INSTITUTE OF MARINE ENGINEERS

INCORPORATED.

SESSION 1916-17.

President : SIR JAMES MILLS, K.C.M.G.

Determination of Steam Engine and Boiler Efficiency.

Engine Testing.

BY MR. G. JAMES WELLS (Member).

**Tuesday, May* 2, 1916.

(1) A mechanical engineer must always supply his clients with a material solution of the problems that are submitted to him, and it follows that the client will require some proof that the solution obtained is satisfactory before payment is made for the services rendered. In this way some generally acceptable methods have to be devised in order that the efficiency of the plant may be measured with the degree of accuracy commensurate with the interests involved.

These tests may be conveniently divided into classes depending upon the objects sought:—

(1) Tests for purely commercial reasons.

(2) Tests for purely scientific purposes—including educational.

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* Arranged to be read on this date but postponed, on account of the small attendance, till re-opening of Session in September, subsequently fixed for October 10th.—J.A.

(3) Tests in which both these objects are more or less in view.

The members of this Institution are most closely interested in marine engines, and have probably assisted in the carrying out of tests belonging to the first of the above classes. These tests are commonly termed trial trips, and the objects mostly in view will be the determination of the speed and coal consumption and to compare the results obtained with the requirements of the specification. If these conditions are complied with, then there is an end to the investigation, but if otherwise, then a closer examination of the results obtained will have to be made and possibly additional trials made in order to discover the reasons for the failure. This risk (usually as a matter of prudence) leads to the third class of tests specified above, so that the delay and costs of the additional tests may be avoided, whilst if the specification is complied with, the additional data obtained is always useful to the builders for use in developing later designs.

(2) The second class of tests are those designed for scientific purposes, or for educational reasons, and consequently need not further engage our attention.

(3) Our President, Sir A. Denny, in the course of his address, called *attention to the wealth of material that the members of this Institution must possess on the subject of performance of engines and boilers working under the conditions imposed by business, and suggested that they should spare some of their time in arranging in order some of this store for the benefit of the designer, who too frequently has little experience of the actual working conditions at sea except by hearsay. It is hoped, therefore, that a fresh examination of the subject would help some of the members to meet this call, and serve to suggest the lines along which such records would prove useful.

(4) The class of tests which will have to be considered belong to the third, because it will be at once obvious that the ordinary work of the ship cannot be interfered with, so that the conditions of running will be strictly those imposed by commercial requirements.

(5) The object of such trials as now contemplated is to find the efficiency of the plant as a whole, also that of each organ, so

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* Pages 372-374. Transactions Inst. Mar. Engineers, April, 1915. Vol. XXVI.

that the possible places for improvement may be at once detected. The efficiency may be defined as the ratio of the heat utilised to the heat supplied. Fundamentally, therefore, a test becomes in the main the measurement of quantities of heat. The engineer in charge is supplied with fuel, either solid or liquid, and it is the latent heat of this fuel that has to be accounted for, and each item of waste valued, and separated into groups—avoidable and the inevitable.

(6) The store of heat locked up in the fuel may be estimated very closely if the chemical composition be known, or it may be determined experimentally by means of a suitable calorimeter. This quantity is usually expressed as so many units per pound of fuel. In order to liberate this heat, an apparatus must be provided by the engineer known as the furnace, and so the processes of combustion must be examined and the exact quantity of heat liberated must if possible be measured and the initial waste due to the imperfect action of the furnace and the waste incurred determined. The wastes being determined, the knowledge obtained must be used for the purposes of improving the conditions of combustion, and so reducing the total losses to a minimum.

(7) The losses will be due to incomplete combustion, and the loss of the heat carried away by the products of combustion into the uptake. To measure these quantities it will be necessary to take samples of the flue gases and to carefully weigh the ashes, and from the results some very valuable deductions can be made. To illustrate this section, reference should be made to Appendix A, in which an extract is made from an analysis of the results obtained upon a locomotive boiler made by L. H. Fry*. This table of results should be carefully studied, for many points are very clearly shown that relate to the behaviour of a furnace under such widely varying conditions as are implied by the combustion of fuel at rates increasing from 30 up to 140 pounds per square foot of grate. From these results it will be noticed that the efficiency of the furnace considered as the mechanism for the liberation of heat units from the fuel, varies from 93·86 down to 55·27 per cent. The reason for this appalling loss at the higher rates of combustion is at once detected in the large quantity of fuel that escapes unburnt. The next point that comes to light quite clearly, is the very small amount of CO present at any of the tests, showing that as far as the reduction of the gases was concerned there was little to

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* See Proc. Inst. Mech. Engineers, p. 269.—1908.

complain about. This result was due to the very efficient mixing of the air with the gases at the proper place, and although there was this efficient mixture, a glance shows that the excess air present, steadily decreased as the rate of combustion increased, showing the advantage of forced combustion in obtaining good mixing of the air with the gases formed.

Another fact that comes out of these tests proves that the boiler when considered as the mechanism for the transference of the liberated heat to the water, