the unusual economy of the boilers was accompanied by an unusual want of economy in the engines. Fortunately the measurements made were sufficiently complete to enable it to be stated positively that (from whatever cause) the whole of the water pumped into the boilers was *not* turned into steam. The observations on which this statement is based are summarised in the next paragraph.

The very complete and uniform series of samples of chimney gases, of which the analyses have been given in Table 5, pages 228–229, enable the calculations connected with them to be made with

"Tartar."

considerable exactness and certainty. The weight of dry air per lb. of coal calculated from these analyses works out to 31·6 lbs., so that the total weight of furnace gases per lb. of coal would be about 32·6 lbs. The gases have been raised in temperature from the temperature of the outer air, say about 55° Fahr., to 477° Fahr., the mean chimney-temperature. Taking the mean specific heat of the gases as 0·238, this corresponds to a loss of 3,307 thermal units per lb. of coal, or 22·1 per cent. of the whole calorific value of the fuel, inclusive of raising through the same range of temperature the steam formed by the combustion of the hydrogen in the fuel. The loss due to evaporation of the moisture in the fuel is so small as to be negligible, and in no one of the twenty-one analyses was any carbonic oxide found to be present in the chimney gases. The loss by radiation was no doubt considerably less than in the "Colchester," the stoke-holds being very much cooler; but taking it as low as 8 per cent., and adding to it the 22 per cent. carried away by the chimney gases, it seems certain that the maximum boiler efficiency which can have been reached cannot have exceeded 70 per cent. This would correspond to an evaporation of 10·8 lbs. of water from and at 212° Fahr. per lb. of coal, which is about 83 per cent. of the apparent evaporation mentioned above. It is moreover to be noted that on the original log sheets memoranda were made in four or five different places at different times by different assistants who were taking indicator diagrams, that they were unusually troubled by the amount of water which came through the indicator cocks of the intermediate cylinder.

Coal Consumption.—The total coal burnt, namely 1,920 lbs. per hour, corresponds to 1·77 lbs. per I.H.P. per hour. This is equivalent to 1·82 lbs. of carbon-value per I.H.P. per hour.

Engine Efficiencies.—Although the total quantity of water pumped into the boilers per indicated horse-power per hour amounted to $\frac{21,564}{1,087\cdot4}$, or at the rate of 19·83 lbs. per I.H.P. per hour, the quantity of steam consumed could not have exceeded 16·5 lbs. per I.H.P. per hour, as the figures in the foregoing paragraph show. The difference must be attributed to priming.

“Tartar.”

Total Efficiency.—The combined efficiency of the boiler and engines, or ratio of the heat turned into work to the total heat of combustion, was 9·7 per cent.

Steam from Indicator Diagrams.—The following are the results of measurements made upon the indicator diagrams taken, to ascertain the proportion of steam accounted for by them. The actual weight of feed-water used per revolution was 5·13 lbs. :—

Proportion of Steam accounted for by indicator diagrams.	Lbs. per Revolution.	Percentage of Total Feed.	Percentage in Jackets or present in cylinder as water.
Steam present in high-pressure cylinder after cut-off, when the pressure was 115·4 lbs. per square inch above the atmosphere	Lbs. 2·32	Per cent. 45·2	Per cent. 54·8
Steam present in intermediate cylinder, when the pressure was 33·4 lbs. per square inch above the atmosphere	2·52	49·1	50·9
Steam present in intermediate cylinder when the pressure was 9·4 lbs. per square inch above the atmosphere	2·99	58·2	41·8
Steam present in low-pressure cylinder near end of expansion, when the pressure was 7·1 lbs. per square inch below the atmosphere	3·10	60·3	39·7

Speed of Vessel.—The following notes from the log book of the ship may be of interest :—

	Time.
Left London Docks	5.0 a.m.
Gravesend	7.20
Nore	8.35
Girdler Light Ship	9.30
Dover	12.40 p.m.
Dungeness	2.20
Royal S. Light Vessel	4.20
Beachy Head	5.0
Owers	8.0
St. Catherine	11.30
Portland	5.0 a.m.

The Research Committee on Marine-Engine Trials, in presenting to the Members of the Institution this second Report upon their work, desire it to be understood that they do not look upon their duties as yet ended. They are glad to be able to think however that they have already done enough to show that engine trials can be conducted on board ship on as complete a scale and in as scientific a method as on land, although perhaps with greater difficulty and discomfort to the observers ; and that this can be done without any undue interference with the normal working of the ship or engines.

The Committee wish also to say that they hope, when their work is completed, to present a comparative summary of all their experiments, in the discussion on which many points as to the influence of design on economy can be better dealt with than at present. Their future work may be much helped however by suggestions made at this stage as to improvements in the methods or in the instruments used, or as to the best means of ensuring the accuracy, or measuring the errors, of gauges, indicators, &c. They would also point out that there still does not exist any satisfactory means for measuring the *effective* horse-power of a marine engine in its actual work, that is, the power actually expended in pushing the ship forward, as represented by the thrust of the propeller and the speed of the ship ; nor for measuring the quantity of the condensing water, a knowledge of which is necessary to enable a "heat balance" for the engines to be made.

There is added to this report Table 6, pages 237-240, showing the comparative results obtained in the four trials thus far made by the Committee ; and also two appendices, the first (page 241) showing the instructions given for taking indicator diagrams, and the second (page 242) giving a list of the Members of this Institution and others who have taken part in the trials.

TABLE 6 (continued to page 240). *Comparative Results of the Trials of Four Steamers,*
 “METEOR,” “FUSI YAMA,” “COLCHESTER,” “TARTAR.”

1	Name of Vessel	Meteor.	Fusi Yama.	Colchester.	Tartar.
2	Date of Trial	24 June 1888	14 & 15 Nov. 1888	9 Nov. 1889	27 Nov. 1889
3	Duration of Trial hours	17·15	13·95	10·88	10·08
4	Type of Engines	Triple	Compound	{ Twin Compound }	Triple
5	Cylinder diameter, high-pressure inches	J 29·37	N 27·35	N (two) 30.	N 26·03
6	„ „ intermediate inches	J 44·03	—	—	J 42·03
7	„ „ low-pressure inches	J 70·12	N 50·3	N (two) 57	J 68·95
8	Stroke, length inches	47·94	33	36	42
9	Boilers, number of main boilers	2	1	2	2
10	„ single-ended or double-ended	double	single	double	double
11	Furnaces, total number	12	3	12	8
12	Heating surface, total square feet	6,648	2,257	5,820	5,226
13	„ „ tubes square feet	5,760	1,689	4,770	4,366
14	Grate area square feet	208	52	220	161
15	Total heating surface to grate area ratio	32·0	43·4	26·5	32·5
16	Tube surface to grate area ratio	27·7	32·5	21·7	27·1
17	Grate area to flue area through tubes ratio		4·0	5·5	4·5
18	„ „ to area through funnel ratio	5·0	3·2	4·8	4·2

J = Jacketed.

N = Not jacketed.

TABLE 6 (continued from preceding page). *Comparative Results of the Trials of Four Steamers,*
 "METEOR," "FUSI YAMA," "COLCHESTER," "TARTAR."

	Name of Vessel	Meteor.	Fusi Yama.	Colchester.	Tartar.
19	Mean boiler-pressure above atmosphere lbs. per sq. inch	145·2	56·84	80·5	143·6
20	„ admission „ high-pressure cyl. above atm. .. lbs. per sq. inch	134·4	50·3	{ 64·3 59·4 }	121·4
21	„ effective „ high-pressure cylinder lbs. per sq. inch	58·46	30·74	{ 45·65 42·07 }	36·89
22	„ „ „ intermediate „ lbs. per sq. inch	19·50	—	—	20·07
23	„ „ „ low-pressure „ lbs. per sq. inch	12·38	10·87	{ 13·42 12·42 }	7·18
24	„ „ „ total referred to low-p. cyl. .. lbs. per sq. inch	29·9	19·9	24·8	19·8
25	„ exhaust „ low-pressure cyl. below atm. .. lbs. per sq. inch	11·6	10·9	{ 10·6 10·5 }	10·5
26	„ vacuum in condenser below atmosphere .. lbs. per sq. inch	12·17	12·48	12·49	12·9
27	Revolutions per minute, mean revs.	71·78	55·59	{ 86·0 87·1 }	70·0
28	Piston constant, high-pressure cylinder H.P.	11·31	5·36	{ 10·71 10·84 }	7·73
29	„ „ intermediate „ H.P.	26·00	—	—	20·42
30	„ „ low-pressure „ H.P.	66·65	18·32	{ 39·55 40·06 }	55·27
31	Indicated horse-power, high-pressure cylinder I.H.P.	662	168·2	{ 490·3 457·9 }	283·7
32	„ „ intermediate „ I.H.P.	507	—	—	408·5
33	„ „ low-pressure „ I.H.P.	825	203·1	{ 532·2 499·3 }	395·2
34	„ „ mean total I.H.P.	1,994	371·3	{ 1022·5 957·2 }	1,087·4

TABLE 6 (*continued from preceding page*). *Comparative Results of the Trials of Four Steamers,*
 “METEOR,” “FUSI YAMA,” “COLCHESTER,” “TARTAR.”

	Name of Vessel	Meteor.	Fusi Yama.	Colchester.	Tartar.
35	Coal burnt per minute lbs.	66·75	16·45	95·7	32·0
36	” ” per hour lbs.	4,005	987	5,742	1,920
37	” ” per square foot of grate area per hour .. lbs.	19·25	18·98	26·1	11·93
38	” ” per square foot of total heating surface per hour .. lbs.	0·602	0·437	0·987	0·367
39	” ” per indicated horse-power per hour .. lbs.	2·01	2·66	2·90	1·77
40	Carbon-value of 1 lb. of coal as used lbs.	0·878	0·878	0·913	1·031
41	” ” equivalent per I.H.P. per hour lbs.	1·76	2·33	2·65	1·82
42	Feed-water per minute lbs.	497·7	131	717	359·4
43	” ” per hour lbs.	29,860	7,860	43,020	21,564
44	” ” per square foot of total heating surface per hour .. lbs.	4·49	3·48	7·39	4·13
45	” ” per lb. of coal lbs.	7·46	7·96	7·49	[11·23]
46	” ” per lb. of coal from and at 212° F. lbs.	8·21	8·87	8·53	[13·06]
47	” ” per lb. of carbon-value from and at 212° F. .. lbs.	9·62	10·10	9·34	[12·67]
48	” ” per indicated horse-power per hour lbs.	14·98	21·17	21·73	[19·83]
49	Calorific value of 1 lb. of coal as used thermal units	12,770	12,760	13,280	14,995
50	Percentage of line 49 taken up by feed-water per cent.	62·0	67·2	62·0	—
51	” ” ” ” carried away by furnace gases per cent.	21·9	23·5	28·0	22·1
52	” ” ” ” lost by imperfect combustion per cent.	3·6	0·0	1·3	0·0
53	” ” ” ” expended in evaporating moisture in coal, per cent.	1·2	0·9	0·4	0·0
54	” ” ” ” unaccounted for per cent.	11·3	8·4	8·3	—

TABLE 6 (concluded from page 237). *Comparative Results of the Trials of Four Steamers,*
 "METEOR," "FUSI YAMA," "COLCHESTER," "TARTAR."

	Name of Vessel		Meteor.	Fusi Yama.	Colchester.	Tartar.
55	Heat taken up by feed-water per minute	thermal units	528,600	141,100	788,700	[403,600]
56	„ turned into work per minute	thermal units	85,240	15,870	84,630	46,490
57	„ taken up by feed-water per I.H.P. per minute	thermal units	265·6	380·0	398·4	[371·2]
58	Efficiency of boiler (line 50)	per cent.	62·0	67·2	62·0	—
59	„ of engine (line 56 ÷ line 55)	per cent.	16·1	11·2	10·7	[11·5]
60	„ of engine and boiler combined (line 58 × line 59)	per cent.	10·0	7·6	6·6	9·7
61	Mean velocity of steam thro' water-surface in boilers per min.	feet	..	6·28	8·60	3·43
62	Space occupied by boilers per I.H.P.	cubic feet	2·72	4·53	2·52	4·33
63	Weight of engines, boilers, &c., with water, per I.H.P.	tons	0·20	0·27	0·20	0·27
64	Clearance volume, high-pressure cylinder	per cent.	12·4	8·5	{9·39} {9·39}	14·51
65	„ „ intermediate „	per cent.	9·3	—	—	9·25
66	„ „ low-pressure „	per cent.	8·02	5·0	{6·23} {6·23}	5·10
67	Clearance surface, high-pressure cylinder	square feet	..	17·3	{22·6} {22·6}	25·4
68	„ „ intermediate „	square feet	..	—	—	40·1
69	„ „ low-pressure „	square feet	..	42·5	{56·9} {56·9}	79·6
70	Speed of vessel, mean during trial	knots	14·6	..	14·4	..

APPENDIX 1.

Instructions given for taking Indicator Diagrams.

See that indicators have proper length of stroke and are not on stops. Blow through before taking every diagram.

Mark number of diagram in top right-hand corner.

Let H.P. top diagrams begin with No. 1, H.P. bottom with 101 ;
I.P. top with 201, I.P. bottom with 301 ; L.P. top with 401,
and L.P. bottom with 501.

Let top and bottom diagrams of each cylinder be taken as nearly as possible together, and the whole set as quickly as possible.

After having taken a set of diagrams and entered time in log &c., put new papers on at once for the next set.

Draw atmospheric line by hand with full stroke.

First watch to get indicators ready before starting, and note on log sheet numbers of indicators and marks and scales of springs.

Second watch to verify these numbers, and after taking last diagrams on the watch interchange top and bottom indicators of each cylinder.

Third watch to verify the changed numbers.

Fourth watch, after taking last set of diagrams, to take indicators off and put them in boxes.

Examine every set of diagrams before putting away, to detect anomalies or errors. Compare top and bottom diagrams of each cylinder for length, pressure and general appearance. If any difference is noticed, or anything suspicious about diagrams, report at once to engineer in charge of watch.

Keep the indicator boxes shut, and the papers in them.

APPENDIX 2.

Staffs of Observers.

* Members of the Institution are marked with an asterisk.

In the "Fusi Yama" trial one watch was taken by Mr. R. H. Willis, with Messrs. L. A. Legros* and J. R. Sharman; and the other by Professor Kennedy,* with Messrs. P. G. Evans and A. P. Head.* Mr. Frederick Edwards,* as superintendent engineer for the owners, took general charge of the working of the engines throughout.

In the "Colchester" trial Mr. Frederick Edwards* took one watch, with Messrs. A. G. Ashcroft, R. H. Willis, P. G. Evans, J. R. Sharman, L. S. Robinson, W. E. Burgess, A. P. Head,* and J. T. Ewen; while Professor Kennedy* took the other watch, with Mr. E. L. Morris,* Professor T. H. Beare, and Messrs. H. R. J. Burstall,* E. C. de Segundo, L. A. Legros,* D. White, and W. A. Cloud. Mr. C. J. Wilson collected the gas samples personally during the whole of the trial.

In the "Tartar" experiments Mr. Frederick Edwards* took one watch, with Messrs. A. G. Ashcroft, C. L. Simpson,* L. A. Legros,* J. R. Sharman, A. P. Head,* Hubert Cochrane, and J. T. Ewen; and Professor Kennedy* took the other watch, with Messrs. R. H. Willis, R. Rogers, D. Capper, E. C. de Segundo, P. G. Evans, W. E. Burgess, and W. A. Cloud. Mr. Wilson again collected the whole series of gas samples personally; and Mr. Bryan Donkin, Jun.,* attended to other duties on deck.

The Captains and Chief Engineers of the three vessels—Captain J. Caine and Mr. W. Towers of the "Fusi Yama," Captain W. Nickerson and Mr. I. Cartlidge of the "Colchester," and Captain D. S. Bailey and Mr. W. Brown of the "Tartar"—gave every assistance to the staff in carrying out the observations, and by their valuable co-operation contributed materially to the success of the trials; and mention should not be omitted of the kind help received from Captain Howard and Mr. Derry, of the Great Eastern Railway, upon the "Colchester" trial.

Discussion.

The PRESIDENT was sure the Members would wish at once to pass a vote of thanks to the owners who had so kindly lent their ships for the trials now reported, and to the Captains and Chief Engineers of the ships who had rendered so much assistance for carrying out the trials. He therefore moved that the thanks of the Institution be given to Messrs. Gellatly Hankey Sewell and Co., the owners of the "Fusi Yama" and the "Tartar," and to the Great Eastern Railway Co., the owners of the "Colchester"; and also to the Captains of the three vessels, and the Chief Engineers and their staffs. He also proposed a vote of thanks to Mr. Wilson, who had so obligingly collected and analysed the samples of the furnace gases and made the analyses of the coal and ash; that was a work which must have been attended with a great amount of labour, and, so far as could be made out from the trials themselves, it had been very well and very carefully done.

The votes of thanks were passed with applause.

Mr. WILLIAM LAIRD, Member of Council, though hardly prepared to enter upon any criticism of the report or of the many facts given in it, could at any rate join in complimenting Professor Kennedy upon the skilful way in which he had organized the trials, and upon the efficient and zealous manner in which they had been carried out by the staffs of observers. There was a great amount of information contained in the present report, which when properly studied and developed would be most useful in a practical way to those who had to compare the working of different engines for the purpose of still further economizing their performance. In his opinion the records of such trials were of great value; and if they could be extended to embrace a few more examples of recently constructed marine engines, the data would be of still greater value for comparison and guidance in the efforts yet further to promote economy in combination with efficiency. It was quite true that the

(Mr. William Laird.)

first trials or trial trips of marine engines, and the performance of ships of all kinds, had for many years past been made the subject of most careful observation by leading engineers and shipbuilders; and the regulations drawn up by the Admiralty for trials of ships of war were very complete, and in many instances had formed a sort of guide for the trials of machinery for commercial purposes. It seemed to him however that the scheme drawn up by Professor Kennedy and his Committee, and carried out in the trials now reported, took in more than the conditions usually observed, and gave special attention to the boiler and to the conditions under which the coal was burnt and the heat utilized; and the observations thus made he thought might have special value, now that assisted draught in stoke-holds by the aid of fans was not unusual. Speaking generally, it was important that any data put forward under the auspices of this Institution should be correct and reliable; and in the hands of Professor Kennedy and his colleagues he felt sure this investigation was being most carefully conducted, and would prove of great help for purposes of comparison and advancement.

Mr. EDWARD H. CARBUTT, Past-President, gladly joined in thanking Professor Kennedy and all the gentlemen who had helped him to give the reliable data which had been placed before the Members. There was one question that he should like to raise in regard to the steam for the circulating-pump engine (page 219), which was stated to be supplied from the donkey boiler. Surely the work done by the circulating pump was part of the work of the engine; and the steam consumed by the circulating-pump engine ought therefore to be added to the steam consumed by the main engines. To that extent he thought the data from the three different types of engines could not be fully compared. Although himself an old marine man, having been some years at Messrs. Palmer's, he certainly should not like to enter into the discussion of the present report until he had had an opportunity of going through the figures much more thoroughly, and particularly those given in the comparative Table 6, which appeared to him to contain the gist of the whole research, and had been so well put together that it was easy to find the information

desired on any point. The Committee had rendered an important service, not only to the Institution, but to the whole country; and he thought the result might already be found in the pockets of steamship owners, of whom one of the largest had lately stated that, although during the last five or six years his coal had gone up five shillings a ton, yet his working expenses had not increased. This clearly pointed to the fact that marine engines had been able to do more work per lb. of coal; and to that extent the improvement was for the benefit of the trade of the country. It was well known that this country did three-fourths of the carrying trade of the world; and it was therefore a great gain that, although coal had gone up to the extent of five shillings a ton, the working expenses had not increased. The trials now made he was confident would help still further towards economising in marine-engine work.

Mr. J. H. HALLETT considered the report now presented was a most important one in itself, and he was also glad to infer from page 236 that still further experiments were contemplated, which he trusted would throw yet more light upon the subject of marine-engine efficiency. Such trials had until recently been very much neglected, principally he thought owing to the hurry with which ordinary cargo steamers were worked, giving little or no time for experiments or investigations of any sort. Now however that there was a better educated class of sea-going engineers, he trusted the difficulties in the way of further research might be got over. What struck him most particularly in the present report was the smoke analysis, which revealed so remarkable a difference in the quantity of air supplied in the three steamers, amounting to 22·8 and 18·5 and 31·6 lbs. of air per lb. of coal in the "Fusi Yama," "Colchester," and "Tartar" respectively. This great difference seemed surprising, as the boilers were all of the ordinary modern kind. He quite agreed with Mr. Carbutt (page 244) that some means should be adopted to measure the steam supplied to the circulating-pump engine, or the quantity of circulating water, for enabling the experiments to be made more conclusive; and he could well understand the difficulties to be surmounted. He should like to know to what extent the inevitable

(Mr. J. H. Hallett.)

waste of water from the glands of the piston-rods and feed-pumps had been noted and taken into account, as no mention of this point was made in the report. He had long looked forward to such trials as these in connection with the working of marine engines. For a number of years a great deal of time had been devoted to locomotives; and as England did the largest carrying trade in the world, he thought that more notice than hitherto should now be taken of marine engines, so as to give the rising generation of engineers an interest in the machinery placed under their charge; and it would be an inducement to them to work their engines in a more economical manner, and get the utmost work out of both engines and boilers, and prove to the ship-owners and others directly interested that these investigations would result in great benefit to commerce.

Mr. P. W. WILLANS considered Professor Kennedy was to be congratulated on having put before the Institution so complete a summary of the three trials described in this report. It was fortunate that all three came together in the same report, because it was interesting to be able to compare the results of trials in which the conditions were so different. The trial of the "Tartar" was especially interesting, because of the large quantity of water that was proved to have been present in the engine: he said proved, because it seemed hardly possible that any serious mistake could have crept in, although it seemed startling that so large a proportion of water was present.

As to the actual efficiency of the engines, he found on a comparison of the work done with the work which could have been done that the efficiency was almost exactly the same in all three. In the "Fusi Yama," taking the two extreme temperatures—the steam-chest temperature and the condenser temperature,—the quantity of water which would theoretically have been required per indicated horsepower per hour was 11·42 lbs., and the quantity actually used (Table 6, line 48) was 21·17 lbs., showing an absolute efficiency of 53·9 per cent. In the "Colchester," in which it was stated (page 224) that the engines were built more for speed than for economy, the water theoretically required was 10·71 lbs., and the water actually

used was 21.73 lbs., giving an efficiency of 49.3 per cent., as against 53.9 per cent. in the "Fusi Yama." In the "Tartar" the measured feed-water was at the rate of 19.83 lbs.; but it had been shown (page 234) that the heat from the coal could not possibly have evaporated more than 16.5 lbs. As a matter of fact 19.83 lbs. did go through the engine; and therefore the heat had been employed not altogether in making steam, but partly in making hot water. On the assumption that the boiler was giving the 70 per cent. efficiency mentioned in page 234, he found that 15.50 lbs. of steam and 4.33 lbs. of hot water must have passed through the engine per indicated horse-power per minute. That was neglecting the jacket water, which was a small matter—only 4 per cent. Supposing there had been the full 16.5 lbs. of steam, the engine efficiency would practically have been 53 per cent. Supposing that the engine took the 15.50 lbs. of steam and the 4.33 lbs. of water, the efficiency would be 54.3 per cent. of what the steam and water together could theoretically do. So that in the "Fusi Yama" and the "Tartar" the comparative efficiencies, calculated from the results given, were as 53.9 to 54.3. He should like to know what there was in the boiler to cause it to send over so prodigious a quantity of water; and taking this into account, it seemed astonishing to him that the engines did as well as they did. In any more of these trials that might be made, it would be of much interest if some kind of calorimeter on the boiler could be devised: not that there was any reason to doubt the figures now given, but it would be well to have an opportunity of corroborating them by a measurement of the water in the steam as it left the boiler. The Barrus calorimeter, though he had not himself tried it, he had heard well spoken of. A tank calorimeter, such as he had himself used, would test within half of one per cent.; but it was not very portable, and not easy to use on board ship. It was not necessary however to do the weighing while at sea; steam might be blown into a known weight of water in a vessel, and the water then weighed again on shore; the only observations necessary while at sea would then be the temperature before and after blowing the steam in.

The indicator diagrams illustrating the report he considered should be given separately both from the upper end of the cylinder

(Mr. P. W. Willans.)

and from the lower end, because he thought there was a great chance of the diagram from the under side of the piston differing considerably from that from the upper side, on account of the presence of water in the lower end of the cylinder. This was a point which he had noticed before in connection with some experiments of his own; but he had not then obtained what he thought absolute proof, and he now wished therefore to revert to the subject. He had lately been experimenting with a vertical compound engine that could be worked either condensing or non-condensing, in which water was found to accumulate in the lower end of the low-pressure cylinder when exhausting into the atmosphere. In designing the engine every precaution had been taken for enabling any water to drain away through the port; and from the section shown in Fig. 67, Plate 117, it would be seen that there appeared little chance of the water accumulating. It was found however that on cold days, and under conditions depending on a variety of small details, the water accumulated in considerable quantities; and then the engine gave out a comparatively small power. In Fig. 68 was shown one of the indicator diagrams taken when the water had accumulated; and in Fig. 69 was one taken when the water had been removed. Sometimes the engine would be running two or three hours without any water accumulating; and at other times he could hear the piston in the down stroke just touching the water in the bottom of the cylinder, but without causing a loud noise. It had therefore occurred to him that if a small copper steam-pipe were laid at C round the inside of the cylinder, in an annular recess formed for the purpose, it would be able to boil the water off; of course there was no steam coming into the cylinder through the pipe, which acted simply like a small boiler fitted into the recess in the cylinder bottom. On blowing steam through the pipe, it was found that the indicator diagrams immediately changed from Fig. 68, with only 19 lbs. initial pressure per square inch, to Fig. 69 with 25 lbs. initial pressure. Possibly a little of the difference might be caused by some distortion of Fig. 68, owing to the water in the indicator; but not much, because it was found that when the steam line was lowered in the low-pressure cylinder the exhaust line in the high-pressure cylinder was also lowered to correspond.

There was only about 4 inches length of pipe from the cylinder to the indicator, which was placed some distance from the point where the water was likely to collect, and just above the bottom of the cylinder, where it would be least likely to get water. As soon as ever the accumulated water in the low-pressure cylinder had been evaporated by the copper steam-pipe, which was done in about a quarter of a minute, the steam-line in the low-pressure diagram rose, and the exhaust line in the high-pressure diagram also rose. Therefore the difference in the low-pressure diagram was not all gain, because a good deal was taken off the high-pressure diagram; still a large margin of gain was left. It was also found in the dynamo which the engine was driving that the volts immediately went up and the current increased, to an extent corresponding with the increased power developed by the engine. As long as the water was present in the cylinder, its effect was seen in the lower compression curve in Fig. 68, showing that part of the steam during compression was condensed in raising the temperature of the water, and so lost as steam. When there was no water in the cylinder the compression curve rose in Fig. 69; it was then more nearly the compression curve of dry steam. A remarkable circumstance noticed was that, after the accumulation of water in the bottom of the cylinder had been driven off by the heat from the copper steam-pipe, and the steam had been shut off from the pipe, the diagrams continued to be the same as in Fig. 69, showing that the cylinder continued dry. It seemed as though, if the water once accumulated to a certain depth, it caused more water to accumulate; and if it were once reduced below that depth, the remainder boiled off, and no further accumulation took place. Theoretically no doubt, if the steam were used without much expansion, water was not likely to accumulate in the cylinder, unless it came in with the steam as priming water; but if on the other hand the steam were expanded down nearly to the back pressure, the probability was that water would then accumulate in the cylinder. In his own experiments the water did accumulate; but after once being driven off, it did not return. He could only account for this by the difference in the conducting power of the cylinder when dry and when water was in it;

(Mr. P. W. Willans.)

or possibly by the depth of the water preventing the bubbles of steam boiled off during expansion from ever reaching the surface of the water and escaping from it as steam until it was too late: the steam condensed owing to work done by the bubbles during expansion might remain in the water and might turn the scale. After the cylinder had once been dried by the copper pipe, the only way in which the water could with certainty be got to accumulate was by pumping cold water through the copper pipe; and when by this means the water had been once got to accumulate, the drying process had to be again resorted to in order to get rid of it. Professor Unwin had suggested trying whether increased external radiation would have the same effect; it had been found that by packing ice round the cylinder outside the same result was obtained, and when the water once accumulated, it could not be got rid of, except by means of the copper steam-pipe. The quantity of steam required in the pipe for drying the cylinder was a little more or a little less, according to the quantity of water accumulated in the cylinder; but the steam did not need to be kept blowing through the pipe; in fact the cost of the increased power was *nil* when the water was once removed. When exhausting into a condenser, he had thus far been unable to succeed in inducing accumulation of water in the cylinder: possibly because of the greater amount of re-evaporation during exhaust; or because of the smaller transmission of heat to surrounding bodies, due to the lower temperature of the cylinder. Although the size of the diagram in Fig. 69 was 30 to 40 per cent. greater than in Fig. 68, yet 15 to 20 per cent. or half of this gain was neutralised by the reduction of power in the high-pressure cylinder; and then the low-pressure and the high-pressure cylinder were about equal in power. The ultimate gain was about 6 to 10 per cent. in the power of the engine. This was not a result deduced merely from the indicator diagrams, but it had been proved by the work actually performed. The reason why he drew attention to this subject was that, where there was such a large quantity of water present in the cylinders, it must seriously affect the power of any engine; and diagrams taken from the under side of the low-pressure piston might show that the cushioning of the piston on that side was

more like that shown in Fig. 68, while on the upper side it might follow more nearly the true compression curve, as in Fig. 69. On this subject there was no doubt a great deal still to be learnt. In page 235 he noticed that the percentage of water calculated as present in the high-pressure cylinder of the "Tartar" strongly corroborated the conclusion that the steam was very wet; the percentage of steam in that cylinder was so much less than in either of the two other trials. It seemed extraordinary that only 45·2 per cent. of the feed-water should be present as steam in the high-pressure cylinder of the "Tartar" at the point of cut-off, in spite of its being a triple engine and steam-jacketed.

Mr. HENRY DAVEY considered that in the report now presented engineers were furnished with everything they could desire in connection with these experiments, in the shape both of data and of calculations. The absence of steam-jackets on the two-cylinder compound engines in the "Fusi Yama" and the "Colchester" was a matter which he could not quite understand, inasmuch as it was seen from line 48 of Table 6 that in the "Meteor" triple engines with steam-jackets, and also in the "Tartar" triple engines with steam-jackets when the correction indicated in the report was made, the economy in the feed-water was something like 25 per cent. It seemed to him that probably an economy of about 12 or 13 per cent. or more might have been effected in the two-cylinder compound engines by the use of steam-jackets, so that instead of being 25 per cent. behind the triple they would be only half as much behind. Great diversity of opinion he was aware existed about the utility of steam-jackets on marine engines; but he failed at present to see why they should not be used. They were said to be troublesome at sea; but he could not see why they should be more troublesome at sea than on land. There would no doubt be difficulties in the way; but he thought a considerable economy might have been effected in the compound engines here referred to, if they had been steam-jacketed.

Another point that occurred to him was in regard to the effect of piston speed on the economy of the engine. Recently he had been

(Mr. Henry Davey.)

making a feed-water trial with a triple-expansion engine running at the low piston-speed of only 140 feet per minute, and with an initial pressure of 130 lbs. per square inch above the atmosphere; and it gave results almost identical with those of the "Meteor." It was a steam-jacketed engine, and with the jackets in action the consumption of feed-water was 15 lbs. per indicated horse-power per hour, which was practically the same as in the "Meteor," where with an initial pressure of 134.4 lbs. the piston speed was 570 feet per minute. If there was any effect from the cooling which took place during exhaust, the time during which the cooling would continue must be greater in a slow-running engine than in a quick-running; the result however, as far as the consumption of feed-water was concerned, was identical.

Another curious point was that in his own trial, to which he was referring, the virtual steam-load on the low-pressure piston—that is, the whole power of the engine referred to the low-pressure piston—was 15 lbs. per square inch, whereas in the "Meteor" the corresponding load was 29.9 lbs., the initial pressure being almost the same in both cases. Therefore the expansion in his own trial must have been greater; and the economy due to the increased expansion appeared to have compensated for the lower piston-speed, so that the results in consumption of feed-water were identical. Thus with the same boiler-pressure, but with only one quarter the piston speed and with greater expansion, the same ultimate economy was found to be realised. There was evidently therefore a great deal to be learnt from engine trials carefully conducted; and such figures as these showed the great importance of the subject. The rough and ready trials that were made commercially did not give results from which such accurate deductions could be drawn as from the results of trials carefully conducted in the manner of those described in the report.

With reference to the question of water in the cylinders, although he had no data to corroborate in any way the argument adduced by Mr. Willans (page 248), he knew from general experience with steam engines that it did happen that water accumulated in a cylinder not exhausting into a condenser. In large horizontal

engines, even where the piston-rod was as much as two feet above the bottom side of the cylinder, water was often found to be coming out through the stuffing-box without any knock in the cylinder, when there was a leak in the stuffing-box: which must be the result he imagined of the steam itself being wet. But if the water accumulated in the cylinder sufficiently to fill the clearance between the piston and the cover, there was a distinct knock. It appeared to him that the great importance of steam-jacketing lay in its rendering the steam dry at the end of the stroke; and if the steam were made dry at the end of the stroke, or soon before the end of the stroke, then great economy resulted from the jacket. It was evident from the report that there must have been a considerable amount of priming water in the "Tartar." That was one of the great bugbears which had to be dealt with in experiments on steam engines; priming water might be present in the cylinder before it was detected. If some ready means could be devised for ascertaining the amount of priming water during the progress of experiments, it would be most valuable. At present a trial conducted with the greatest care and accuracy might be vitiated by the unrecognised presence of priming water.

The efficiency of the engines in the trials now reported was expressed in terms of the total quantity of heat received by the feed-water. This was probably the most reasonable way of expressing it, because all steam engines could then be referred to the same standard. But he could not help thinking that it would be further desirable if an expression could be introduced which would give an idea of something beyond. For it was obvious that if a two-cylinder compound engine were working with a boiler pressure of say 65 lbs., and a triple-expansion engine were using 130 lbs., it would be found that the efficiency of the latter, expressed in terms of the heat turned into work out of the total quantity of heat supplied in the feed-water, would be much better; but then the question was whether it was as much better as it ought to be. Hence the idea of expressing the efficiency of the engine in terms that included the range of temperature through which it worked seemed to him to be not so purely theoretical as it was sometimes imagined to be. It was true

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that such an expression was generally used under the form of what was known as Carnot's function ; but instead of this he should prefer to express the heat utilised as a fraction of the heat practically available for the production of work. By way of illustration, if it were supposed that water was being drawn off from a tank through a pipe in the side of the tank and above the bottom, it was only the water above the mouth of the pipe that could be made use of ; the remaining water below the pipe was of no use, and it did not matter how much water the tank could contain below the pipe, because it could not be made use of. So the heat below the normal temperature of the place where the engine was working was heat that could not be made use of ; the only heat that could be made use of was what was above that temperature. Hence if the heat turned into work by the engine were 12 per cent. of the total quantity of heat taken up by the feed-water, and if the range of temperature through which the engine worked were such that the maximum work possible would be equivalent to 40 per cent. of the heat in the feed-water, then the expression for the practical efficiency of the engine would be $12 \div 40 = 30$ per cent. In this way the practical condition might be associated with the actual result obtained in the quantity of heat converted into work ; and thereby more information would be furnished than was afforded by merely expressing the work as a fraction of the total quantity of heat.

In the two-cylinder compound engines of the "Fusi Yama" and the "Colchester," looking at the small extent of expansion in the high-pressure cylinder, he thought a better result might be expected if more expansion could be obtained in that cylinder. Better results were obtained in land compound engines having the same proportions of cylinders. That naturally arose from the fact that marine engineers had to produce a commercial result ; it was not simply a matter of reducing the consumption of feed-water. If complications were introduced into the engine, they gave rise to difficulties which more than counterbalanced any gain in economy. Marine engineers therefore had to content themselves with simple valve-gear, which meant confining themselves generally to the ordinary link-motion and the ordinary slide-valve, and doing as well as they could with

these, having no separate expansion-valve on the different cylinders. Better results he was convinced could be obtained if separate expansion-valves were used; but he did not mean to say that it would be worth while commercially to use them; probably in practice it would not be found to be so. Nevertheless with compound engines working under the conditions described in the report, he thought that the better results obtained in land engines might render it worth while for marine engineers to turn their attention to getting more complete valve-gear for expansive working.

Mr. WILLIAM SCHÖNHEYDER suggested that the report on the "Fusi Yama" trial, which had been made in November 1888, should have been presented earlier by itself, instead of waiting for the two later trials. Progress was now made so rapidly that such a report was of very little use after twelve or eighteen months; future trials he therefore hoped would be described a little sooner. In all the three trials now reported he noticed that the steam for the circulating pump was taken from a separate boiler; but there were many marine engines in which it was taken from the main boiler; and as the power required for the circulating pump was often great, he hoped it might be possible in future cases to take indicator diagrams from the engine which drove the circulating pump, so as to ascertain what power was thereby added practically to the main engines. He also thought the report would have been more valuable if, in addition to the statements in figures, the indicator diagrams had also been combined, as had been done in the case of the "Meteor" (Proceedings 1889, Plate 48), in order that it might more readily be seen whether there was any loss due to wire-drawing and condensation between the cylinders, or to other causes. From line 44 in Table 6 it appeared that the amount of water evaporated per hour per square foot of total heating surface was 3.48 lbs. in the "Fusi Yama," and 7.39 lbs. in the "Colchester": so that the rate of evaporation in the "Colchester" was more than twice that in the "Fusi Yama." Thence it would naturally be expected that the efficiency of the boiler in the "Colchester" would be much less than in the "Fusi Yama"; but it was seen from line 58 to be not much less. What then was the good

(Mr. William Schönheyder.)

of all the figures given in the report? They seemed to him to be practically useless, and the report itself to be only a half-and-half sort of production. What he wanted was drawings of the engines and boilers, in order to find out what it was that caused the efficiency to be so different from what it ought to be; at present he considered the figures given were next to useless.

MR. LAVINGTON E. FLETCHER wished to join in thanking Professor Kennedy for the trouble he had taken in conducting these marine-engine trials and in laying the results before the meeting; and hoped he should not be considered unmindful of the labour which the investigations and the report had entailed, if he asked for a little more information still. The proportion of steam accounted for by the indicator diagrams was given in the "Fusi Yama" without steam-jackets as 70·8 per cent. (page 211), and in the "Tartar" with steam-jackets as 60·3 per cent. (page 235). Having always been an advocate of steam-jackets, he did not understand how the loss of steam was greater with the steam-jacket than without it; and he should be glad if Professor Kennedy could offer some remarks on this point. It would also be of assistance in studying the report, he thought, if the "piston constant" for each cylinder were given, that is the horse-power exerted in the cylinder for every pound of mean effective pressure per square inch on the piston. Piston constants were very convenient in forming comparisons between different engines, as well as between the different cylinders in the same engine; for they showed the relative capacities of the cylinders, including the speed of piston; or in other words, they showed the comparative "piston sweep." In Table 6 the mean effective pressures per square inch in the several cylinders were given, as well as the total effective pressure when referred to the low-pressure cylinder. These figures were very valuable, and coupled with the piston constants would be found of considerable service in studying the results of different engines and comparing one with another.

MR. FREDERICK EDWARDS, as superintendent engineer to the owners of the "Fusi Yama" and the "Tartar," said that the "Fusi

Yama" had been purchased and overhauled just before the trial now reported. The voyage during which the test took place was her first voyage under his supervision. The cylinders had not been re-bored, but the pistons had been fitted with new spring rings. In order as far as possible to ensure everything being in order, he had had the engines indicated, and had made some alterations in the setting of the slide-valves. Unfortunately the new spring rings in the pistons did not quite fit the worn parts of the cylinders, time being required for the cylinders to wear up to a good surface. The high-pressure cylinder was the worst, and the stiffness of the rings accounted for the difference in the powers as given in page 208. After a voyage or two the surfaces had now worked up to a first-rate condition, and the powers had become equal, the two cylinders together giving something like 450 indicated horse-power.

The "Fusi Yama" he believed was the first steamer that had been fitted with permanent tanks for measuring the feed-water. They were fitted above the engines, on a level with the tops of the cylinders; and the air-pump delivered into them. There was no objection to that arrangement; it worked well, provided the air pipe or overflow pipe stood a few feet above the tanks. It was also necessary of course to have a sufficient air-vessel on the delivery pipe, and then the extra pressure on the delivery valve made little apparent difference in the working of the air-pump. The discharge pipe from the tanks led directly down to the feed-pumps; consequently there was a pressure in the suction pipe, which he found always unsatisfactory in working, that is, if the pressure was at all great. In the present case the feed-pumps apparently filled right up with water, and no air got in to cushion the return stroke of the plunger; hence any leakage there might be round the plunger was of water, none of it was air. Consequently the pumps worked under an undue pressure; and in all future cases therefore he was satisfied it would be better to fix a third tank at about the level of the pumps, for them to draw from, and for the measuring tanks to drain into. When he had an opportunity, he should fit another tank below in the "Fusi Yama," and let the upper tanks drain into it; this would do away with the undue pressure or shock on the pumps.

(Mr. Frederick Edwards.)

He had since had another steamer, the "Olympo," also fitted with permanent tanks, as shown in Figs. 59 to 62, Plates 114 and 115. Here TT were the two rectangular measuring tanks, each of 100 gallons capacity and each draining into the reservoir R below. The arrangement of the pipes was as follows:—A the discharge from air-pump U to measuring tanks T; B suction from measuring tanks through reservoir R to feed-donkey and engine feed-pump P; C suction from hotwell W to feed-donkey and engine feed-pump P; D suction from measuring tanks or hotwell through valve-box to engine feed-pump; E suction from measuring tanks or hotwell through valve-box to feed-donkey; F suction from condenser to feed-donkey; G delivery from feed-donkey to boilers; H delivery from feed-donkey to high-pressure valve-box V; K delivery from feed-donkey to distributing valve-box S; L delivery from feed-donkey, overboard, and on deck, and to sanitary tank, and to fresh-water condenser; M delivery from feed-donkey to feed-heater; JJ overflow pipes from measuring tanks; Q discharge overboard from air-pump.

Objections had been raised against fitting permanent tanks, on account of the room they occupied; but he preferred the tanks to meters, because meters had an error to be allowed for, and it was preferable to work if possible without unnecessary errors. In an ordinary cargo steamer the question of sacrificing space in order to make room for permanent measuring tanks did not arise, because in order to meet certain requirements of the tonnage laws the engine-room had to be made larger than otherwise necessary. But in full-power steamers it had appeared to him to be impossible to find room for the tanks, until it had been suggested to him by Mr. Macfarlane Gray that they might be used ordinarily for oil storage. That was a good idea, and he was grateful for it. The tanks were wanted only occasionally for testing the consumption of water, during which time the oil could be left in the drums; and the tanks must of course have man-holes, through which the grease could be cleaned out before they were used for feed-water measurement. While they were being used as oil tanks, the connections with the feed-pumps should be broken or entirely removed. The report from the last steamer fitted with these permanent feed-measuring tanks showed a consumption he believed

of about 14 lbs. of water per indicated horse-power per hour; but the evaporation was low, thus showing clearly that the engines were giving good results, but that the boilers were not as efficient as they should be, and that in order to obtain better results attention must be directed to the boilers rather than to the engines. In case of the consumption being more than it should be, the tanks gave the means of ascertaining in a short time where the fault lay, whether it was in the engines or in the boilers; and this was a great convenience.

With regard to the trial of the "Colchester," he wished to mention that it was owing to the prompt orders given previously to the commencement of the trial and in the middle of the night by Mr. George Derry, the marine superintendent at Parkeston Quay, Harwich, that the trial had been saved from being a failure; and the Committee were much indebted to him for having certain necessary alterations made.

With regard to the "Tartar" trial, the excessive priming mentioned in the report was certainly astonishing. During the trial there had been no indication of priming, beyond the little water that was coming out of the intermediate cylinder through the indicators. When the "Tartar" was built about three years ago, he had attended the trial then made; that was the time when priming would be expected, but there had been absolutely no sign of it whatever. The proportion of steam space in the "Tartar" boilers, shown in Plate 113, was greater than in any of the other steamers under his care. During the trial there was no discharge of water through any of the escape valves on the cylinders, nor was there any knocking heard in the cylinders, nor any other sign of priming; and it was difficult to understand how the water could have been carried over in such large quantities. The steam stop-valves were situated on the extreme end of each boiler, and were fitted with internal steam-pipes. This matter he considered important, because, if these boilers were priming, then in his opinion there could be very few boilers that did not prime, and prime badly. The height from the top of the combustion chamber to the top of the boiler was more than a third of the diameter of the boiler; and he had boilers in which it was a good deal less than a third, and yet there was no sign of priming. He had also seen

(Mr. Frederick Edwards.)

drawings of boilers in which this height was less than a quarter of the diameter, and he had been assured by the builders that when working at 160 lbs. pressure there was no priming. He had looked through the log books of the "Tartar," and could find no record of any trouble with water in the cylinders. It was important to bear in mind that the only indication there had been of priming during the trial had been in the intermediate cylinder; and as far as he could gather, in triple-expansion engines the signs of priming almost always showed themselves in the intermediate cylinder. There was only one exception that he knew of, where damage or trouble had arisen from priming in a high-pressure cylinder; in that case the top of the cylinder and cover had been broken clean off by priming, and had to be patched up in order to send the vessel on her voyage; but then he believed the high-pressure cylinder had been fitted with a piston-valve and had no escape-valves. On the other hand, he had had two if not three cases, where the damage had been done by priming in the intermediate cylinder. The reason of this he did not understand; and he should be glad if any one could throw light upon it.

During the trial of the "Tartar" he had tried to get diagrams from the feed-pump and the circulating pump, but had found it was impossible to do so for want of room while the rest of the observations were all being made. Therefore after the ship sailed on her next voyage he had had them taken by the chief engineer, and they were shown in Figs. 63 to 66, Plate 116. Although the working boiler-pressure at the time was not more than 143 lbs. per square inch and the speed only 62 revolutions per minute, the indicator diagram, Fig. 63, showed that a pressure of as much as 220 lbs. per square inch had been required in the feed-pump for forcing the water into the boiler. As the pump was single-acting, $3\frac{1}{2}$ inches diameter and 27 inches stroke, making 62 effective strokes per minute against a mean pressure of 98 lbs. per square inch, it was consequently requiring 4 horse-power to drive it. The circulating-pump pressure was also high, Figs. 65 and 66; and mounted up much higher still when the snifting valves were shut, Fig. 64, and there was no air to cushion the pump. Consequently he had given instructions for diagrams to be taken with the snifting

valves shut, Fig. 64, then partly open, Fig. 65, and then full open, Fig. 66, in order to show the difference in the pressures. The circulating pump was double-acting, 11 inches diameter with rod $2\frac{1}{2}$ inches diameter, and 27 inches stroke, making 62 double strokes per minute. When the snifting valves were shut, the mean pressures on the top and bottom of the circulating-pump piston were respectively 14·7 and 12·3 lbs. per square inch, and the horse-power consumed was 10·5; when the snifting valves were one-quarter of a turn open, the mean pressures were 13·7 and 12·2 lbs. per square inch, and the horse-power 10·1; and when the snifting valves were full open, the mean pressures were 11·9 and 11·5 lbs. per square inch, and the horse-power 9·2.

Mention had been made in the report (page 230) of the frequent intervals at which the samples of furnace gas had been collected and the chimney temperatures read; and he was glad that attention had been drawn to this portion of the work, because it had involved throughout the whole trial unremitting care and watchfulness on the part of Mr. Wilson, who had been an example to all the staff of observers. As to the results of the "Fusi Yama" trial not having been supplied sooner (page 255), he thought if any Member who was in a hurry for the information would kindly help to work out the results it would be much better than complaining; and the Committee would be glad of any help that could be given.

Mr. J. F. L. CROSLAND considered that, while drawings of the boilers would be useful in other respects, the information already given in Table 6 was sufficiently complete for enabling some reasonable idea to be formed as to why there was so much difference in the rate of evaporation of feed-water per square foot of total heating surface per hour (page 255), namely 4·49 lbs. in the "Meteor," 3·48 lbs. in the "Fusi Yama," 7·39 lbs. in the "Colchester," and 4·13 lbs. in the "Tartar." From line 37 in Table 6 it was seen that the coal burnt per square foot of grate per hour was 19·25 lbs. in the "Meteor," 18·98 lbs. in the "Fusi Yama," 26·1 lbs. in the "Colchester," and only 11·93 lbs. in the "Tartar"; and it appeared to him that the much greater rate of consumption of coal

(Mr. J. F. L. Crosland.)

per square foot of grate per hour in the "Colchester" fully explained the higher rate of evaporation in that trial per square foot of total heating surface, and he thought the information supplied in Table 6 was therefore ample. The results of the trials now reported were to himself a source of great gratification, because they completely dispelled the illusion hitherto prevailing as to the special economy of marine engines. The public had for many years been given to understand that marine engines worked at what many engineers considered, with the conditions given, impossible rates of coal consumption per indicated horse-power per hour, such as $1\frac{1}{4}$ lb. The present report had now given some real facts on this subject, showing that the consumption with two-cylinder compound engines was 2.66 lbs. and 2.90 lbs.; and even with triple-expansion engines, with 150 lbs. boiler pressure and with the most modern improvements, excepting only that there were no special expansion-valves, the consumption of coal had not been brought down lower than 2.01 lbs. in the "Meteor" and 1.77 lbs. in the "Tartar."

Mr. CHARLES E. STROMEYER considered that, so far from the present report being an incomplete one, it was about as thorough a report as he had ever read. An enormous amount of information was condensed into it, in a form which ought to prove of great assistance. In response to the appeal made at the end of the report for suggestions as to improvements in the instruments to be used for such trials, it seemed difficult enough to propose anything that had not probably occurred already to the Committee. When he first went to sea many years ago, he had tried to make accurate trials which were to extend over many hours, and he had found the spring balances unsatisfactory for weighing the coal, because the pointers would keep moving up and down while the coal was being weighed. He had therefore substituted a steelyard, which was pretty steady in its readings, even when there was a considerable up and down motion of the vessel. As long as the water was smooth, it did not make any difference which instrument was used; but in a rough sea the steelyard answered better than the spring balance.

In the trials now reported the temperature of the discharged condensing water did not appear to have been measured; it would be a valuable addition he thought if that could be given, and also, as suggested in page 236, the quantity of water which was discharged. It was therefore desirable in his opinion that the dimensions of the circulating pumps should be given; for although it was true that the quantity of the condensing water could not be measured exactly in that way, yet he saw no other means of measuring it. Considerably more water he believed actually passed through the circulating pump than that due to the volume of the pump and the number of strokes per minute. At any rate this additional information would be some sort of guide as to the quantity of condensing water used, and might throw some light on the question of condensation.

It might also be possible to measure the quantity of air that was mixed with the steam as it came from the boiler. In the first ship he was in he had measured it by leading condensed boiler-steam under an inverted bucket, which had been filled with water and placed in a tub of water; all the air which was previously in the steam of course gathered in the bucket, and by noting the time it took to fill the bucket with air, and comparing it with the time required to fill the same bucket with condensed water, he had been able to estimate how much air there was in the boiler. As the snifting-valves of the air-pumps and feed-pumps were all open to the atmosphere, it was clear that a large amount of air must have been driven into the boiler. The estimate so obtained of the volume of air was that it equalled the volume of the feed-water. Air he felt sure collected round the tubes in the condenser, and hindered the steam from reaching the cooling surfaces quickly and from condensing; it thus caused the vacuum to be reduced more than was perhaps imagined.

With regard to coal dust and soot in the boiler tubes, it was of course difficult to measure these; still they were not products of combustion, and therefore ought not to be included in the coal consumed or in its carbon value. If, instead of using coal which produced much smoke and a lot of fine dust, a better coal were used, a better evaporation per pound of coal would be obtained from the boiler. The actual efficiency of the boiler was accordingly not given

(Mr. Charles E. Stromeyer.)

in the report ; what was there given as the efficiency of the boiler was really the efficiency of the boiler and the coal combined, and not of the boiler by itself. Although the tables of analyses of the funnel gases were very complete, they might be improved he thought if the temperature of the uptake, corresponding with each analysis of the products of combustion, were also given. It was true that the average temperature from all the observations was stated ; but if it could be given for each analysis a good deal of useful information would be obtained, especially if also the differences of pressure or the draught pressure, as shown by the water gauge, could be stated. These were points about which little was as yet known, and the value of the report would be much increased if they could be added. He had been looking into this very matter with the intention of finding out if possible what the temperature was in the combustion chamber ; and by assuming a certain coefficient for transmission of heat through the tube surface, he had arrived at the conclusion that the temperature in the combustion chamber was generally about 2,000° Fahr. higher than in the uptake, taking into account the amount of tube surface, and also the weight of the gas which passed through per hour. But on calculating the temperatures by that plan, he had arrived at the conclusion that the temperature in the combustion chamber must have been 7,670° in the "Fusi Yama," which seemed impossible, while it was 2,550° in the "Colchester" and the "Tartar." The only explanation which occurred to him was that possibly there might have been a mistake in observing the temperature of the gases in the uptake. An idea of the importance of this subject would be obtained if it was borne in mind that the relation between the quantity of air and the heating surface was pretty nearly the same in the "Fusi Yama" and the "Tartar" ; yet in the "Tartar" there was a difference of only 115° between the temperature of the water and the temperature of the uptake, while in the "Fusi Yama" the difference was about 274°. This great difference seemed to point to something being wrong in the "Fusi Yama," but he did not know what it was.

The draught was another subject which might perhaps be thoroughly explained, if the particulars of the temperatures in the

uptake were given: namely the influence of the cold air when it mixed with the hot gases at the time of opening the fire-doors for firing, or the influence of the cold air getting in through the fire-bars. Supposing 10 per cent. more air had been admitted than was necessary for combustion, then not only were the gases cooled in the combustion chamber, but also their volume was increased, and therefore the speed with which they passed through the tubes was increased, whereby the efficiency of the tube surface was reduced: at the same time the volume of the gas which went away was larger, so that there was a possibility of an addition of cold air in the furnace producing an increase of temperature of the waste products.

The trial which he had himself made many years ago had been carried out under unfavourable conditions, because he was then only third engineer and could not get the chief or the second to help him with it, and he had had to do all the work himself, continuing the trial for twelve hours during three watches; but during his own watch he had been able to take a considerable number of indicator diagrams, and the results were interesting as showing the influence of cleaning fires. There were six furnaces. In one watch he had noticed that the engines started with 570 horse-power; the fires were then cleaned, and the power dropped to 505. It took an hour from the commencement before it rose again to 570; then it was kept at 600 for the rest of the three hours of that watch. In another watch it had started at 570 and dropped to 515, and had taken an hour and a half to rise to 570; after which it remained stationary at 580 horse-power for the rest of the watch.

Mr. G. R. BODMER considered it remarkable that, although the diameters of the high-pressure cylinders of the three engines were not very different, yet there was so great a difference in the initial condensation, or the number of heat-units given up to the body of the piston and the cylinder walls and covers, previous to cut-off. Curiously enough the number of heat-units lost by initial condensation was much greater in the high-pressure cylinder of the "Tartar" than in the larger high-pressure cylinders of the two other engines. In the "Fusi Yama" he calculated that the number of heat-units lost

(Mr. G. R. Bodmer.)

per single stroke in the high-pressure cylinder by initial condensation up to the point of cut-off was only 125·8, while in the "Colchester" it was 523·6, and in the "Tartar" it was as much as 841 after allowing for priming. Notwithstanding this great loss, it was seen from line 48 in Table 6 that the "Tartar" was nevertheless the most economical of the three in the quantity of feed-water used per indicated horse-power per hour, even irrespective of the allowance that was made (page 234) for priming. It thus appeared that the number of heat-units lost by initial condensation in the engine of the "Fusi Yama" was much less per stroke than in the more economical triple-expansion engine of the "Tartar." From certain other experiments he had been trying to arrive at some rule which might be approximately satisfactory for the amount of heat lost per stroke by initial condensation; but he confessed that the figures now presented quite upset any attempt to formulate the results. Although there seemed at present no sort of consistency or relation between them, it would be interesting if the clearance surface in square feet, which was given in Table 6 for the "Colchester," could also be added for the other engines.

In regard to the absence of any satisfactory method for measuring the quantity of condensing water, he ventured to suggest, though with some diffidence as he had not had anything to do with the trials, an instrument for gauging water which had recently been devised by an American, Mr. Clemens Herschel, who called it the Venturi meter. The principle of the instrument was that the velocity of flow was calculated from the difference of pressure at two points in a pipe having its bore relatively much reduced at one part; one point of measurement was where the sectional area was greatest, and the other was at the most contracted part. It was said to give accurate results, but he did not know how far that was the case. It had occurred to him that it might be worth while to try such an instrument, and see whether it would be possible to use it for measuring the circulating water.

Mr. CHARLES J. WILSON said that, as the results of these trials were calculated on a heat basis, the analyses of the coals and gases

were of considerable importance. In order therefore to ensure the accuracy of the figures, precautions had been taken which did not appear in the report. The whole of the coal samples from each trial had been reduced to a fine powder before a portion was taken for analysis. The analyses given in the report had been made throughout in duplicate, separate quantities being weighed for each of the two. Hence any want of uniformity in the samples analyzed would have appeared as a discrepancy in the analyses; but as a matter of fact the analyses agreed precisely. In the case of the furnace gases, every precaution had been taken to prevent air from leaking in, and to ensure collecting a really representative sample in each case. The gas pipe was completely exhausted of air, by drawing off a large volume of furnace gas before a sample was taken; and the gas after it was collected came in contact with nothing but dry mercury and dry clean glass. When it was taken to the laboratory to be analyzed, the determinations were again all made in duplicate. He therefore felt confidence in the figures which he had given in the report.

Mr. JOHN PHILLIPS considered the boiler was not to be blamed at all in the case of the "Tartar"; and he thought it had really produced all the steam that it was credited with. The engines appeared to have been working with too small an amount of power for them to work economically. From Table 6 he found that the indicated horse-power per square foot of grate area was only 6.75 in the "Tartar"; while in the "Meteor," which was also a triple-expansion engine, it was 9.6. Then looking at the capacity of the cylinders per horse-power—that is the aggregate volume swept through per minute by the pistons, taking the aggregate area of the three pistons in square inches and the piston speed in feet per minute—in the "Meteor" this capacity amounted to 1,743, and in the "Tartar" to 2,548; the "Meteor" thus had about two-thirds the piston displacement of the "Tartar" per horse-power per minute. Moreover the mean pressure referred to the low-pressure cylinder in the "Meteor" was 29.9 lbs. per square inch, while in the "Tartar" it was only 19.8 lbs. per square inch. Hence the cause of the great

(Mr. John Phillips.)

amount of water used in the "Tartar" lay in the endeavour to get a small amount of power out of a large engine. Moreover, while the boiler pressure in the "Meteor" was 145·2 lbs. per square inch, the initial pressure in the high-pressure cylinder was 134·4 lbs.; whereas in the "Tartar," with the boiler pressure of 143·6 lbs. per square inch, the admission pressure in the high-pressure cylinder was only 121·4 lbs., showing that there must have been a large amount of condensation between the time of the steam leaving the boiler and its admission into the cylinder. With such large boiler-power in proportion to the small quantity of work done by the engine, it seemed to him simply impossible that the boiler could prime, and he had never known of a boiler priming under such conditions. The work the boiler was required to do was exceedingly small for its heating surface or fire-grate area.

Mr. CHARLES E. COWPER, referring to the complaint (page 255) as to the delay in reporting the "Fusi Yama" trial, thought it was much better to have these three trials reported together, because the figures could now be more conveniently compared, and the subject was thus rendered much more interesting. The Institution he considered was to be congratulated upon having such an excellent report upon engines doing practical work. In the endeavours which engineers of the present day were making to investigate the real condition of the steam—or rather of the working mixture of steam and water—in the cylinder of the steam engine, any facts bearing upon the important subjects of cylinder condensation and re-evaporation were of great interest. Looking at the figures giving the proportion of steam accounted for by the indicator diagrams, and the "missing quantity" or percentage present as water, it would be noticed that the steam decreased from the cut-off in the high-pressure cylinder to near the end of the expansion in the low-pressure cylinder, and the missing quantity or water increased, both in the "Fusi Yama" (page 211) and in the "Colchester" (page 223), these engines being not jacketed; whereas in the "Tartar" the case was reversed (page 235), the steam increasing and the water decreasing, which was probably owing to the steam-jackets on the intermediate and low-pressure cylinders.

The high-pressure cylinder of the "Tartar" was not jacketed in the trial (page 232); that would probably account for a large amount of initial condensation in the high-pressure cylinder. In the "Meteor" trial (Proceedings 1889, page 245), the high-pressure cylinder being steam-jacketed, it would be seen that the quantity of steam at the beginning and at the end was nearly the same, namely 77.1 per cent. of steam after cut-off in the high-pressure cylinder, and 75.3 per cent. near the end of expansion in the low-pressure. He should therefore like to know whether Professor Kennedy considered that the difference between the "Meteor" and the "Tartar" in this particular was accounted for by the steam-jackets. For comparison he might mention two other instances that he was acquainted with—one a slow-working pumping engine, and the other a quick-working engine of Mr. Willans's, the former being steam-jacketed: in the slow-working jacketed engine it had been found that the percentage of water diminished continuously to the end, until the final measurement gave only a small proportion of water; while in the quick-working unjacketed engine the proportion of water continuously increased all through to the end.

In regard to the several sets of indicator diagrams not having been drawn out in a combined form (page 255), as had been done in the case of the "Meteor" (Proceedings 1889, Plate 48), possibly it had been thought wiser not to do so, because there was always a difference of opinion as to the correct mode of combining indicator diagrams. In a previous discussion (Proceedings Inst. C.E. 1889, vol. xcix, page 235) he had himself suggested that it would be highly advantageous if some method of combining could be agreed upon, so that all indicator diagrams from compound and triple-expansion engines might be combined in the same way; useful comparisons could then be made. He would now further suggest that a method should be agreed upon for calculating efficiencies, in regard to which the same divergence of practice prevailed. As the Institution of Mechanical Engineers had appointed Research Committees, they might well appoint a committee which could settle a standard system that all might adopt, in the same way as the British Association had determined a standard system of

(Mr. Charles E. Cowper.)

electrical units. He also suggested that the Research Committee on the value of the steam-jacket might make some experiments with jacketing at different temperatures with different pressures of steam. It appeared to him that the jackets on the intermediate and low-pressure cylinders of the "Tartar" had not been so efficient as they might be, because the steam in the jackets had been reduced in pressure and therefore in temperature.

Mr. DAVID JOY said the plan here adopted of adding together all the indicator diagrams and then averaging them to get a mean result did not seem to him at all satisfactory, because it did not really give the best that the engine was capable of; the whole result was a mixture of the top and bottom ends of the cylinders. It appeared to him that it would be preferable to have one of the best diagrams from the top and bottom separately of each cylinder; then it would be seen what the engines were doing at their best. It seemed to him a matter of regret that such elaborate experiments should have been carried out in what he thought were such ordinary ships; for he considered that two-cylinder compound engines were now really obsolete for marine purposes. It was very desirable in his opinion that trials should be made on some of the highest-class boats, so as to show the best that could now be done, and not merely what could be done ordinarily; and he thought he saw his way to getting the use of some 3,000 horse-power engines of the most recent kind, which had been running for only a short time and he believed would give fine results.

Mr. ALFRED WATKINS thought it curious that the higher-class engines in the "Tartar" apparently did not give a result in any way superior to the engines in the "Meteor," which were professedly not built for economy. The remark made (page 268) about the poor result in the "Tartar" engines possibly not being due to priming he thought was true, because he believed experience proved that unless an engine was worked at full power the benefit expected from it was lost. It was no use designing an engine to work with high-pressure steam, and then working it at low pressure; it would not

give nearly such good results as an engine designed to work with low-pressure steam ; this he supposed was obvious. If the reason of the "Tartar" not giving a better result was in the boilers, supposing the measurement of water supplied to the boilers to be correct, it would be well to try the result of working with one boiler only, instead of two. The coal burnt per square foot of grate in the "Tartar" was little more than half that burnt in the "Meteor," and yet the "Meteor" boilers could not be said to be overworked during the trial ; for during one half of her regular work they were worked with forced draught and generated 50 per cent. greater power than during the trial, during which the forced draught had not been used. According to the report it therefore appeared to him that there had been a waste of money and space in the "Tartar" by giving her two boilers, when one boiler would have been as effective. The report also showed that these lightly worked boilers primed heavily, while similar boilers worked twice as hard did not prime : a result which was, to say the least, surprising.

Mr. JOHN G. HUDSON believed the surface condensers for marine engines had hitherto been almost always designed by rule of thumb ; and the present trials went so far towards supplying the means of arriving at a more rational method, that he ventured to ask for the additional information needed for the purpose. If the temperatures of the inboard and the overboard condensing water could be stated, it would thence be known how much water was passing ; and if also such particulars were given of the condenser as would allow the speed of the water over the surface to be ascertained—namely whether the water passed through the tubes or around them, whether it entered at the top or bottom of the condenser, the number of currents, and the number and bore and length of the tubes in each section—there would be the means of arriving at the laws governing the transmission of heat through the condenser tubes, and of designing surface condensers in accordance with them. The report already dealt with the generation and use of the steam, and its condensation would complete the cycle.

Mr. J. MACFARLANE GRAY said that in engineering there were many constants used, some of which were mainly rules of thumb, but were nevertheless useful. The experiments which had now been made might be utilised he thought for verifying those constants. For instance, Rankine's rule for the number of heat units that would pass through a square foot of heating surface, such as that in boilers and tubes, was the square of the difference of temperature divided by from 160 to 200. Another rule made it proportional only to the simple difference of temperature, instead of to the square of the difference. In entering upon a set of experiments it ought to be understood at the outset what were the definite objects worked for ; and then all the particulars for those objects would be given in the report. He had tried to verify the above rule, but the essential particulars were not given ; and assuming them on the best theory he could think of, the report gave very inconsistent results. There was a great deal of information to be got from the report as it was, and everyone could get from it something useful for himself. He suggested that it would be better if the statement of the particulars respecting the trials and the engines were arranged somewhat differently. By arranging them geographically according to a standard system, the particulars of a large number of engines could all be got into a small note-book with only a few figures. This could be done by dividing a card into spaces, like the panes of a window, with dark and light lines, and writing in each space what was wanted to be there recorded. Then by recording always the corresponding particulars in the same spaces on each successive page, there was no need to encumber the record with words. In that way all the particulars of an engine could be put upon the back of an address card, and it was then far easier to find anything that was wanted.

Mr. G. S. YOUNG suggested that the capacity of the steam space in the boilers should be given, as that was an important matter in designing boilers. If there was priming to such an unusual extent as stated in the triple-expansion engine, it could be discovered by a comparison of the saltiness of the water in the boiler and in the

hot well. As a rule, if a marine boiler primed to the extent of 20 per cent. of the mixture of steam and water passing off to the engines, the salt so mixing with the condensed steam in the hot well could be detected by the ordinary salinometer; or, if that was not sufficiently accurate, a chemical analysis of the water in the boiler and the water in the hot well would demonstrate whether the water from the boiler had all passed through the engine in the form of steam or whether a part of it had gone through as water. Such a test, combined with other means, would help to settle the question as to whether priming was actually going on.

MR. LESLIE S. ROBINSON, referring to formulæ in use for calculating the draught which a certain height of funnel would produce, observed that in the report the vacuum in the funnel was given, and it would be interesting if the vacuum could also be taken in the ash-pit or as near the furnace as possible. It would then be seen what force of draught there was in the furnace.

Another interesting point, upon which he hoped Professor Kennedy would be able to throw some light, was the great difference in the proportion of heating surface to grate area in these boilers (Table 6, line 15). Three of them had the usual proportion of about 30 to 1, namely 32 and $32\frac{1}{2}$ in two cases and $26\frac{1}{2}$ in the other; but in the "Fusi Yama" the proportion was 43·4 to 1. In some boilers that he knew of, the proportion ran as high as 60 to 1. If any information could be given with regard to the difference produced in the efficiency of a boiler by an increase in the proportion of heating surface to grate area, it would be of great service to engineers generally.

MR. W. WORBY BEAUMONT pointed out that, although in the jacket on the high-pressure cylinder of the "Tartar" the steam was stated in page 232 to have been shut off, yet further on in the same page it appeared that steam enough leaked through into the jacket to give a pressure varying from zero up to more than 50 lbs. per square inch. There would thus be a difference of temperature between the steam inside the cylinder and the vapour outside in the jacket, varying from perhaps 60° to considerably over 100° Fahr., which seemed to be an

(Mr. W. Worby Beaumont.)

unfavourable condition for that cylinder to work under. Was there any other evidence than that obtained from the analysis of the gases, from the water in the indicators, and from the estimation of the indicator diagrams, upon which it had been decided that so large an amount of priming must have taken place? There was certainly great difficulty in believing that the boiler would evaporate as much as 13 lbs. of water per lb. of coal; but he hardly understood how, under the various conditions reported, there could have been such a large amount of priming. Mention was made in page 224 of the weather having been sufficiently rough to cause the engines to race a little during the latter part of this trial; and it occurred to him that a rough sea might have caused the water to be thrown about in these boilers, and that, as in some of the rapid-circulation boilers, this might cause a good deal of water to be carried away as spray with the steam; but there was no adequate proof that such priming occurred throughout the trial.

The PRESIDENT, referring to the remark (page 271) that it would have been better to work the "Tartar" engines with one boiler than with two, said this had not held good in practice with locomotive engines. There, the more heating surface could be got into the boiler, the less coal would be burnt to do a given amount of work; and it appeared to him that the same might hold good with marine engines as with locomotives. If it were attempted to run a given weight of train with an engine having a small boiler, it would require more fuel per mile to do the work than in the case of another engine with cylinders of the same size but having a larger boiler and burning the fuel more slowly.

Marine engineers had lately been going in for triple and quadruple expansion engines; but what he desired to impress upon their consideration was the importance—indeed the absolute necessity—of getting something like uniformity in the work done on each crank. This had not been realised hitherto; and in this respect he did not know that he had ever seen what he could call a perfect set of indicator diagrams. In this connection he had already made some remarks upon the "Meteor" trial at the previous meeting (Proceedings

1890, page 93). From the present report it appeared that in the "Fusi Yama" (page 208) the high-pressure cylinder did 45·3 per cent. of the work and the low-pressure 54·7 per cent. The "Colchester" (page 220) was the nearest to uniformity, doing 48 per cent. in the high-pressure cylinder of each engine, and 52 per cent. in the low-pressure. In the "Tartar" (page 231) there was only 26·1 per cent. in the high-pressure cylinder, against 37·6 in the intermediate and 36·3 per cent. in the low-pressure cylinder. So unequal a distribution of the power could not be good either for the cranks or for the engine. If such conditions were allowed in a locomotive, it would never be able to run at all; the driver would not be able to stand on the foot-plate, but would be thrown off the engine. There ought to be some provision in marine engines he considered, by means of pressure-gauges on the receivers and on the cylinders, and by reducing valves, so that the steam could be throttled in its passage from the boiler to the high-pressure cylinder and thence to the other cylinders, in order that something like uniformity of power might be obtained in each. There must necessarily be great difficulty he was aware in accomplishing this object, because the condenser maintained a uniform vacuum, whatever the power; and therefore the problem to be dealt with was an intricate one. He had no doubt however that it would be solved as thoroughly as it ought to be with the marine engine, and almost as completely as had already been done with the pumping engine. In the latter it could be accomplished perfectly, the work being fairly constant.

Professor KENNEDY, in reply, noticed that Mr. Carbutt (page 244) not unreasonably thought the steam for the circulating-pump engine should in fairness have been supplied by the main boiler in the case of the "Colchester." The fact was that the pipe arrangement was such that this could not have been done without at the same time sending steam from the main boiler to the dynamo engine.

In reference to Mr. Hallett's remarks (page 246), he could not say what the waste of water from the glands had been, but only that there was nothing exceptional about it.

(Professor Kennedy.)

It had been suggested by Mr. Fletcher (page 256) that the piston constant for each cylinder should be given; and he should have much pleasure in adding these figures to Table 6. The discrepancy between the amounts of steam accounted for by the indicator diagrams in the "Fusi Yama" and in the "Tartar" he thought could only be properly explained if the cause of the large steam or water consumption by the "Tartar" were known. Of this he should have something to say further on. The same remark would apply also to the difference between the "Meteor" and the "Tartar," alluded to by Mr. Cowper (page 269).

Passing now to the more general questions raised by the report, he confessed that he was still in considerable perplexity in reference to the water consumption during the "Tartar" trial, about which so much had been said. Having himself no figures in reserve beyond those given in the report, he therefore could not add anything to what was there said. He felt quite as much as other speakers the great difficulty of supposing that by any possibility such a large amount of priming could have occurred. There were none of the usual signs of priming, except the apparent wetness of the steam in the intermediate cylinder; while the supplementary feed-water put into the boiler was not remarkable in any way. In view however of the contention of some speakers, that the water which went into the boiler was really evaporated, he must point out that, whatever might be the real explanation of the matter, this one could hardly be true. He thought himself that nothing could be more certain than that the boiler did *not* turn into steam all the water which passed through the feed tanks; and although he had endeavoured to make his reasons for this conclusion plain in the report, he would here repeat them. If all the feed-water had been evaporated, the boiler efficiency must have been 84 per cent. of the whole calorific value of the fuel. The furnace gases were known to have carried away from 21 to 23 per cent. of that heat, which added to 84 made 107; and the further losses by radiation would bring the total heat accounted for in this case to 15 or 20 per cent. more than the amount corresponding with the theoretical calorific value of the coal: which he need not point out was a result physically impossible. Whatever happened to the

water therefore, it was not wholly turned into steam. The result of the first working out of the figures had been such a complete puzzle to him that he had gone through them all again, in case there might be some mistake, but had been unable to find any. He had hoped that some suggestion would be made in the discussion as to why or how such an exceptional amount of water should have passed through the boiler without evaporation; but thus far no suggestion had been made. Even Mr. Edwards, whose opinion he should certainly trust more than his own in such a matter, and who objected so strongly to the idea that there was any priming, had said (page 260) that the place where water showed itself in the case of priming was generally the intermediate cylinder; and oddly enough this was the very place in which water had been met with in the "Tartar." He confessed however that he was himself not at all satisfied with the priming explanation, but was unable to suggest anything better.

It had been pointed out in the report (page 224) that the "Tartar" had been tested quite light; she had no cargo on board, nothing but water ballast, and this of course accounted for her requiring so little driving power. No objection had been taken at the time to the trial being made on a light ship, nor until after the results were known, when it was regretted that the ship had not been fully loaded. He had expected to be asked why she had been tested under such conditions; and although the question had not actually been put, he would answer it. The reason was the simple one that it was with great difficulty the Committee had succeeded in getting steamers which could be tested at all; and therefore they were very glad to avail themselves of the opportunity of testing such excellent machinery as that of the "Tartar," even if the circumstances were not such as to bring out its highest economy. The arrangements for the trial had all been practically completed before it was known that the run would be made quite light; and as no objection was raised by the engine builders' representative on board, it was not thought proper to postpone the trial, and so waste much laborious and expensive preparation. When the "Meteor" trial was discussed a year ago, several enthusiastic offers had been made of steamers to test, but up to this date he had heard nothing further about them.

(Professor Kennedy.)

The objection to the trials, that they were carried out in such ordinary steamers (page 270), he thought was really not justified. The "Tartar" was a very fine example of a triple-expansion engine made by one of the best firms. The "Colchester" engines also were quite new, although they did not happen to be triple-expansion.

As to the question of determining the water in the steam as it left the boiler (page 247), of course no weighing apparatus sufficiently delicate for this purpose could be applied on board a steamer. The superheated-steam calorimeter of Mr. Barrus, which had been mentioned in this connection, was very ingenious. It seemed to him however that the formulæ used with it required much more convincing experimental proof than they had yet received, before they could be freely accepted. He also understood that its instrumental correction for radiation amounted in all cases to a very large percentage of its whole reading, which if true was of course a serious drawback. The action of this calorimeter, as he understood it, rested upon the assumption that, immediately steam reached a temperature even one degree above that of saturation at its particular pressure, it became superheated and could be treated as if it were a perfect gas. This assumption certainly seemed one which was open to question, or which in any case needed experimental demonstration. At the same time he knew that various engineers in the United States used Mr. Barrus' instrument, and considered it correct.

Measurements of circulating water (page 245) he feared were not likely to come about. He was very sorry that the temperature of the sea and of the discharge had not been taken (page 271); this had been an omission.

In the report he had purposely steered clear of two matters which had been raised in the discussion, namely the combining of indicator diagrams, and the standard of theoretical efficiency. The former had been discussed at meetings of the Institution over and over again; and it was therefore thought by the Committee that there was no occasion for bringing it up once more. As to efficiency, the figure given in the report was the simple ratio between the heat received and the work done, which expressed an indisputable fact. This form of expression everyone could modify for himself as he might wish.

Referring once more to the "Tartar," he wished to point out that at the end of the low-pressure stroke there was actually present as water in the cylinder and jackets together 39·7 per cent. of the whole feed (page 235). Of this, the jackets were answerable for 4 per cent. ; so that, as compared with the whole quantity of the feed-water, there was present apparently 35 per cent. as water in the low-pressure cylinder. In the unjacketed low-pressure cylinder of the "Colchester" however, the proportion of water was 47·3 per cent. (page 223). In the very economical engines of the "Meteor" it was about 25 per cent. ; so that the quantity in the "Tartar," although large, was by no means incredible, and did not of itself suggest that the whole measured feed-water had in some way failed to get to the engines, although it had arrived at the boilers. All engineers who had ever compared the steam shown by indicator diagrams with measured feed-water would be unfortunately familiar with the fact that 35 per cent. of water at the end of the low-pressure stroke was by no means unheard of.

The desirability had been suggested of knowing what was going on during the trial (page 253), so as to modify arrangements accordingly. But it had to be borne in mind that a trial at sea was by no means so simple an affair as a land trial, and that it was hardly possible under the average conditions of such experiments to find out with accuracy during the trial what the horse-power was, or what the rate of feed consumption ; and even if weather and other circumstances allowed it to be known at all accurately within the first few hours of the trial, it would probably be impossible to alter the conditions of working beyond very narrow limits.

As an addition to the present report he should be happy to lay before the Members the particulars of a trial which he had made a short time ago on a Thames tug, the "Eagle"; he was indebted to Mr. G. A. Key for permission to publish these figures. The "Eagle" trial had been made on exactly the same lines as the trials of the Research Committee, although its primary purpose was a different one ; and as such a trial was not often made with a small steamer of this kind, he thought the results might be interesting. The engines were ordinary compound screw engines of thoroughly

TABLE 7 (*continued on opposite page*).*Results of Trial of Steam-tug "EAGLE."*

1	Name of Vessel	Eagle.
2	Date of Trial	6 Nov. 1889
3	Duration of Trial hours	7·32
4	Type of Engines	compound
5	Cylinder diameter, high-pressure . . . inches	19
7	" low-pressure . . . inches	35
8	Stroke, length inches	22
9	Boilers, number of main boilers . . .	1
10	" single-ended or double-ended . . .	single
11	Furnaces, total number	2
12	Heating surface, total square feet	900
13	" tubes square feet	728
14	Grate area square feet	36
15	Total heating surface to grate area ratio	25·0
16	Tube surface to grate area ratio	20·2
17	Grate area to flue area through tubes ratio	5·58
19	Mean boiler-pressure above atmosphere lbs. per sq. in.	76·0
20	" admission " high-p. cyl. above atm. lbs. per sq. in.	65·7
21	" effective " high-pressure cyl. lbs. per sq. in.	36·82
23	" " " low-pressure " lbs. per sq. in.	8·56
24	" " " total referred to low-pressure cyl. lbs. per sq. in.	19·41
25	" exhaust " low-p. cyl. below atm. lbs. per sq. in.	11·5
26	" vacuum in condenser below atm. lbs. per sq. in.	12·7
27	Revolutions per minute, mean revs.	107·25
28	Piston constant, high-pressure cylinder . . . H.P.	3·38
30	" " low-pressure " . . . H.P.	11·46
31	Indicated horse-power, high-pressure cylinder . . I.H.P.	124·2
33	" " low-pressure " . . . I.H.P.	97·8
34	" " mean total I.H.P.	222·0

(concluded from opposite page) TABLE 7.

Results of Trial of Steam-tug "EAGLE."

	Name of Vessel	Eagle.
35	Coal burnt per minute lbs.	12·35
36	" " per hour lbs.	741
37	" " per sq. ft. of grate area per hour . . . lbs.	20·6
38	" " per sq. ft. of total heating surface per hour lbs.	0·82
39	" " per indicated horse-power per hour . lbs.	3·34
40	Carbon-value of 1 lb. of coal as used . . . lbs.	0·83
41	" " equivalent per I.H.P. per hour . . lbs.	2·77
42	Feed-water per minute lbs.	81·28
43	" " per hour lbs.	4,877
44	" " per sq. ft. of total heating surface per hour lbs.	5·42
45	" " per lb. of coal lbs.	6·59
46	" " per lb. of coal from and at 212° F. . lbs.	7·56
47	" " per lb. of carbon-value from and at 212° F. lbs.	9·11
48	" " per indicated horse-power per hour . lbs.	22·0
49	Calorific value of 1 lb. of coal as used . thermal units	12,000
50	Percentage of line 49 taken up by feed-water . per cent.	60·8
51	" " " " carried away by furnace gases p. cent.	14·3
52	" " " " lost by imperfect combustion p. cent.	14·6
53	" " " " expended in evaporating moisture in coal per cent.	1·0
54	" " " " unaccounted for . . . per cent.	9·3
55	Heat taken up by feed-water per minute . thermal units	90,100
56	" " turned into work per minute . . . thermal units	9,490
57	" " taken up by feed-water per I.H.P. per minute Th. U.	405·9
58	Efficiency of boiler (line 50) per cent.	60·8
59	" " of engine (line 56 ÷ line 55) . . . per cent.	10·5
60	" " of engine and boiler combined (line 58 × line 59) . . . per cent.	6·4
61	Mean velocity of steam through water-surface in boilers per minute . . . feet	6·56
62	Space occupied by boilers per I.H.P. . . . cubic feet	3·94

(Professor Kennedy.)

good and substantial design; the cylinders were 19 and 35 inches diameter, with 22 inches stroke. The boiler pressure was 76 lbs. per square inch above the atmosphere, the mean speed 107 revolutions per minute, and the indicated horse-power 222. The consumption of coal was 3·34 lbs. per indicated horse-power per hour. The coal was of very poor quality; and the equivalent of the 3·34 lbs. in actual carbon-value was only 2·77 lbs. The efficiency of the boiler was about 60 per cent. Other details were given in Table 7 (pages 280–281), and the observations were plotted in Plates 101 and 102 in the same manner as for the trials recorded in the report. The indicator diagrams nearest to the mean were shown in Plate 103.

The PRESIDENT said it was now his pleasing duty to move that a cordial vote of thanks be given to Professor Kennedy for the trouble he had taken in preparing the present report; and also to the Committee of which he was Chairman, and to the staffs of observers who had assisted in carrying out the trials.

Mr. D. B. MORISON, being unable to be present at the meeting, wrote as follows respecting the trial of the “Tartar,” whose engines had been designed and built by the firm he represented, Messrs. Thomas Richardson and Sons of Hartlepool.

The most important point to be noted is that the “Tartar” was absolutely without cargo during the trial, and that the engines were consequently working under conditions which were not conducive to economy. These engines were designed to do their best work when the ship is fully loaded; and the mean effective pressure referred to the low-pressure cylinder will then be from 27 to 29 lbs. per square inch. On the trial this mean pressure was 19·8 lbs., a difference which cannot be without a great effect on the economy. If 29 lbs. corresponds to an expansion of 10 times, 19·8 will correspond to an expansion of about 15 times. Hence it is evident that the expansion was carried much beyond the extent for which the engines were designed and at which they would be most economical. Although

the engines were running somewhat faster than they would at fully loaded draught, the gain due to this small increase in their speed would not compensate for the above extreme range of expansion. It should also be noted that the engines were working at a still further reduced power for 75 minutes or nearly one eighth of the total time of the trial. Although this is taken into account in calculating the average power and revolutions, it is impossible to take into account the diminution in efficiency, consequent upon the slower speed and lower power. From this cause it is impossible to allow correctly for the period during which the engines were working at reduced power; while to include this period with the rest is to introduce an element of error which must tell greatly against the engines. Under these circumstances it cannot but be regretted that the ship was tried when light, as it is not fair to the engines that erroneous impressions should be formed with regard to their economy; and except for comparison with a further trial of the same ship when loaded, the present trial seems to be of but little value. If however the engines could be again tried with the ship fully loaded and under the conditions for which they were designed, the comparison would be interesting and instructive, and would give a useful indication of the probable economical range of expansion.

Regarding the manner in which the machinery was tried, there can be little doubt that, with a staff of as many as seventeen trained engineers and a chemist experienced in these matters, a reliable trial may be made even on board ship; but there is equally little doubt that such trials are hardly likely to be undertaken by private firms, unless the number of engineers necessary can be largely reduced.

The cubic capacity of the boilers in the "Tartar," found by taking their mean diameter and total length, is 3,910 cubic feet. Taking the "Fusi Yama" and the "Colchester" in the same way, their respective boiler capacities are 1,529 and 4,850 cubic feet. Dividing these figures by the indicated horse-powers, the boiler capacity per indicated horse-power in the three steamers will be respectively 3.60 and 4.28 and 2.45, instead of 4.33 and 4.53 and 2.52 as given in the report (page 224). Had the "Tartar" engines been working at their economical power of say 1,350 I.H.P., the above boiler capacity of 3.60

(Mr. D. B. Morison.)

would have been reduced to 2·90 cubic feet per indicated horse-power. It seems strange that, with the very ample boilers of the "Tartar," priming should be assigned as an explanation of a high boiler efficiency, when it is remembered that with the relatively smaller boilers of the "Meteor" no priming was hinted at, and that the only evidence of priming is the reading from a single thermometer placed in the funnel.

Since the valve-gear for each cylinder can be varied separately, it is easy to make the powers developed in the three cylinders exactly equal, if this is wished.

Mr. MICHAEL LONGRIDGE, as a member of the Committee and unable to attend the meeting, wrote that the results of the "Tartar" trial were altogether anomalous, and the Committee had held more than one meeting before deciding what to say about them. Ultimately the opinion expressed in page 234 was arrived at, that the difference between the measured quantity of feed-water or 19·83 lbs. per I.H.P. per hour, and the maximum probable rate of consumption or 16·5 lbs. per I.H.P. per hour, "must be attributed to priming." It had since occurred to him that it would be better to say "must *for the present* be attributed to priming," so as not to imply that the Committee were satisfied with this explanation. Although the results of the trial were so unexpected and apparently inconsistent, it did not follow that they were incorrect or useless; and it was quite possible that they only required correct interpretation to render them as valuable as any others of the results recorded. The solution of the difficulty he hoped would be found in the mean indicator diagrams which had been plotted at his own request from the entire set of diagrams taken during the whole of each trial; these mean diagrams he considered were the only kind of indicator diagrams that were of use for analysing the working of the engines. As the engines were working against a constant resistance, with constant ratio of expansion, under a nearly constant boiler-pressure, and at a nearly constant speed, the diagrams taken were all of the same general form as the mean diagrams. Separate mean diagrams from the top and bottom of each cylinder would serve no useful purpose, inasmuch as the quantity

of feed-water supplied to each end could not be measured separately.

For the analysis of these mean diagrams, the volumes of the clearances and receivers should first be ascertained. Then from these volumes, and the pressures shown by the mean diagrams, the weight of steam present at each twentieth of the stroke should be calculated, and should be plotted in curves showing the weight of steam present at every point throughout the revolution, and the weight of water present at every point during expansion and compression. Next, the heat contained in the steam and water, and the heat equivalent to the work done either by or upon the steam, should be calculated and plotted; and their sum should be deducted from the total heat received by each cylinder, in order to arrive at the quantity of heat absorbed by the iron. Thirdly, the surfaces of the clearance spaces and receivers should be obtained; and the indicator diagrams should be divided, not into equal parts representing equal distances of piston travel, but into parts representing equal divisions of the circle described by the crank-pin, that is, equal intervals of time; and from these data calculations similar to the former should be made for ascertaining the quantities of heat absorbed per square foot of metallic surface per unit of time. If this analysis were made not only for the "Tartar" but also for the other trials, he believed that many things now obscure would be made clear. The work would be very laborious, but he thought it could be done without much expense; and unless it were carried out, the labour and money already spent upon the trials themselves would have been spent in merely proving that such trials could be conducted on board ship, and that a few particular engines and boilers had worked with certain consumptions of feed-water and coal; while the much more important question, why these particular rates of consumption were required, would be left without even an attempt at a solution.

The need for such an investigation was apparent from the report. In the "Tartar" it was stated (page 235) that the mixture in the high-pressure cylinder after the point of cut-off consisted of 45·2 per cent. of steam and 54·8 per cent. of water. From a similar

(Mr. Michael Longridge.)

calculation made a little later in the stroke, he had found that either the cut-off had not taken place when the pressure was 115·4 lbs. per square inch, or else the valve was leaky. This was shown by the accompanying Table 8, calculated from the mean indicator diagrams on the assumption that the feed-water was 5·13 lbs. per revolution, and that the clearance spaces contained only dry steam at the beginning of the compression. These figures he thought disposed of the suggestion that the excessive consumption of feed-water was due to the light load.

In regard to the gas analysis, he was certainly in favour of continuous aspiration, in preference to the method adopted in these trials. Although the analyses given were doubtless correct as far as they went, he thought they did not go far enough, the consequence being that the results were not concordant. The whole of the residue left after the measurement of the carbonic acid, carbonic oxide, and oxygen, was put down as nitrogen; but if the oxygen in the carbonic acid and in the carbonic oxide and the free oxygen were added together, they amounted to less than corresponded with the nitrogen. This was nearly always the case in what was called technical gas analysis; and the fact of the disagreement opened up the important question of the escape of free hydrogen and unburnt hydro-carbons in the gases. It was often stated that carbonic oxide could not be found when there was considerable excess of air; but his own experience had satisfied him that this was incorrect, and that carbonic oxide could frequently be found when the excess of air was great. Might not free hydrogen and hydro-carbons pass off unburnt in the same way? He understood Mr. Wilson's opinion was that hydrogen burnt so easily that it was not possible for it to escape from the furnace if there was oxygen to burn it. On the other hand the experiments of Mr. Scheurer-Kestner ("*Recherches sur la combustion de la houille*," Mulhouse 1868) showed that about 20 per cent. of the hydrogen in the coal passed off unconsumed, whether the supply of air was large or small. Dr. Bailey of Owen's College, Manchester, had come to a similar conclusion with regard to hydro-carbons whenever the supply of air fell below or exceeded certain limits, and whenever the firing was irregular (Journal of the

TABLE 8.—*Weight of Steam and Water in Cylinders of S.S. "Tartar."*

Cylinder.	Weight in pounds, and Percentage, at successive stages of the stroke.	Steam.		Water.		Total.
		Lbs.	Per cent.	Lbs.	Per cent.	Lbs.
High-pressure.	Steam left from previous stroke, at beginning of compression	...	...	...	...	0·58
	Supplied during admission	...	...	...	...	2·56
	Present at 50 per cent. of stroke	2·070	66·0	1·070	34·0	3·14
	" " 55 " "	2·080	66·3	1·060	33·7	3·14
	" " 60 " "	2·080	66·3	1·060	33·7	3·14
	" " 65 " "	2·100	66·9	1·040	33·1	3·14
	" " 70 " "	2·110	67·3	1·030	32·7	3·14
	" " 75 " "	2·120	67·6	1·020	32·4	3·14
	" " 80 " "	2·180	69·6	0·960	30·4	3·14
Intermediate.	Steam left from previous stroke, at beginning of compression	...	...	...	...	0·40
	Supplied during admission	...	...	...	...	2·56
	Present at 65 per cent. of stroke	1·936	65·4	1·024	34·6	2·96
	" " 70 " "	1·902	64·3	1·058	35·7	2·96
	" " 75 " "	1·900	64·2	1·060	35·8	2·96
	" " 80 " "	1·871	63·5	1·089	36·5	2·96
	" " 85 " "	1·836	62·0	1·124	38·0	2·96
Low-pressure.	Steam left from previous stroke, at beginning of compression	...	...	...	...	0·24
	Supplied during admission	...	...	...	...	2·56
	Present at 55 per cent. of stroke	1·675	59·8	1·125	40·2	2·80
	" " 60 " "	1·707	61·0	1·093	39·0	2·80
	" " 65 " "	1·724	61·6	1·076	38·4	2·80
	" " 70 " "	1·765	63·0	1·035	37·0	2·80
	" " 75 " "	1·765	63·0	1·035	37·0	2·80
	" " 80 " "	1·814	64·8	0·986	35·2	2·80
	" " 85 " "	1·799	64·2	1·001	35·8	2·80

(Mr. Michael Longridge.)

Society of Chemical Industry, 31 May 1889). In future trials therefore he trusted that complete analyses both of coals and gases might be made, so as to be considered in conjunction with the forms and dimensions of the furnaces; for he imagined the quantities of combustible gases passing off depended a good deal on the way in which the air was admitted, and on the way in which the flame was brought into contact with the boiler plates.

There was at present a want of a reliable and workable thermometer for high temperatures, and also of an instrument for measuring the percentage of water in steam. When furnace temperatures and wetness of steam could be accurately measured, a great advance in the comprehension of both boilers and engines would follow. Until they could be measured, the laws of transmission of heat through boiler plates and into cylinder metal would probably remain unknown.

Professor KENNEDY wrote that, in reference to Mr. Morison's letter (page 282), he had nothing to add to the remarks he had already made (page 277) about the lightness of the "Tartar" during her trial, and about the priming. He believed Mr. Morison was perfectly right in saying that if the engines had exerted more power, as they certainly did under the conditions of working for which they were designed, they would have been more economical. He pointed out however that, if his estimate of the steam actually used by the engines (page 234) was correct, they were already working with very considerable economy; and whatever blame was due was to be attached rather to the boilers.

Mr. Longridge's remarks in regard to furnace-gas analyses (page 286) somewhat surprised him. He believed it was perfectly impossible for free hydrogen to pass away unburnt. The hydrocarbons which no doubt would be formed to a greater or less extent, and whose determination was, as Mr. Longridge said, undoubtedly important, would, he feared, elude gaseous analysis for the simple reason that they would condense either in the chimney or in the sample bottle. No signs of any were found in the latter, in any of the cases under discussion. He also doubted very much whether any

thoroughly good analyses had ever shown carbonic oxide to be present in furnace gases with great excess of air, although no doubt this was possible under conceivable conditions. Of course the analysis of furnace gases with anything approaching to accuracy was not an extremely simple chemical operation; and many results which had been published in perfect good faith must no doubt be taken as only rough approximations. The apparent discrepancy pointed out by Mr. Longridge in the quantity of nitrogen present was mainly accounted for by the fact that a portion of the oxygen would pass away combined with hydrogen as steam, and that this oxygen was not included at all in the analysis, which like all furnace-gas analyses was made of the *dry* gas. If Mr. Longridge would take this quantity into account, making any reasonable assumption as to how much hydrogen had been burnt completely, he would find that the remaining discrepancy was well within the limits of error of the instruments and methods used. If Mr. Longridge could bring forward any way in which more complete and also more trustworthy analyses could be made of either coal or gas—for he seemed to think that both sets of analyses were incomplete—he would do all in his power to secure that such analyses should be made. At present it appeared to him that the suggested incompleteness was due to mistake on Mr. Longridge's part, and not on his own. Certainly if the furnace gas from a hydrogenous coal gave an average analysis of only 79 per cent. of nitrogen, it would be presumptive evidence that the analysis was wrong, and not right.

The thermometer which he had employed was an ordinary mercury thermometer containing compressed nitrogen over the mercury, which he considered was an instrument quite reliable and workable (page 288) for temperatures up to about 420° centigrade or 788° Fahr.; this was quite high enough for all ordinary chimney-gases. He agreed that it was most important that some instrument should be devised for measuring in a trustworthy manner the wetness of steam (page 288).

In conclusion, while he had every wish to make these trials as complete as possible in every respect, yet it should be borne in mind

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that the functions of the Research Committee were precisely those which Mr. Longridge thought so insufficient (page 285). The Committee had been appointed under the following resolution of the Council (17 Dec. 1886):—"That a Research Committee on Marine-Engine Trials be appointed, with instructions to endeavour (1) to draw up a standard system for conducting Marine-Engine Trials, and (2) to arrange for the carrying out of such trials in accordance with this system." In view of the strenuous denials expressed beforehand of the possibility or practicability of such trials, he considered it was no mean or unworthy result even simply to have shown that they were possible and practicable.

MARINE-ENGINE TRIALS. *Plate 87.*
Feed-Water Measuring Tanks. Fig. 1. Plan.

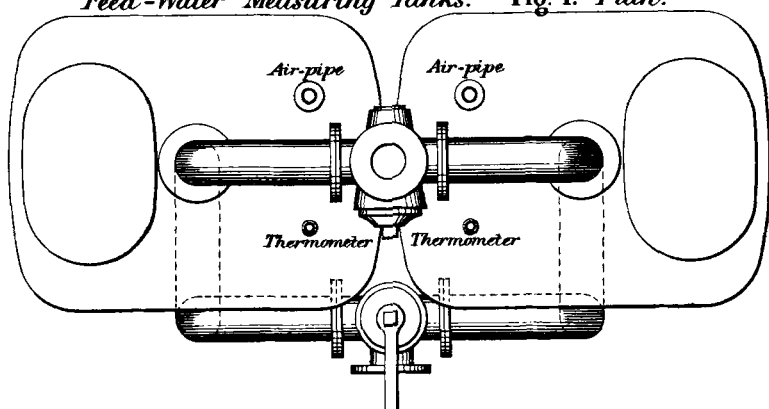
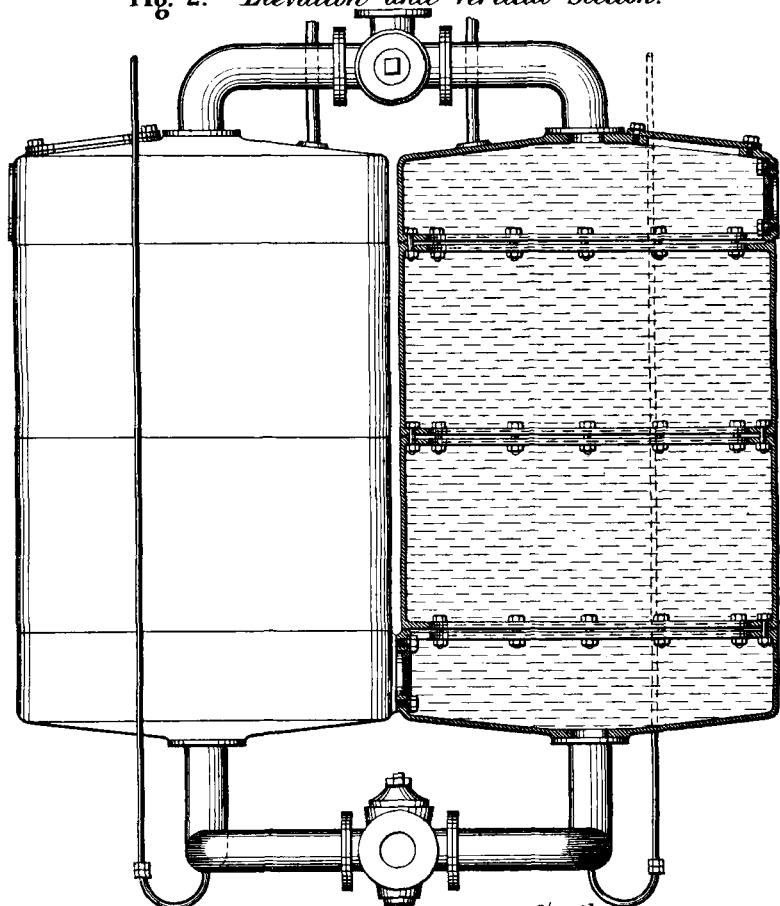
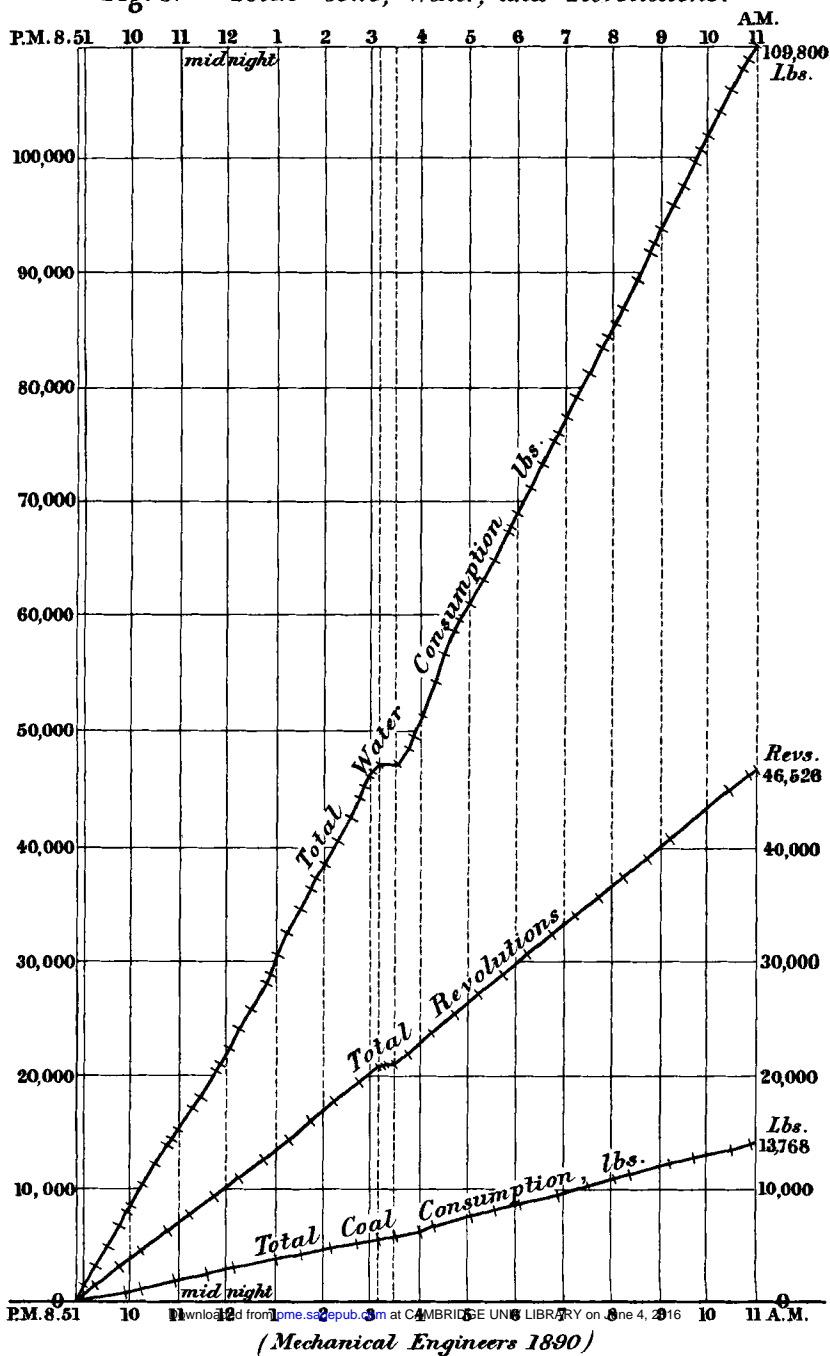


Fig. 2. Elevation and Vertical Section.

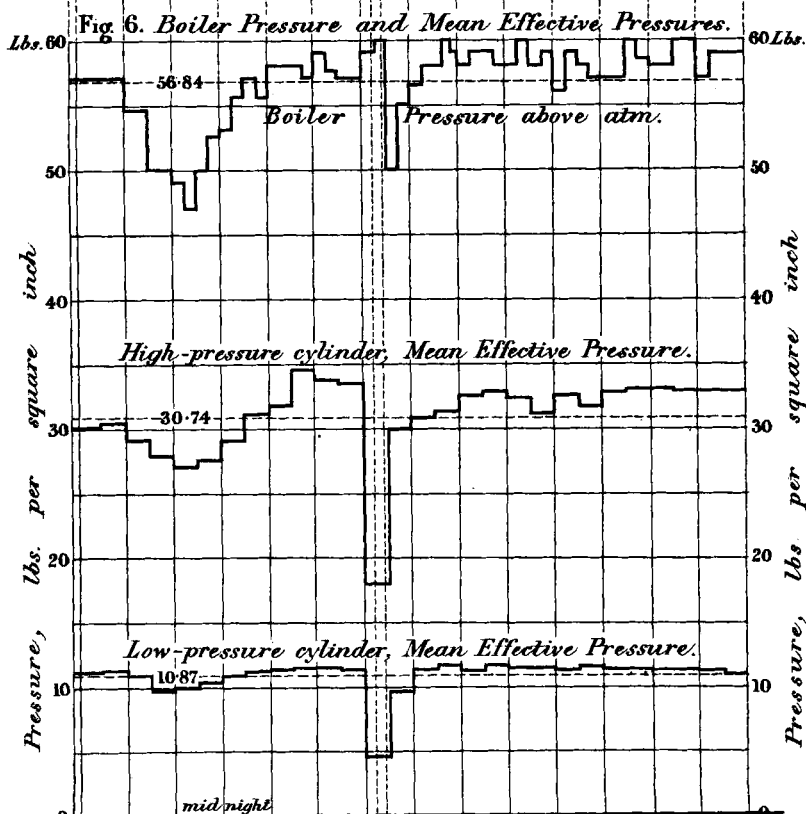
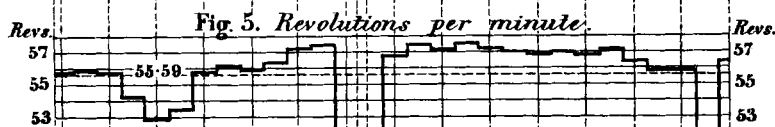
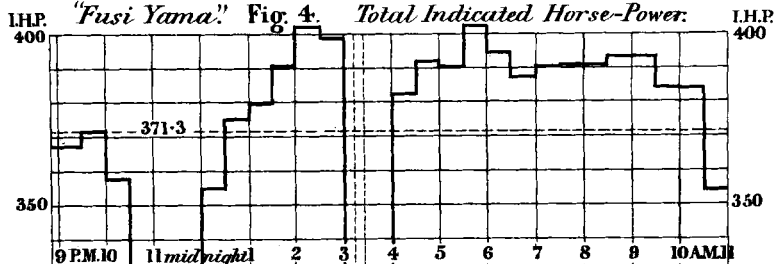


*Trial of the "Fusi Yama."*Fig. 3. *Total Coal, Water, and Revolutions.*

MARINE - ENGINE TRIALS.

Plate 89.

"Fusi Yama." Fig. 4. Total Indicated Horse-Power.



"Fusi Yama" Indicator Diagrams, Set 2.

Revs. 55.9 per min. Total I.H.P. 371.2.

Fig. 7. High-pressure cylinder. I.H.P. 164.1.

Lbs. Mean Pressures, Top end 30.37 lbs., Bottom 30.60 lbs. Lbs.

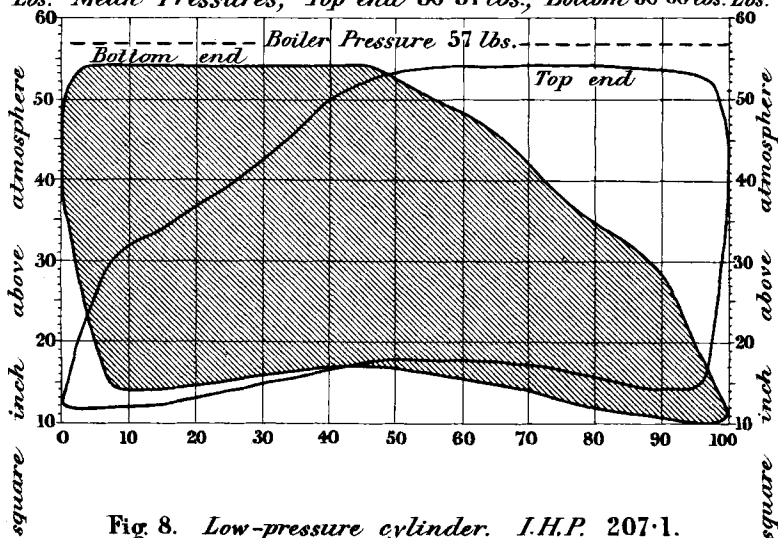
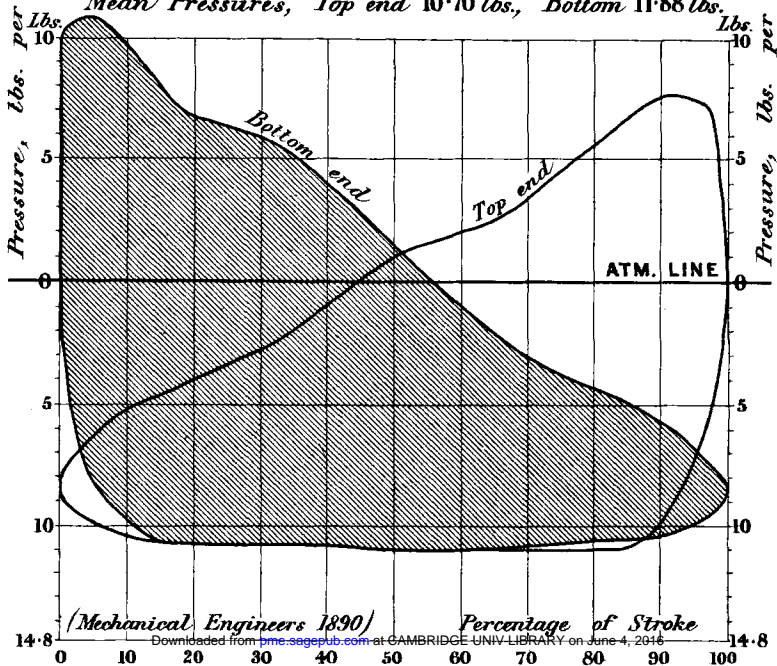
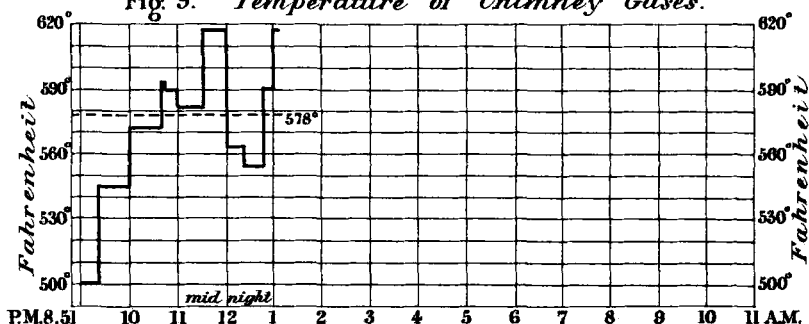
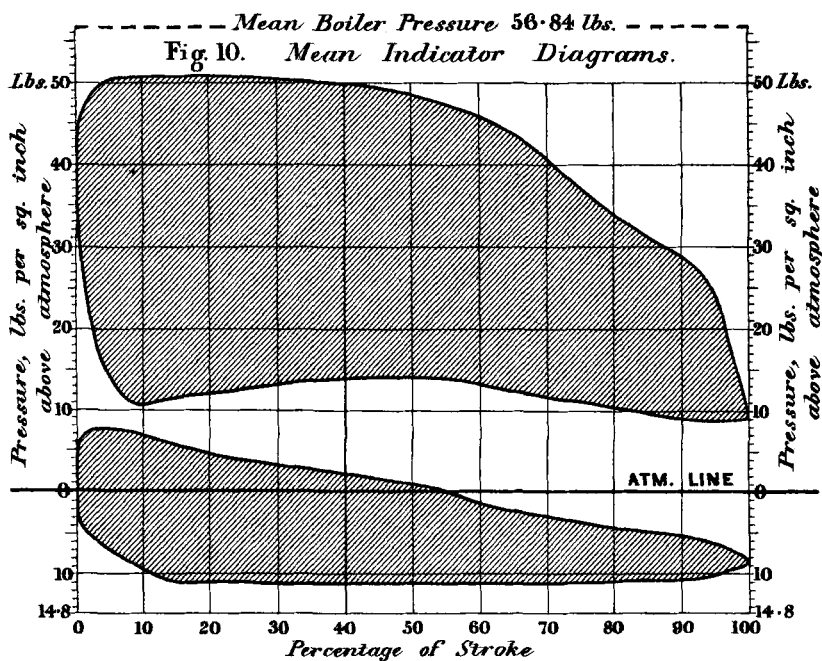
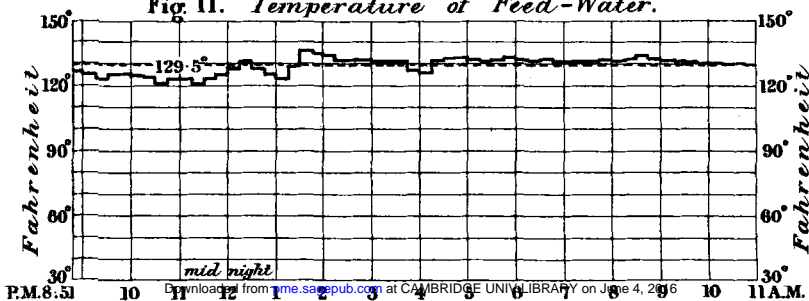


Fig. 8. Low-pressure cylinder. I.H.P. 207.1.

Mean Pressures, Top end 10.70 lbs., Bottom 11.88 lbs.

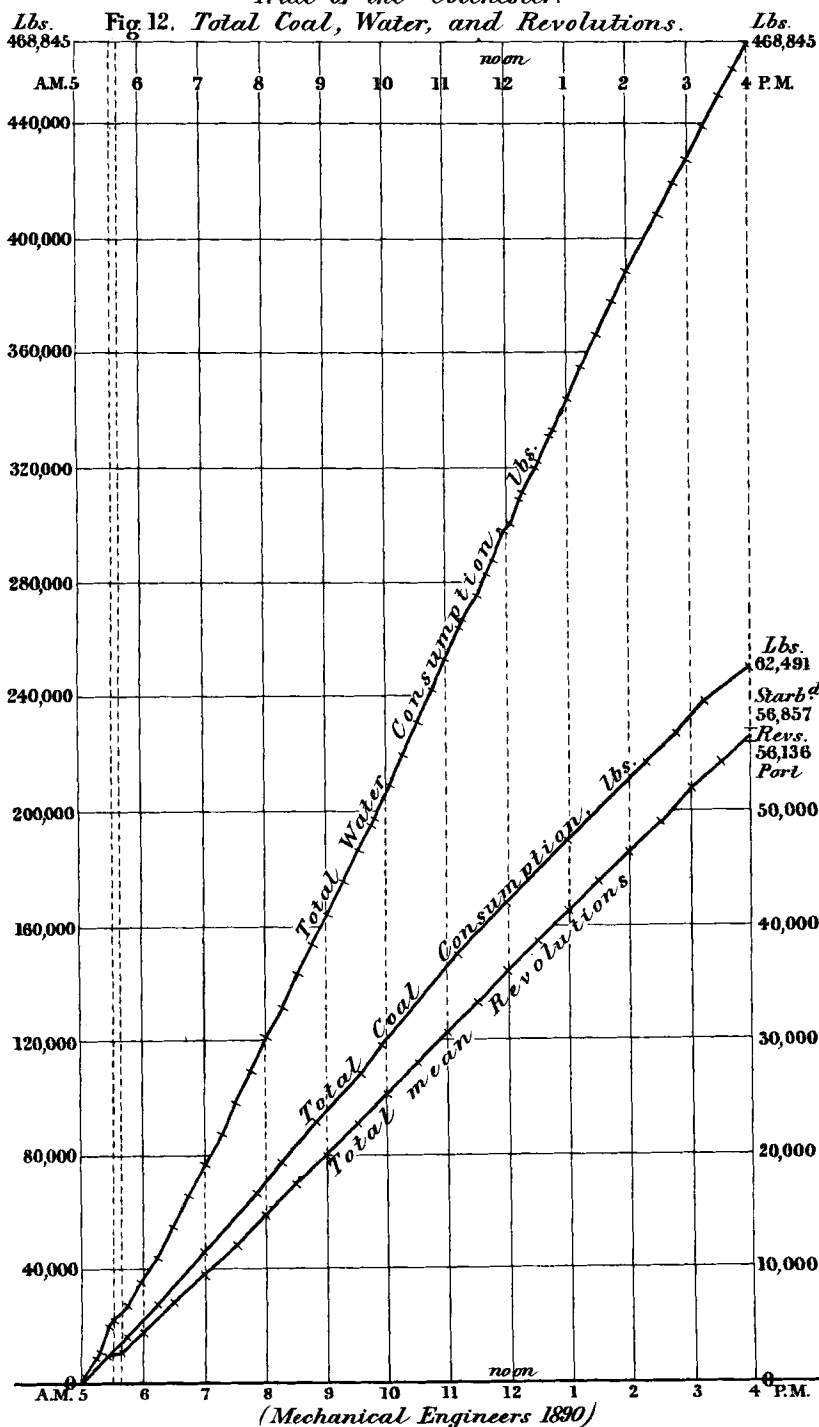


*Trial of the "Fusi Yama."*Fig. 9. *Temperature of Chimney Gases.*Fig. 10. *Mean Indicator Diagrams.*Fig. 11. *Temperature of Feed-Water.*

MARINE-ENGINE TRIALS.

Plate 92.

Trial of the "Colchester."



MARINE-ENGINE TRIALS.

Plate 93.

I.H.P. "Colchester." Fig 13. Indicated Horse -Power. I.H.P.

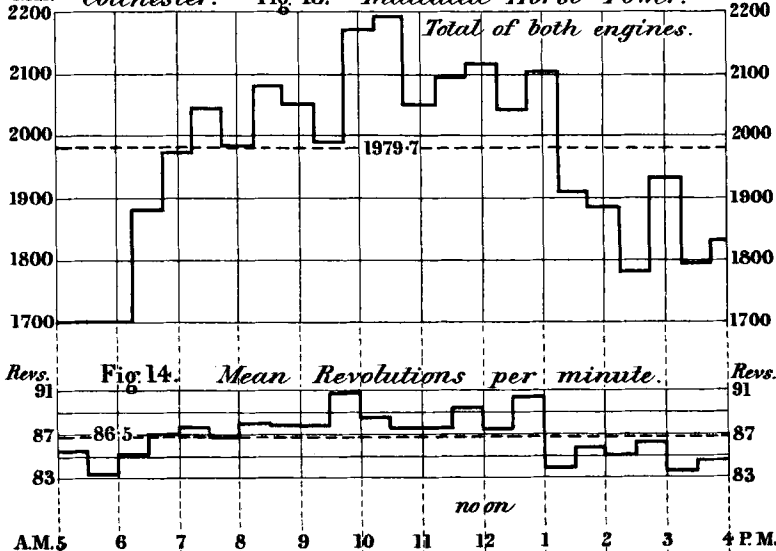


Fig 15. Indicated Horse -Power. Total of each engine.

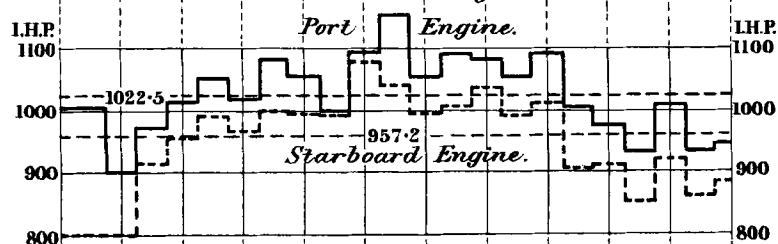


Fig 16. Boiler Pressure above atmosphere.

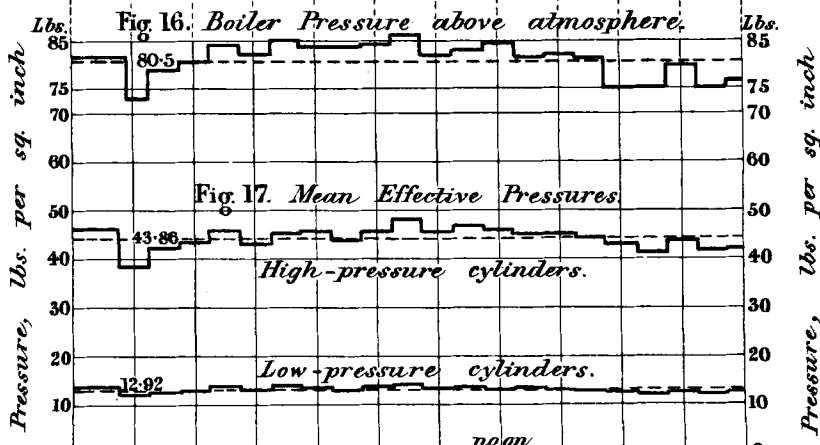
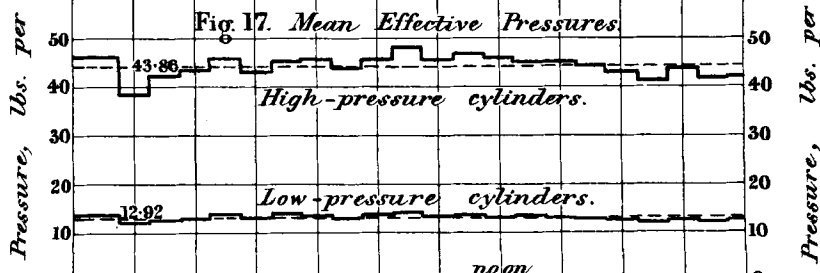


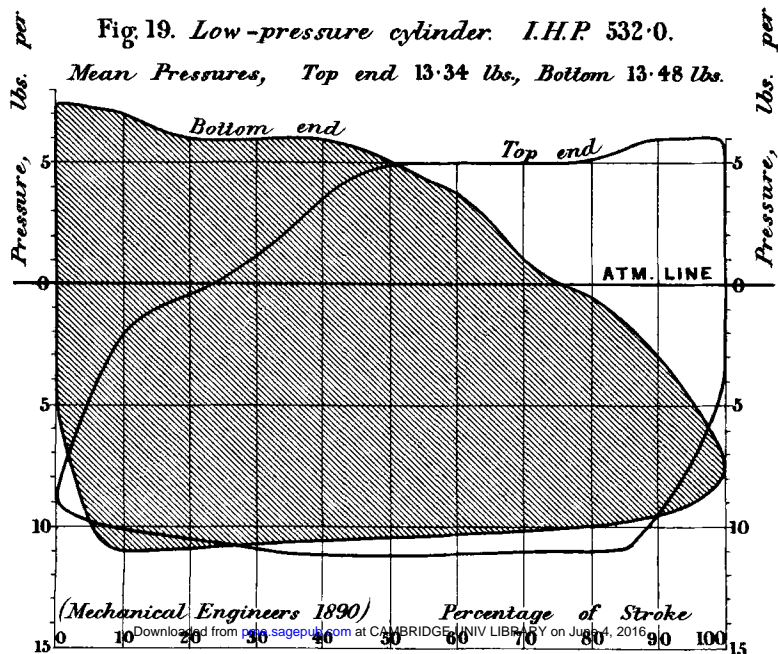
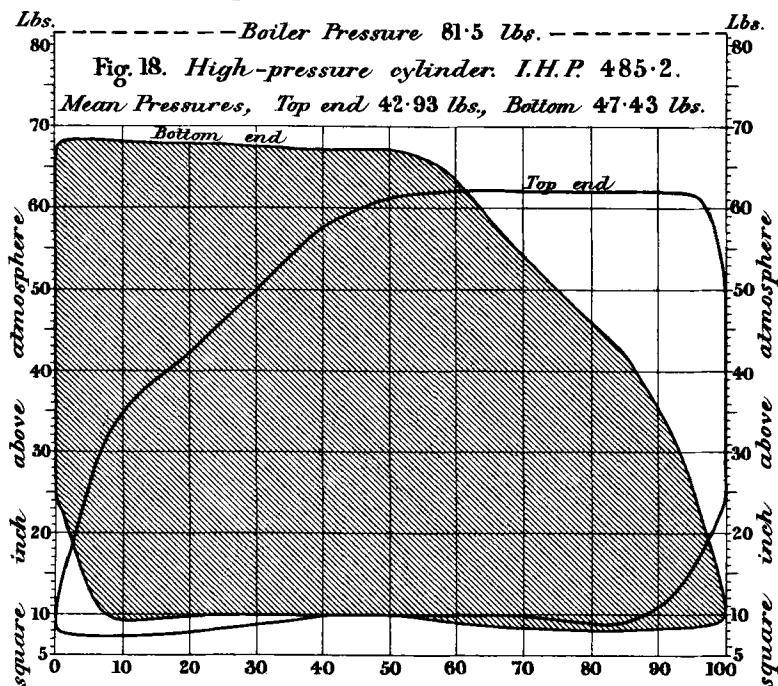
Fig 17. Mean Effective Pressures.



MARINE-ENGINE TRIALS. *Plate 94.*

"Colchester" Indicator Diagrams, Set 8, Port Engine.

Revs. 86.3 per min. Total I.H.P. 1017.2.



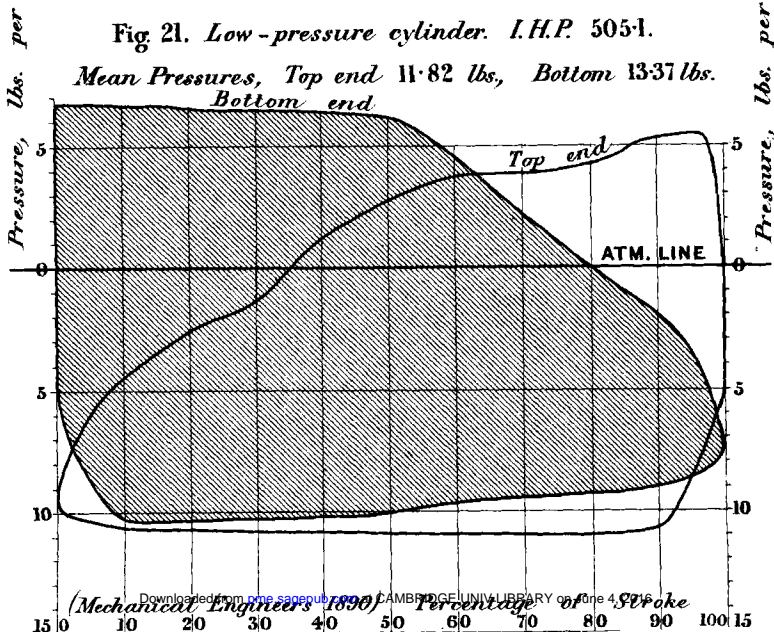
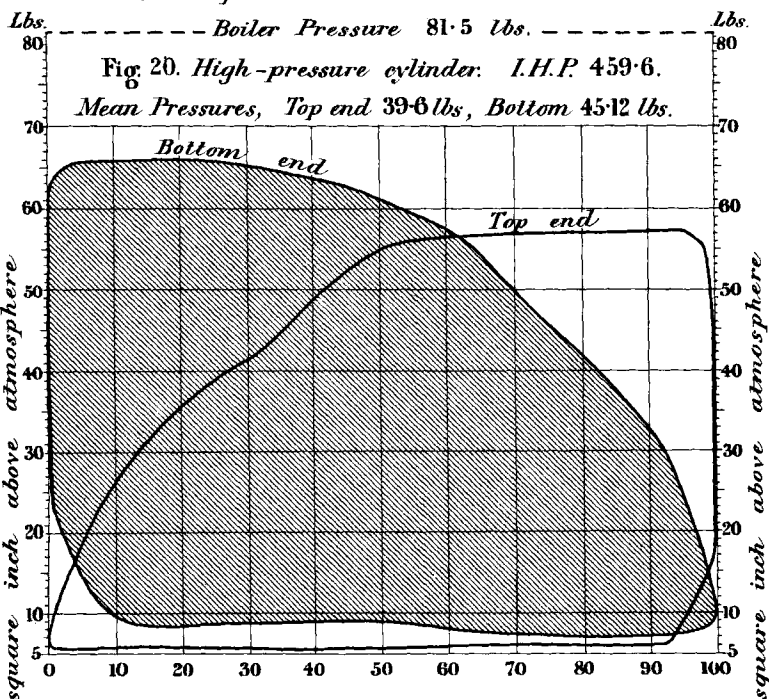
(Mechanical Engineers 1890)

Percentage of Stroke

MARINE-ENGINE TRIALS. Plate 95.

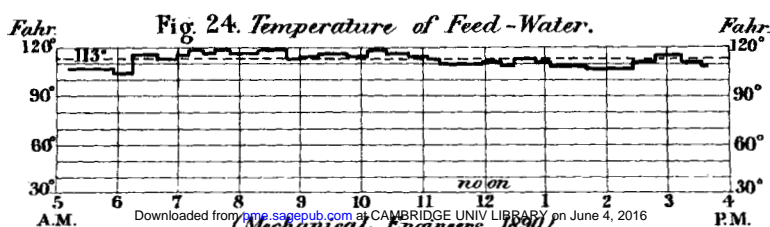
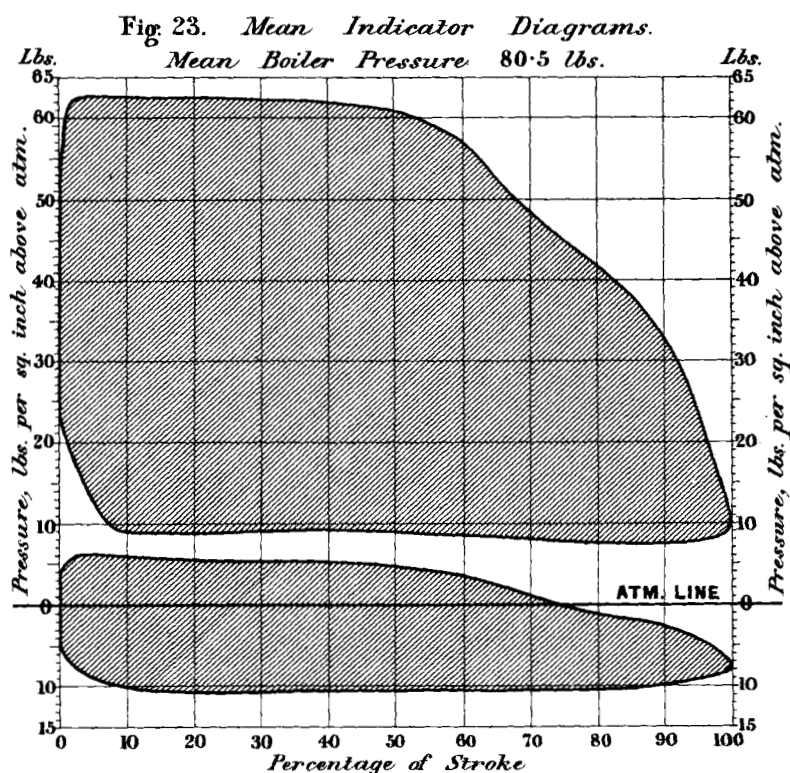
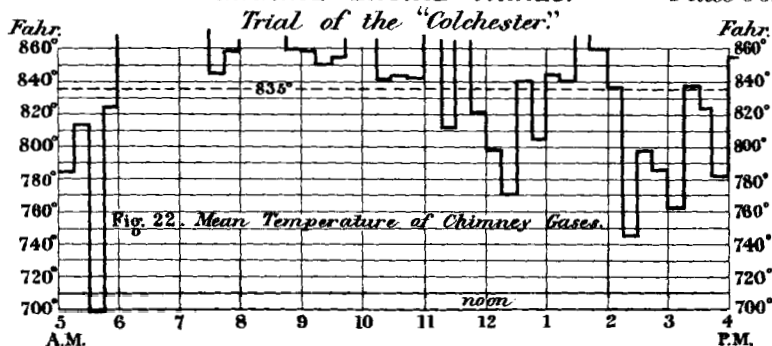
"Colchester" Indicator Diagrams, Set 6, Starboard Engine.

Revs. 87.2 per min. Total I.H.P. 964.7.



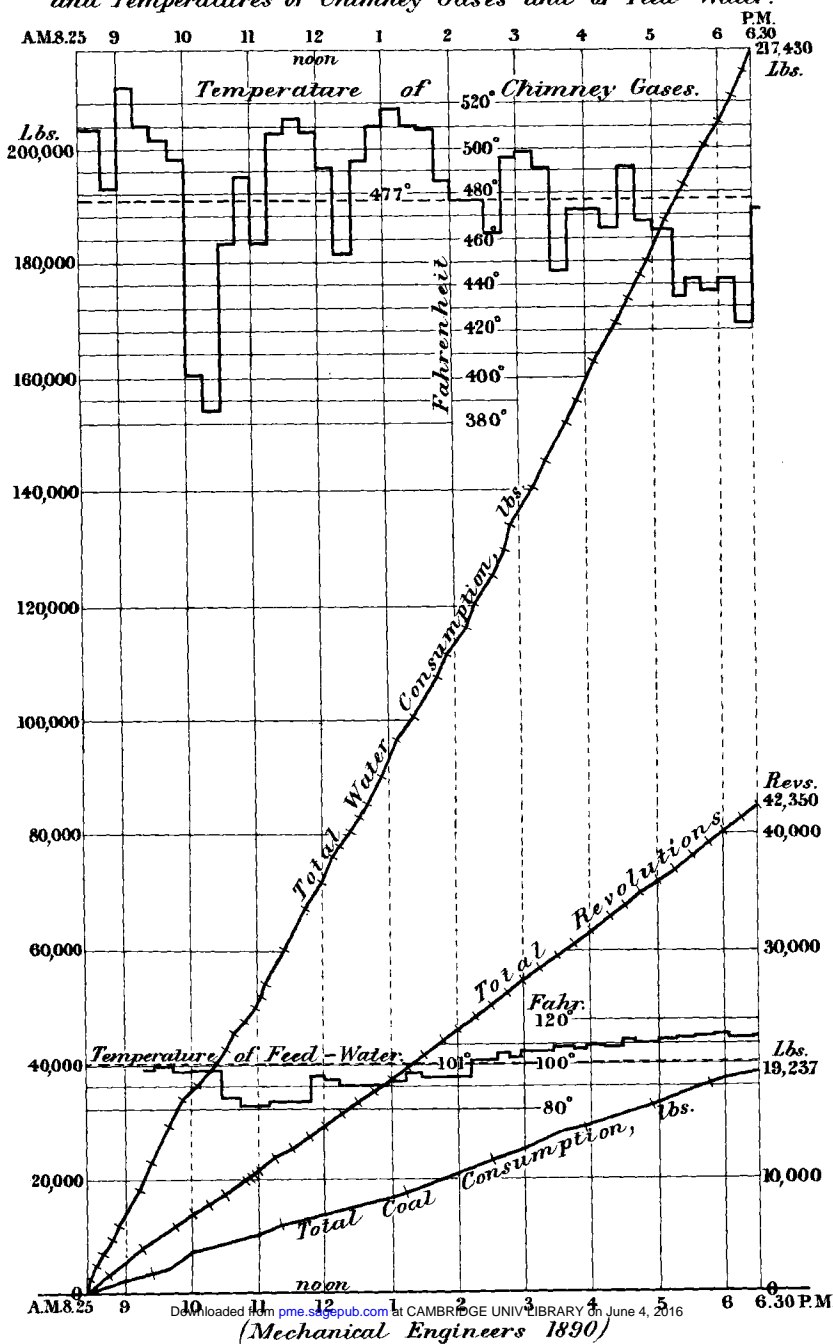
MARINE-ENGINE TRIALS.

Plate 96.



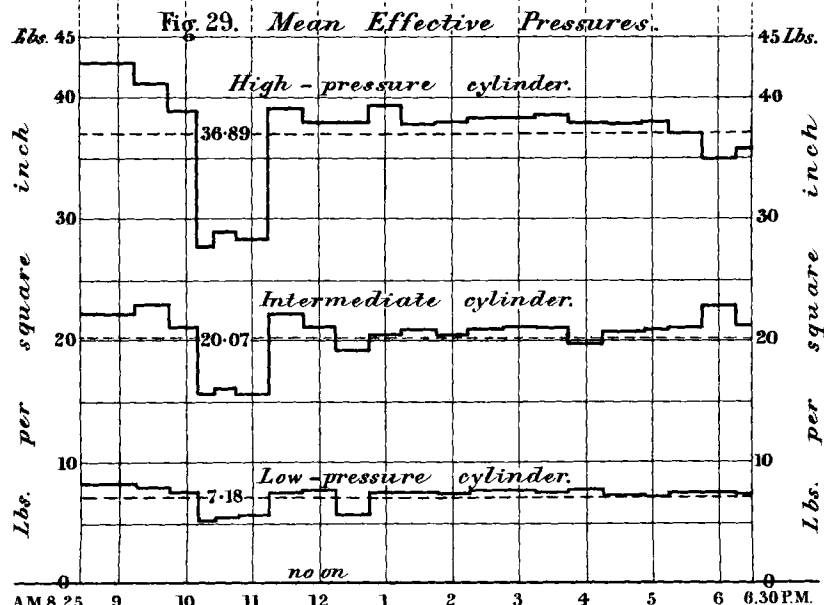
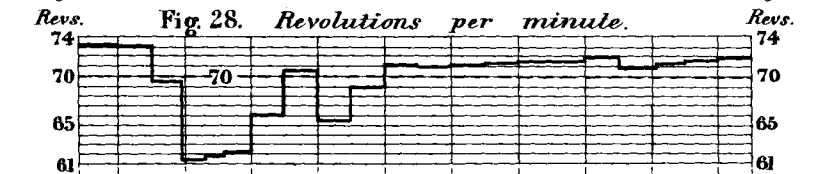
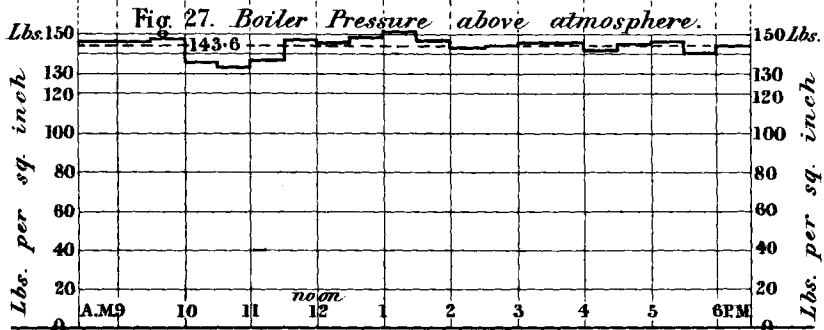
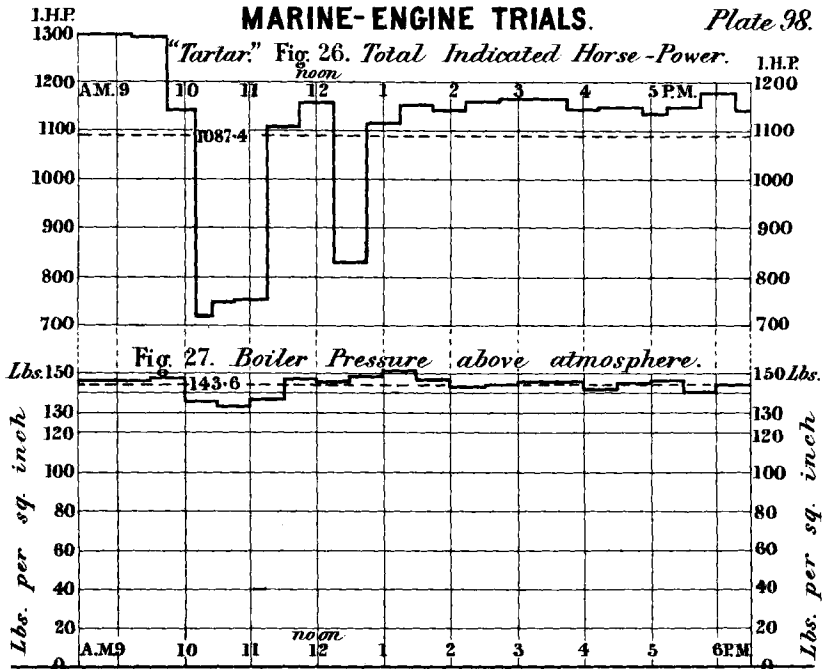
Trial of the "Tartar."

Fig. 25. *Total Coal, Water, and Revolutions;
and Temperatures of Chimney Gases and of Feed-Water.*



MARINE-ENGINE TRIALS.

Plate 98.



"Tartar" Indicator Diagrams, Set 7.

Revs. 660 per min. Total I.H.P. 1105.9

Boiler Pressure 141.4 lbs.

Fig. 30. High-pressure cylinder. I.H.P. 284.8.

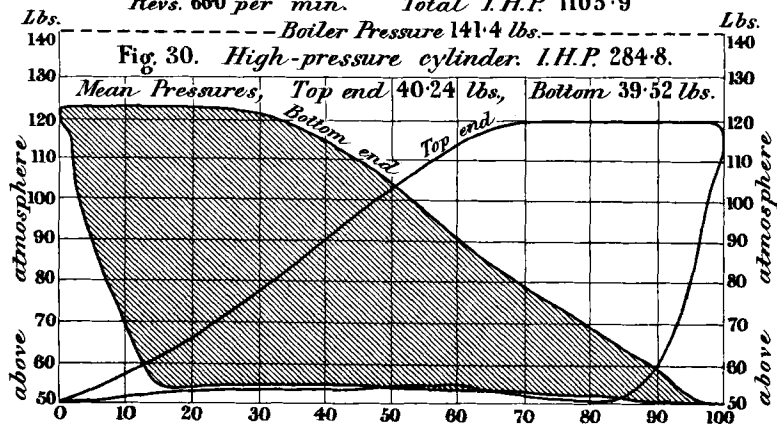


Fig. 31. Intermediate cylinder. I.H.P. 427.9.

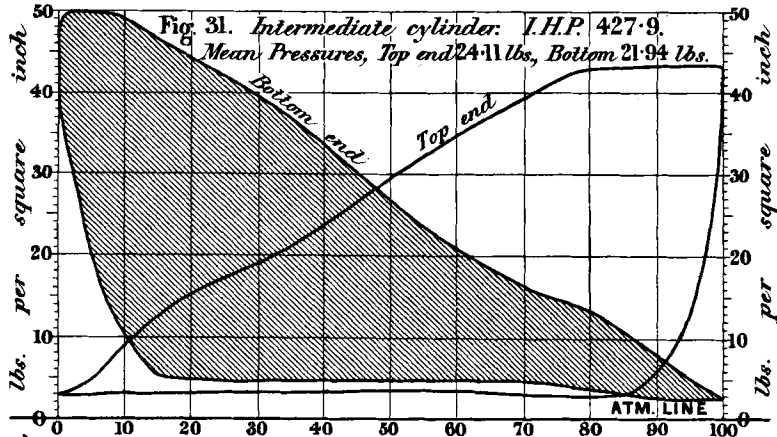
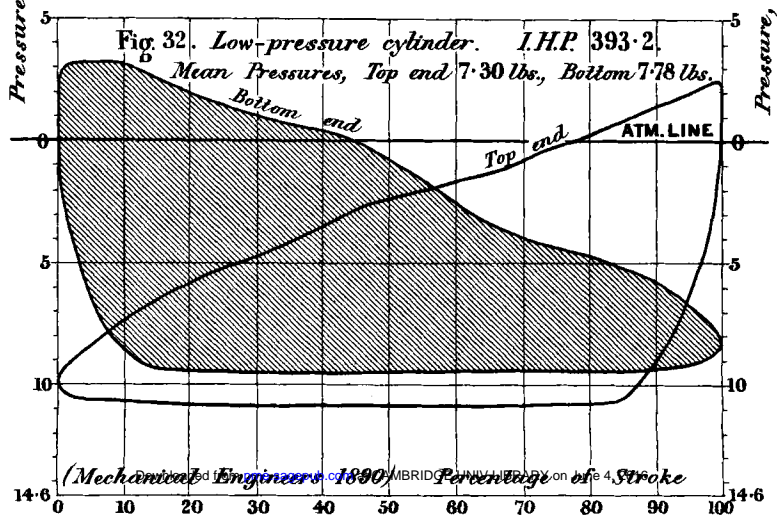
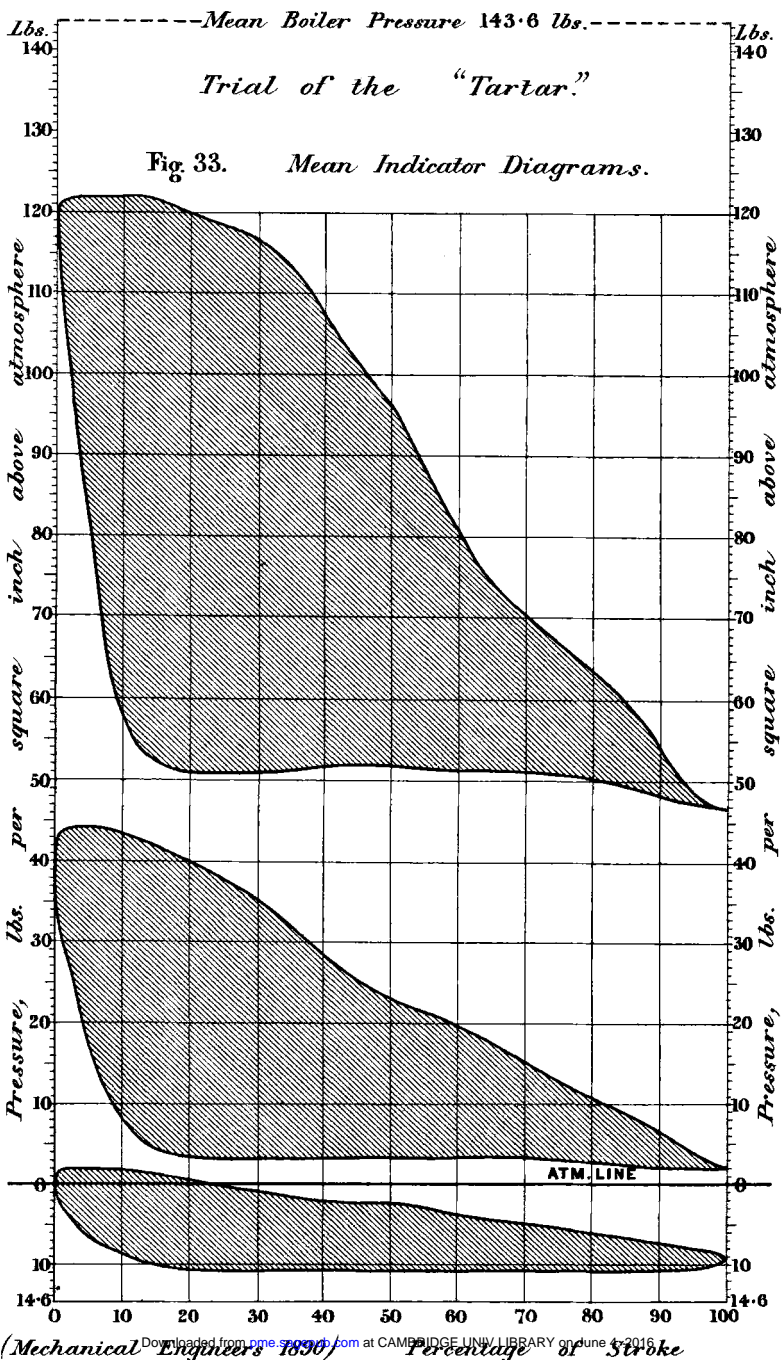


Fig. 32. Low-pressure cylinder. I.H.P. 393.2.

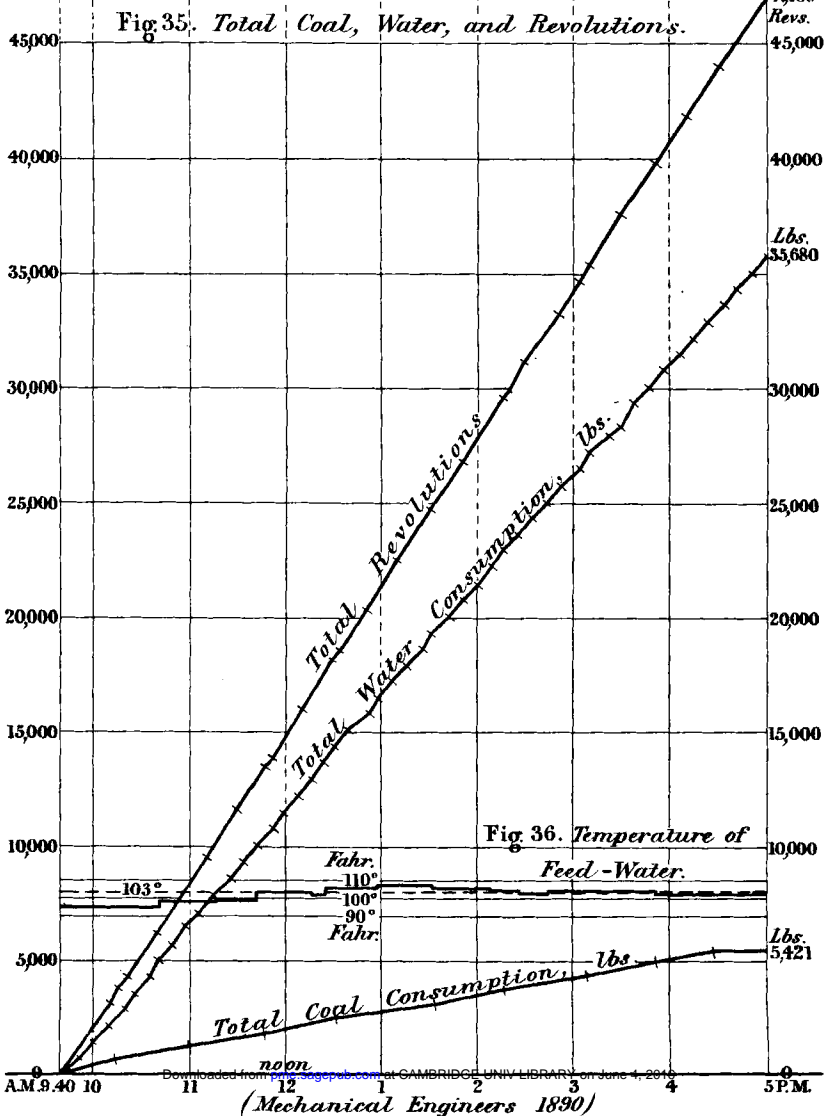
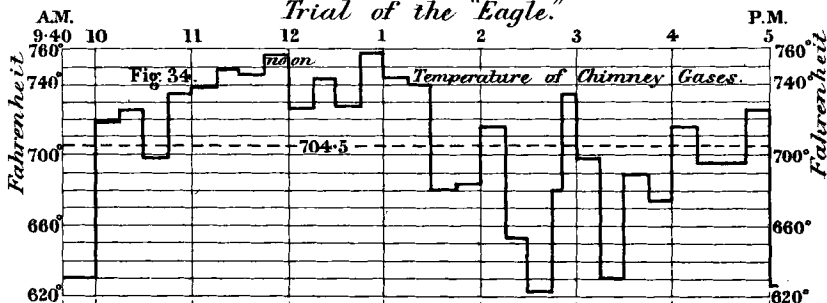


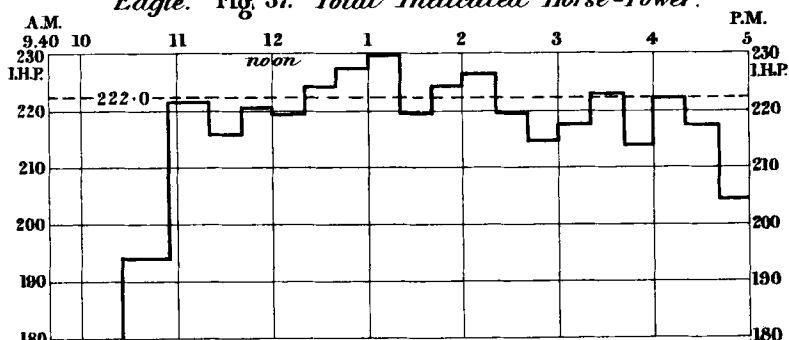
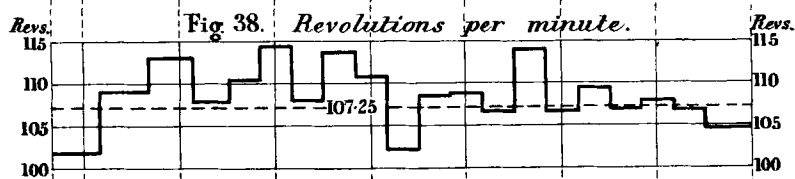
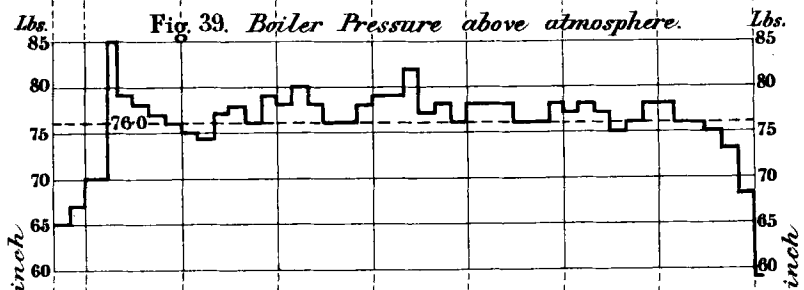
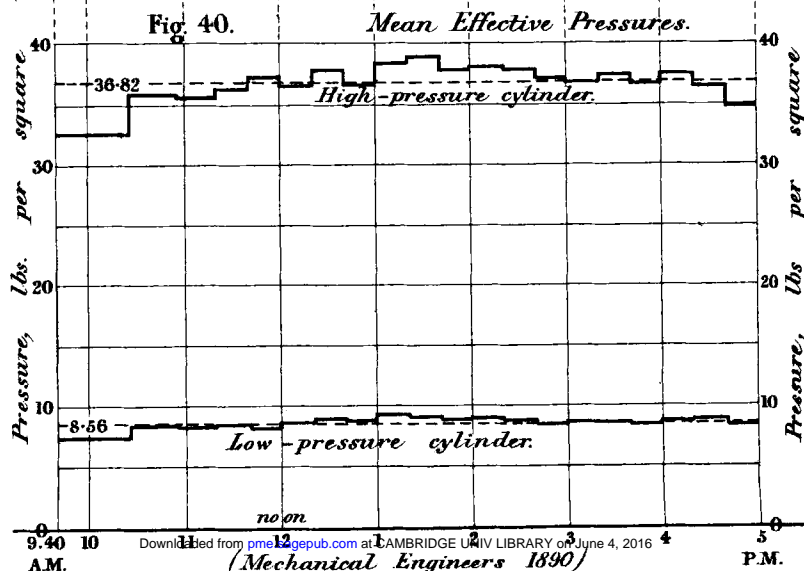


MARINE-ENGINE TRIALS.

Plate 101.

Trial of the "Eagle."



"Eagle." Fig 37. Total Indicated Horse-Power.Fig 38. *Revolutions per minute.*Fig 39. *Boiler Pressure above atmosphere.*Fig 40. *Mean Effective Pressures.*

MARINE-ENGINE TRIALS.

Plate 103.

"Eagle" Indicator Diagrams, Set 15.

Revs. 106.7 per min. Total I.H.P. 217.4.

Fig. 41. High-pressure cylinder. I.H.P. 119.7.

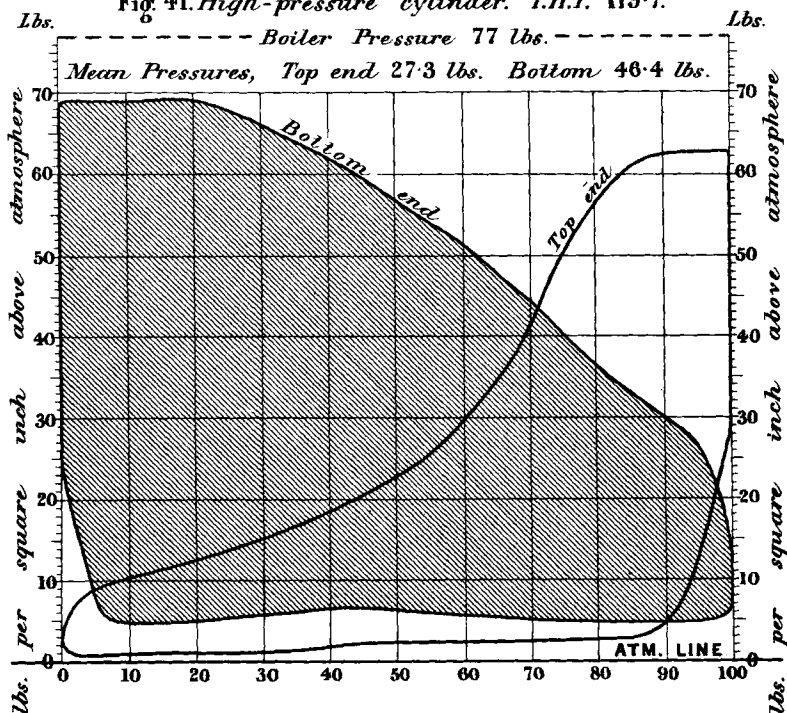
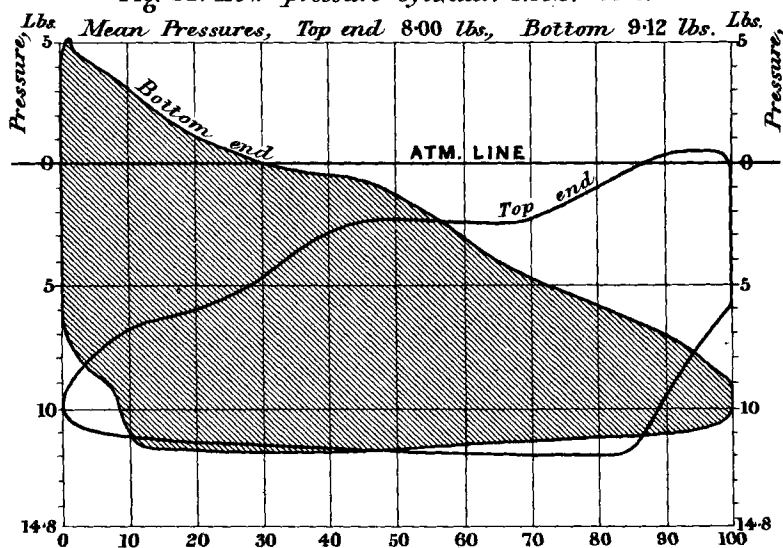


Fig. 42. Low-pressure cylinder. I.H.P. 97.7.

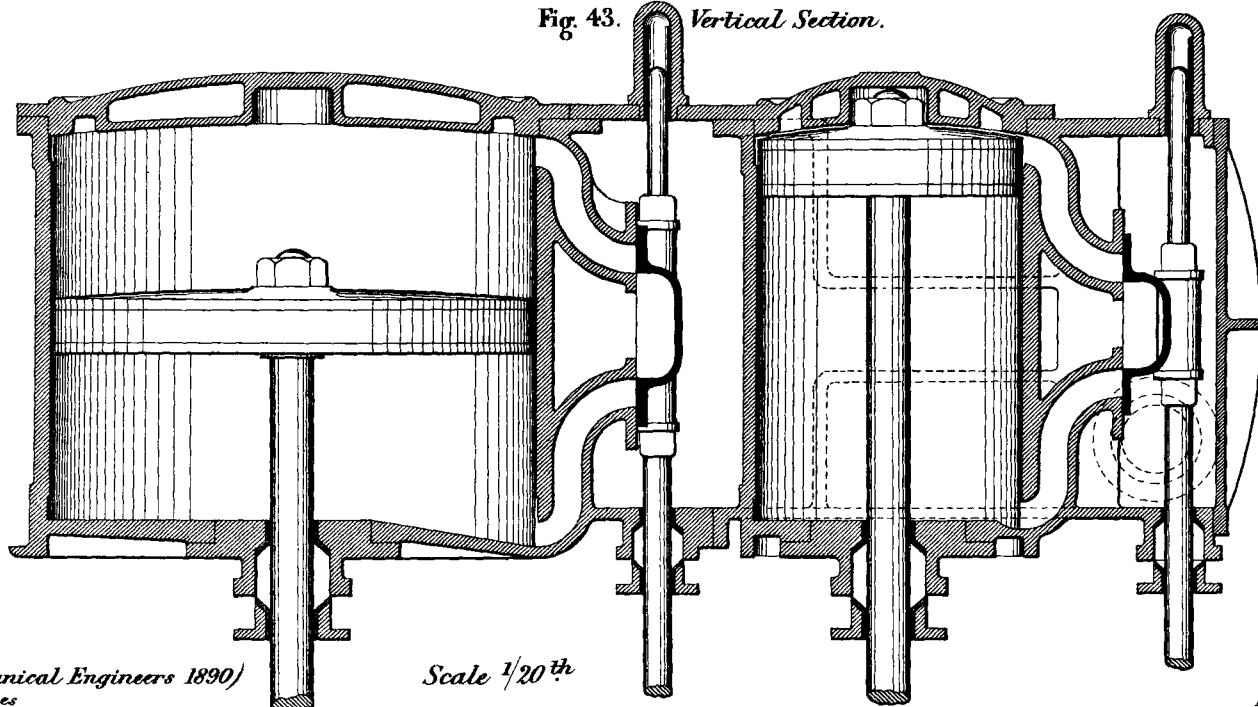


MARINE-ENGINE TRIALS.

Plate 104.

Cylinders of the "Fusi Yama."

Fig. 43. *Vertical Section.*



(Mechanical Engineers 1890)

Scale $\frac{1}{20}^{th}$

Inches

12 6 0 1 2 3 4 5 6 7 8 9

Feet.

10

Plate 104.

MARINE - ENGINE TRIALS.

Plate 105.

Cylinders of the "Fusi Yama".

Fig. 44. Sectional Plan.

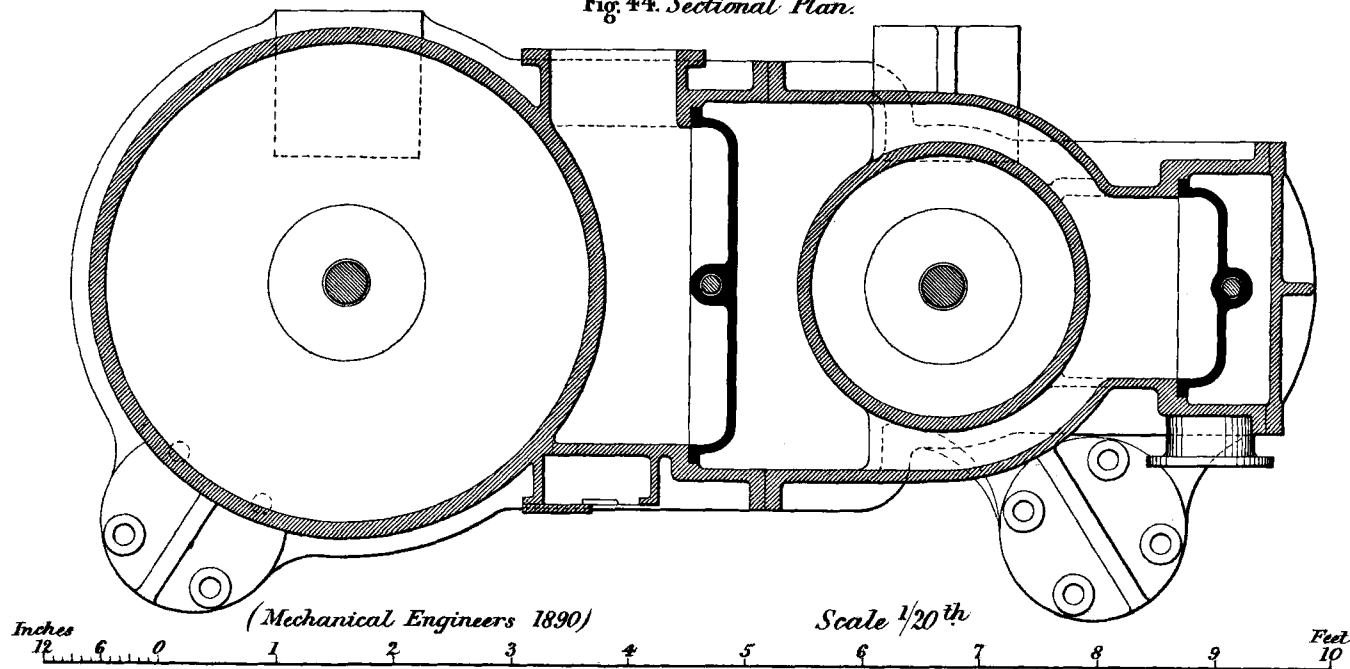


Plate 105.

MARINE-ENGINE TRIALS.

Plate 106.

Boiler of the "Fusi Yama."

Fig. 45.

Transverse Section.

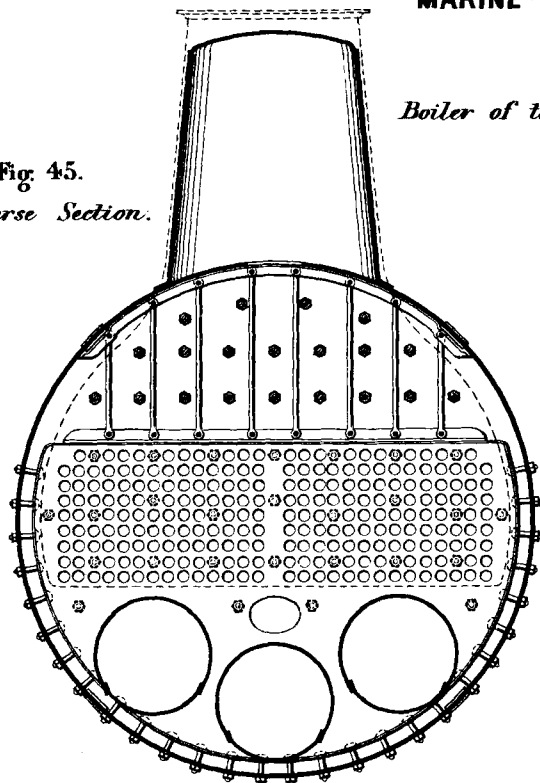
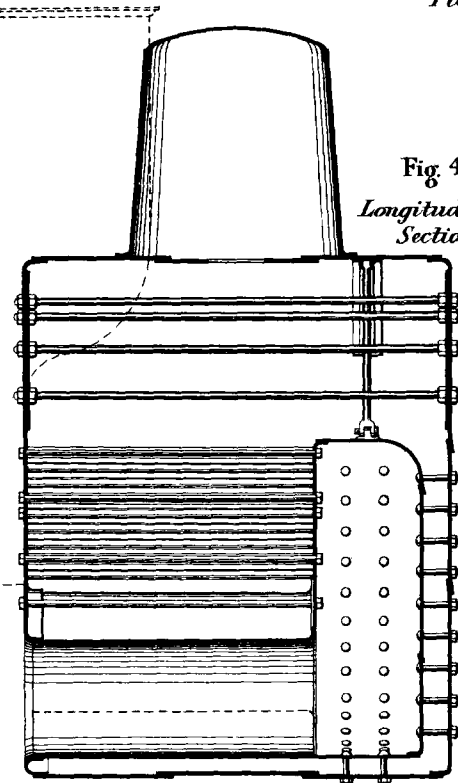


Fig. 46.

Longitudinal Section.



Scale $\frac{1}{60}$ th

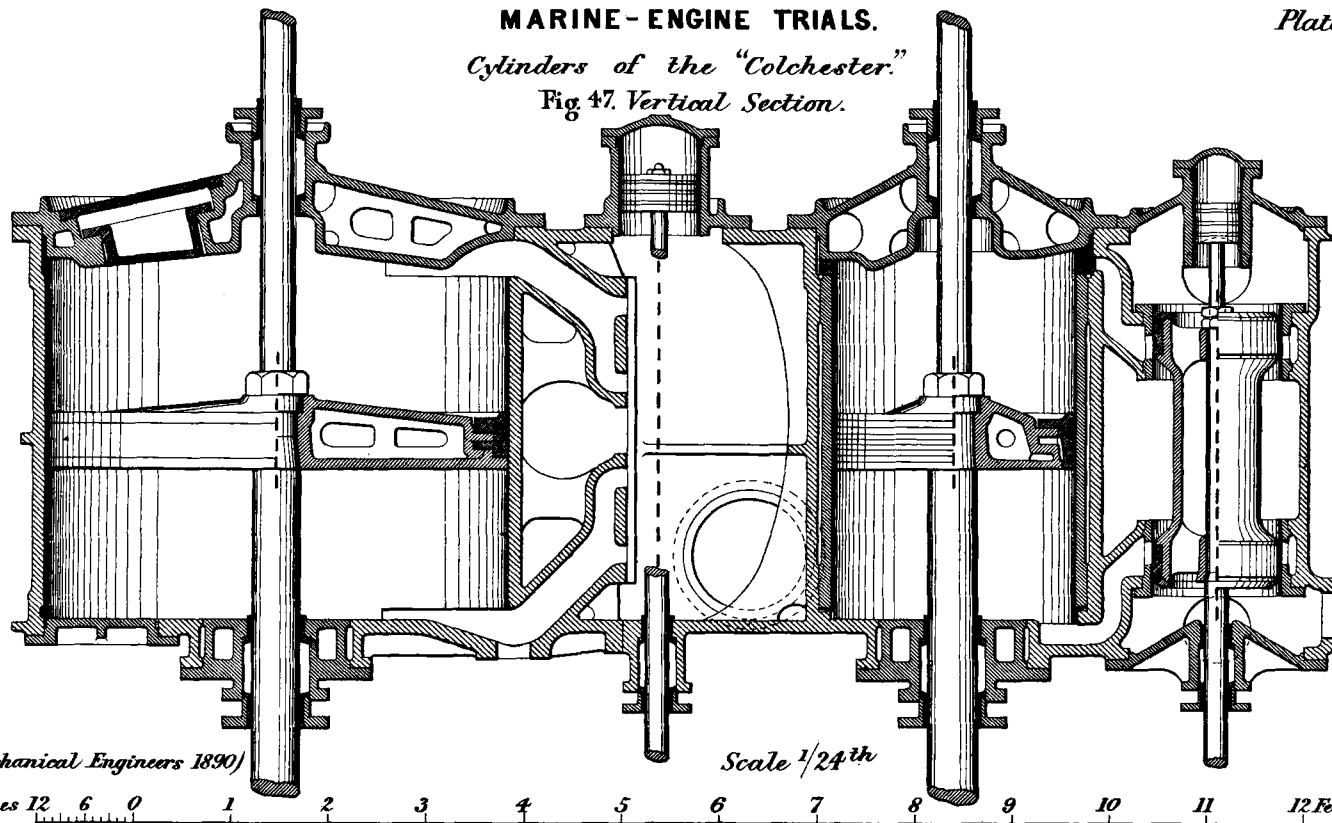
(Mechanical Engineers 1890)

Inches 12 0 5 10 15 20 Feet.

Plate 106.

MARINE-ENGINE TRIALS.
Cylinders of the "Colchester."
Fig 47. Vertical Section.

Plate 107.

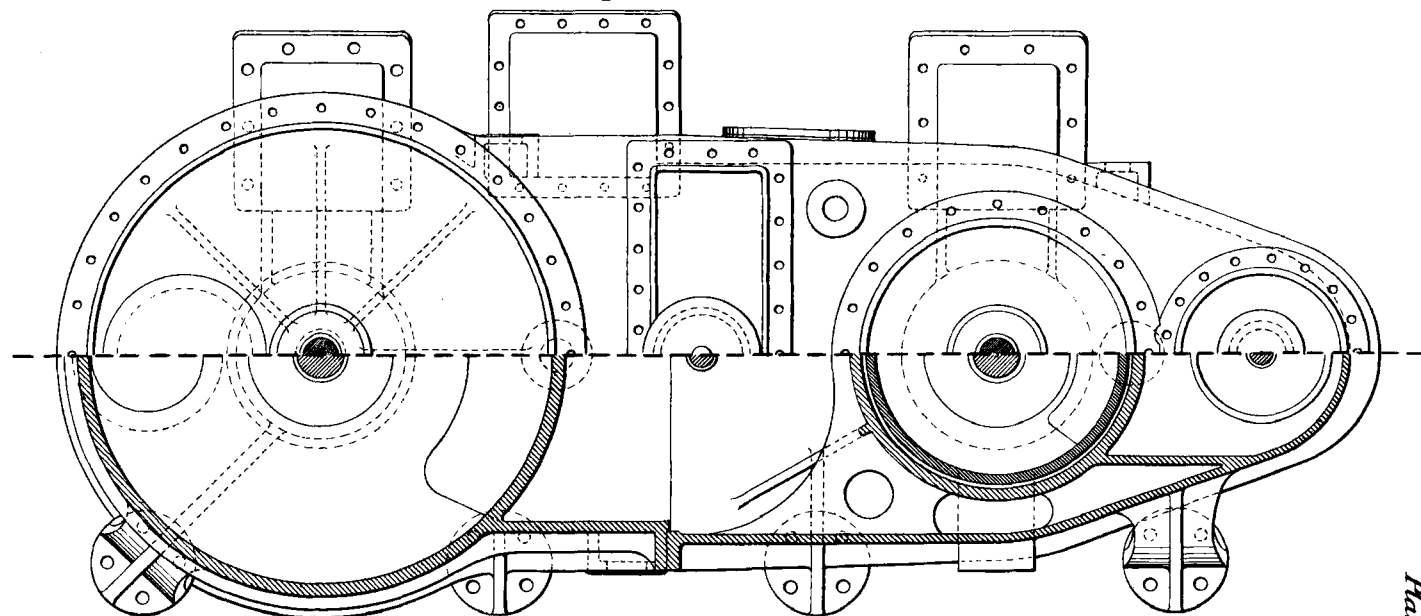


MARINE-ENGINE TRIALS.

Plate 108.

Cylinders of the "Colchester."

Fig. 48. Sectional Plan.



(Mechanical Engineers 1890)

Scale $\frac{1}{24}$ in

Inches 12 6 0 1 2 3 4 5 6 7 8 9 10 11 12 Feet.

Plate 108.

MARINE - ENGINE TRIALS.

Plate 109.

Boilers of the "Colchester."

Fig. 49.

*End Elevation
and Transverse Section.*

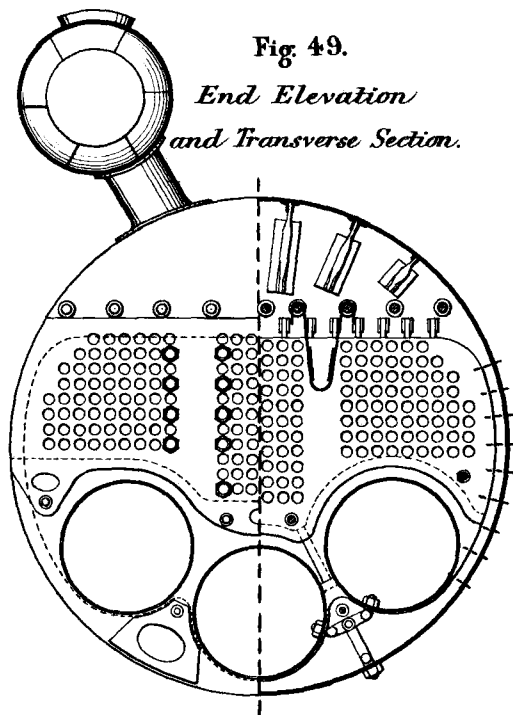
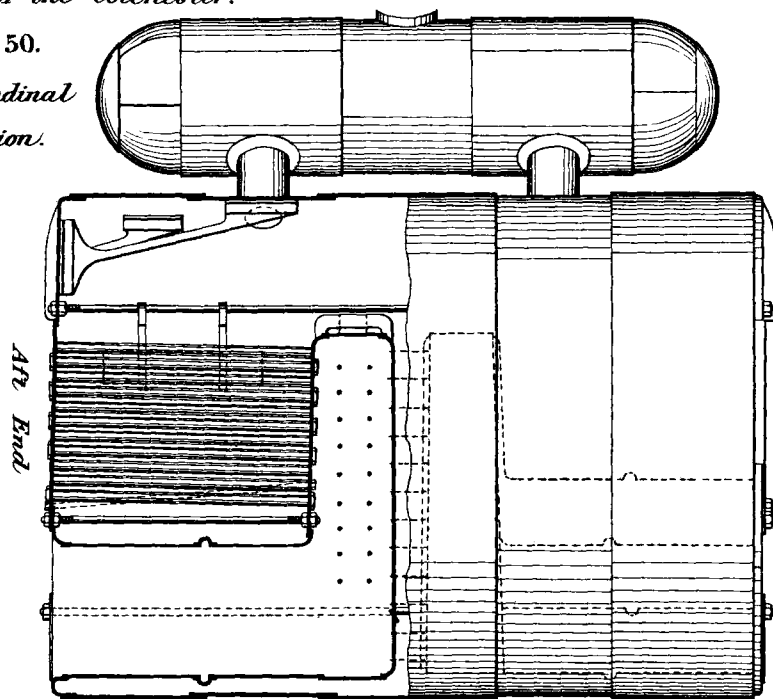


Fig. 50.

*Longitudinal
Section.*



Scale $\frac{1}{60}^{th}$

Inches 12 6 0

5

10

15

20 Feet.

(Mechanical Engineers 1890)

Plate
109.

High-Pressure Cylinder of the "Tartar."

Starting Valve Fig. 51. *Sectional Plan.*

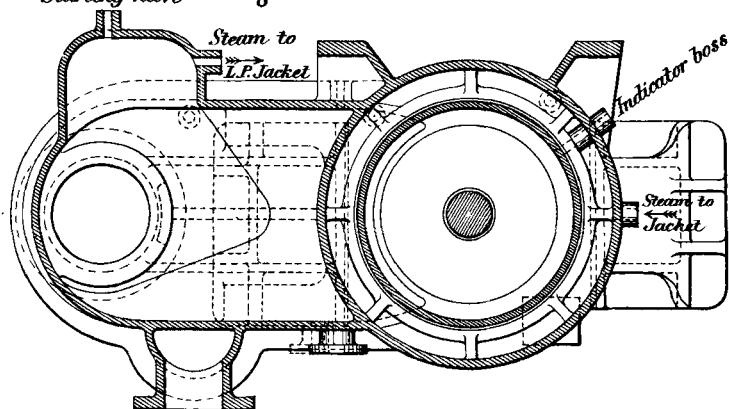
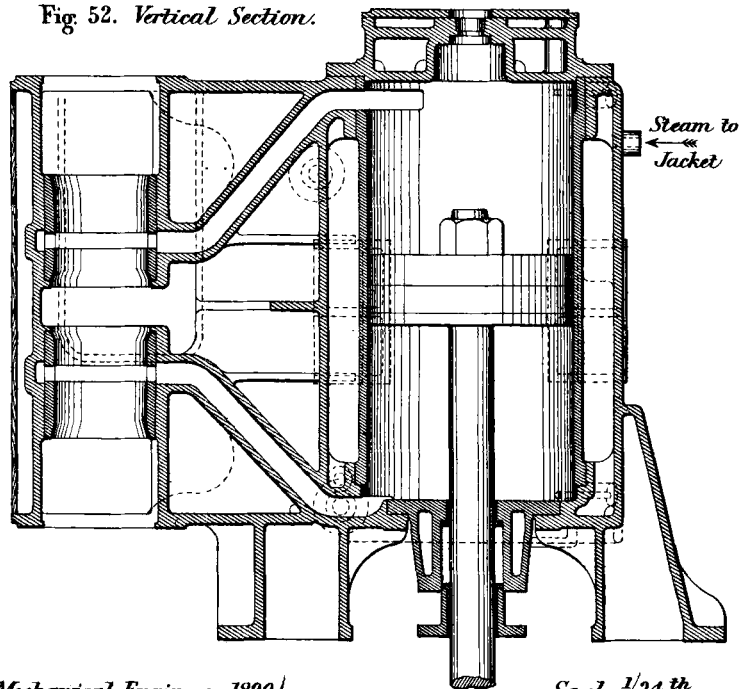
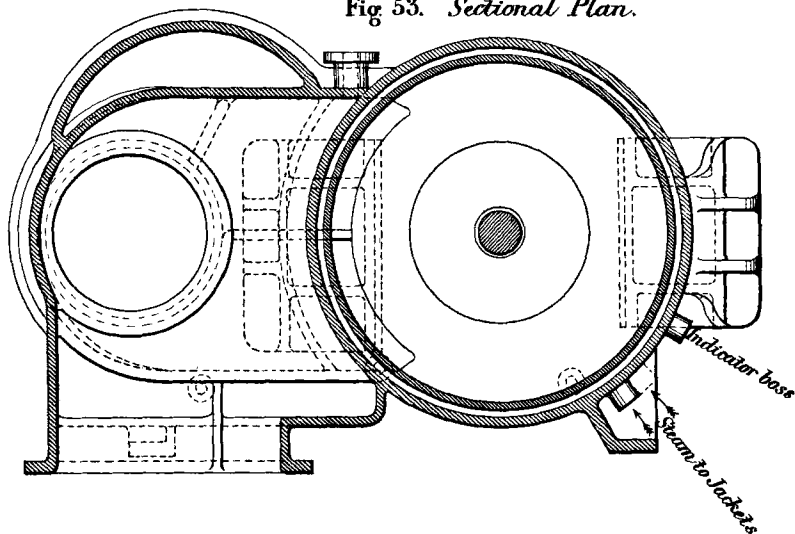
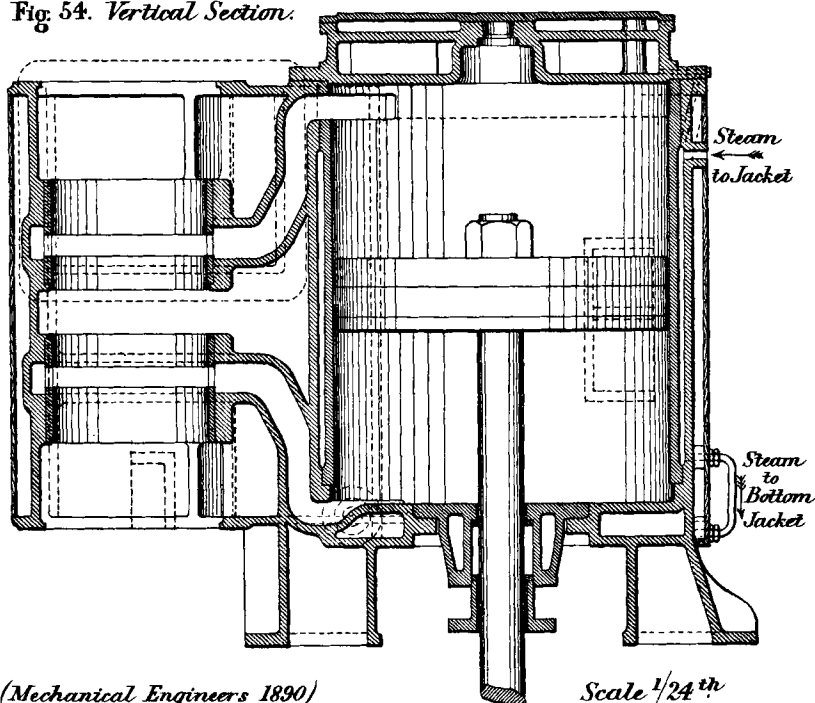


Fig. 52. *Vertical Section.*



(Mechanical Engineers 1890)

Inches 12 6 0 1 2 3 4 5 6 7 Feet. Scale $\frac{1}{24}^{th}$

*Intermediate Cylinder of the "Tartar."*Fig 53. *Sectional Plan.*Fig 54. *Vertical Section.*

(Mechanical Engineers 1890)

Inches

12 6 0 1 2 3 4 5 6 7

Scale $\frac{1}{24}$ "

Feet

MARINE-ENGINE TRIALS. *Plate 112.*
Low-Pressure Cylinder of the "Tartar."

Fig. 55.

Sectional Plan.

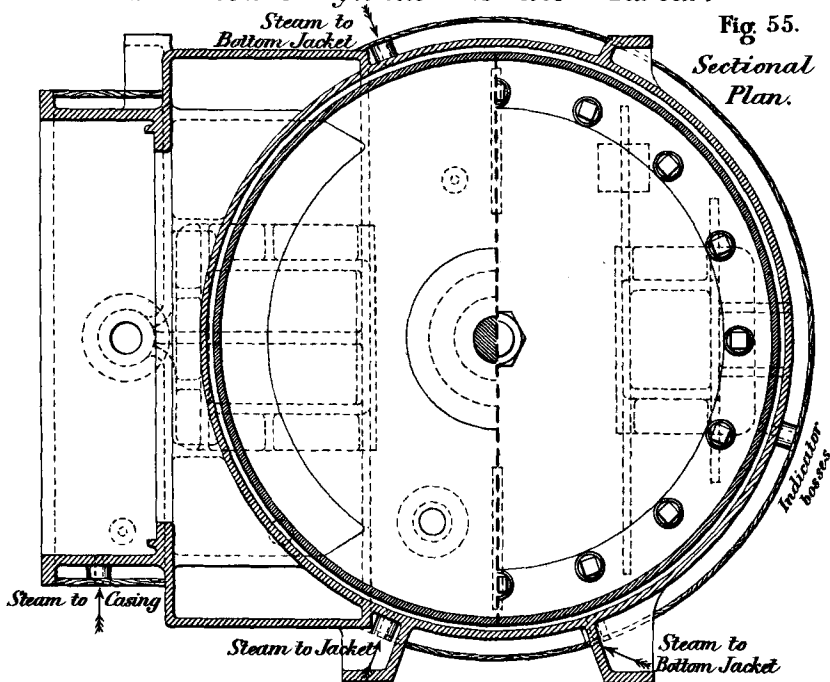
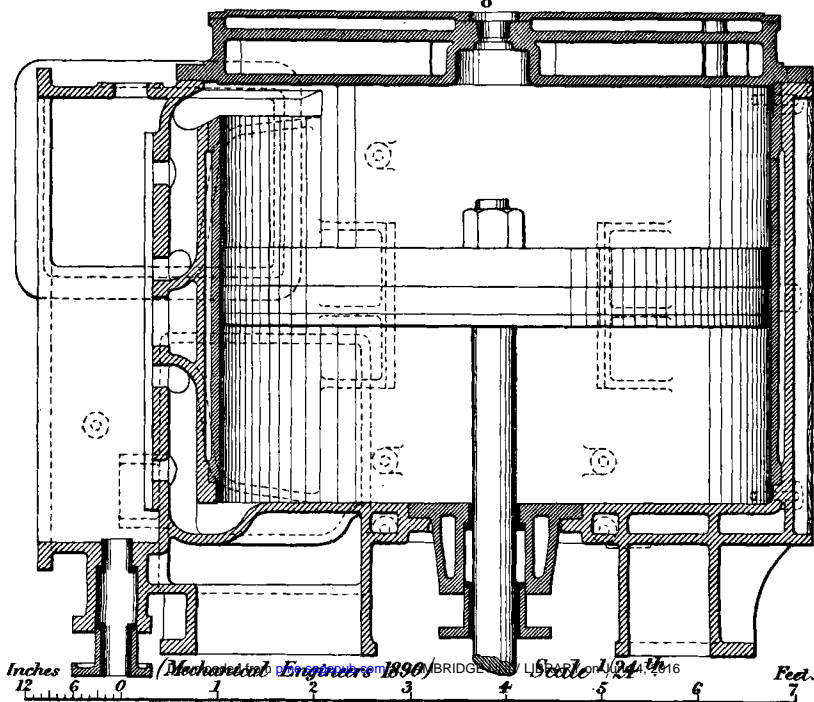


Fig. 56. *Vertical Section.*



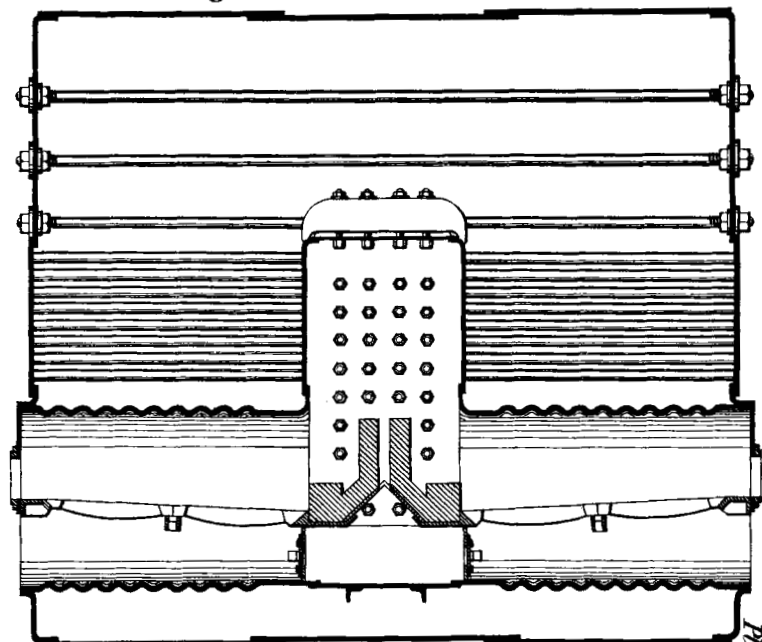
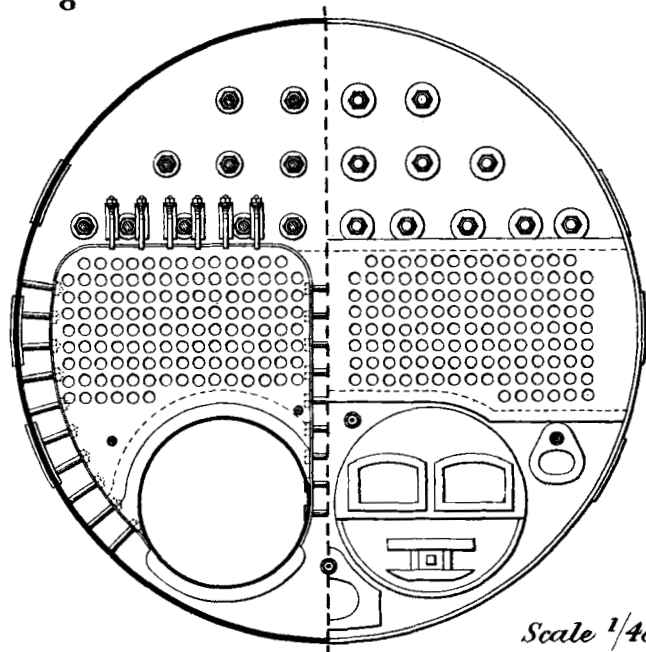
MARINE-ENGINE TRIALS.

Boilers of the "Tartar."

Plate 113.

Fig 57. *Transverse Section and End Elevation.*

Fig 58. *Longitudinal Section.*



Scale 1/48th

Inches 12 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 Feet.

(Mechanical Engineers 1890)

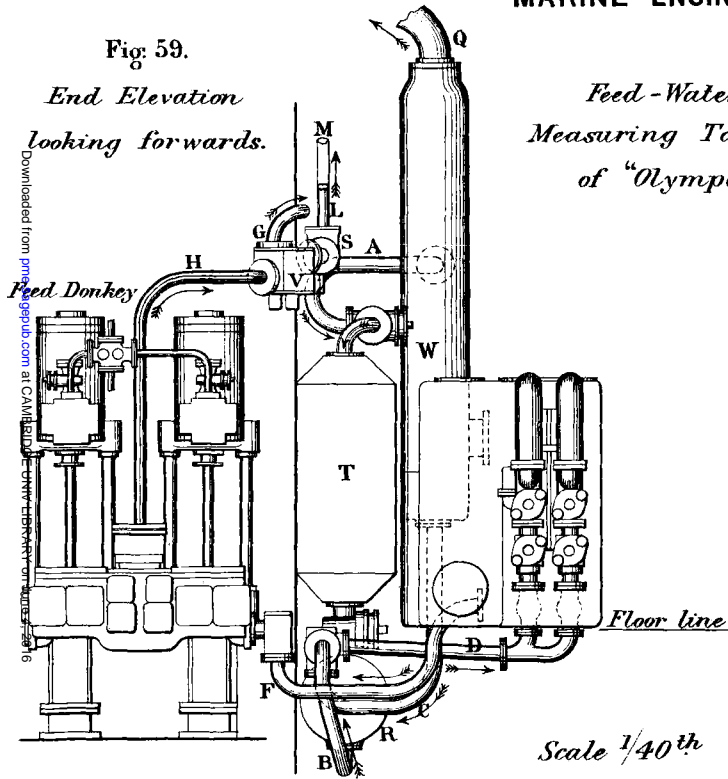
Plate 113.

MARINE-ENGINE TRIALS.

Plate 114.

Fig. 59.

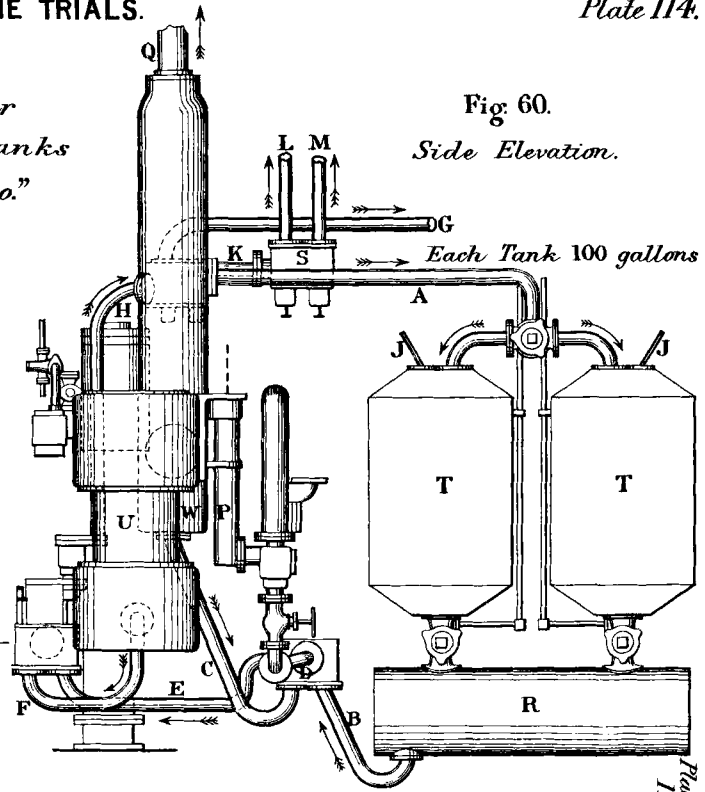
End Elevation
looking forwards.



Feed-Water
Measuring Tanks
of "Olympo."

Fig. 60.

Side Elevation.



Each Tank 100 gallons

Scale $\frac{1}{40}^{th}$

Inches 12 6 0 1 2 3 4 5 6 7 8 9 10 Feet.

(Mechanical Engineers 1890)

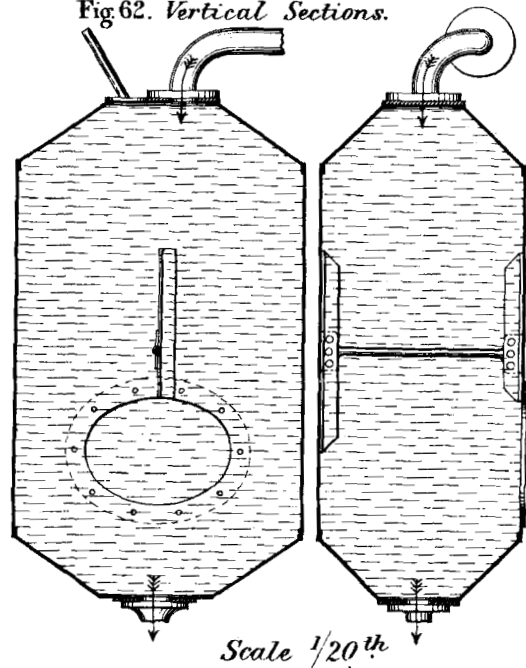
Plate 114.

MARINE-ENGINE TRIALS.

Plate 115.

Feed-Water Measuring Tanks of "Olympo."

Fig. 62. Vertical Sections.



(Mechanical Engineers 1890)

Fig. 61. Plan

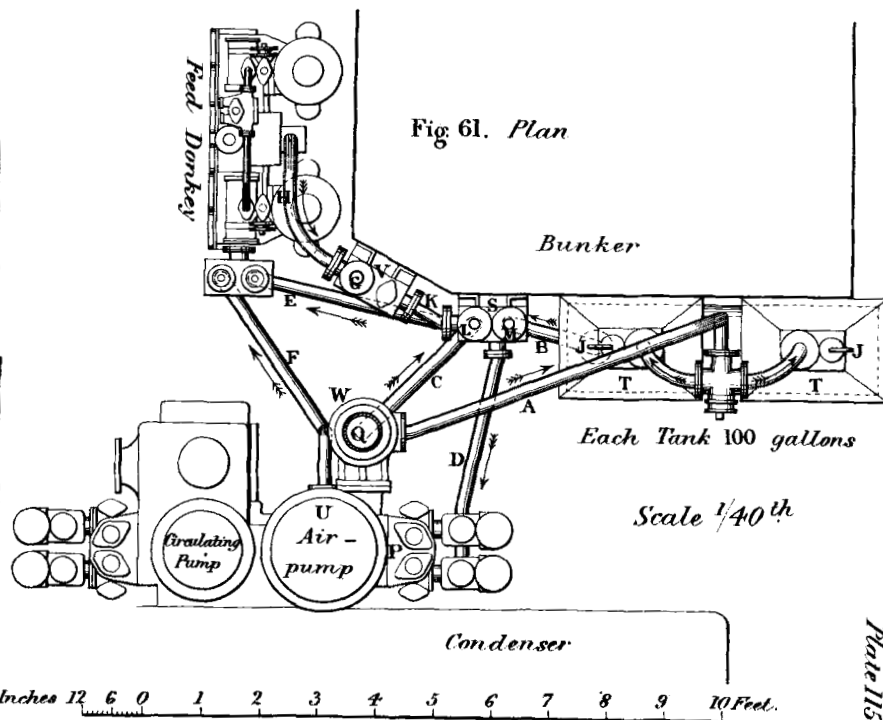


Plate 115.

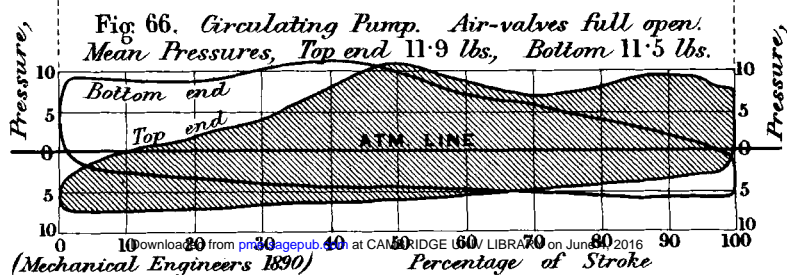
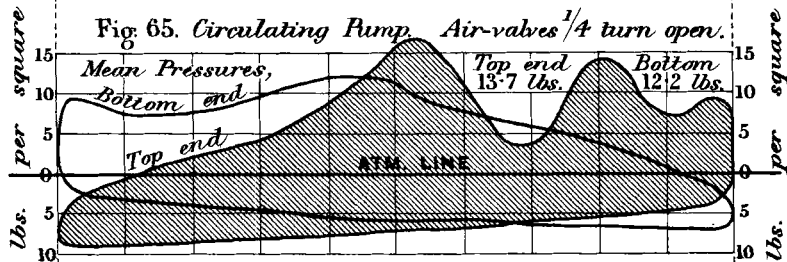
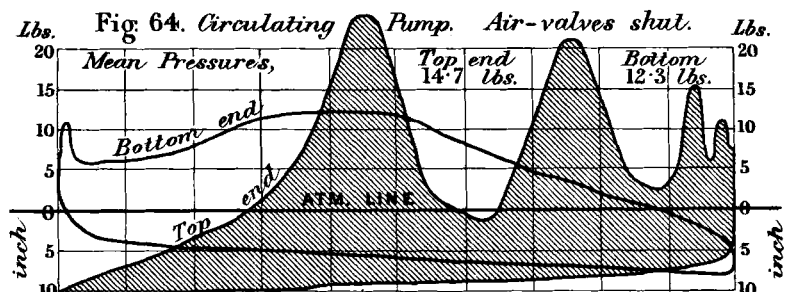
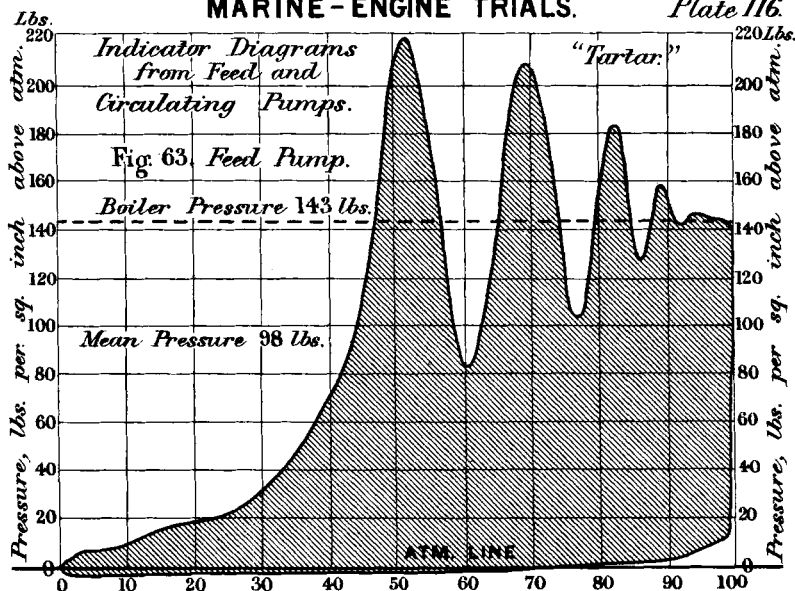


Fig. 67.

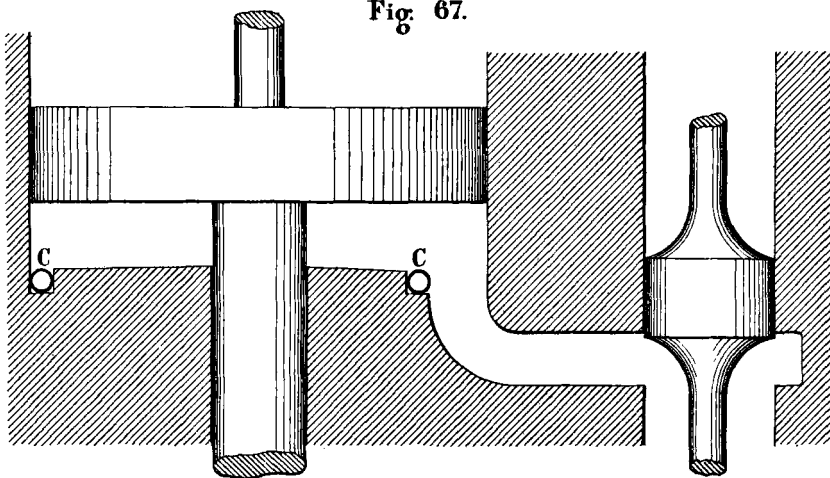


Fig. 68. Indicator diagram with water in cylinder.

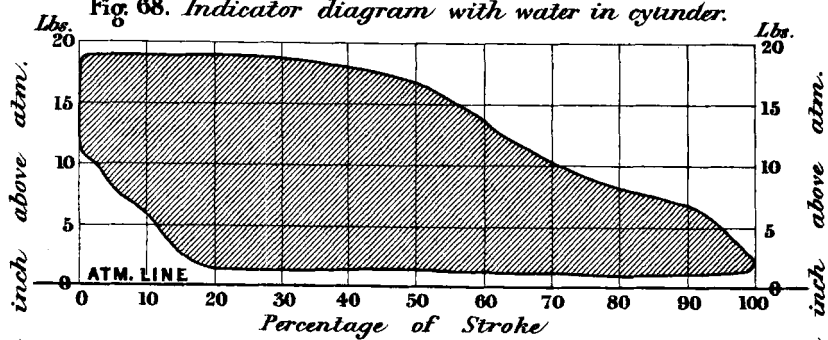


Fig. 69. Indicator diagram with cylinder dry.

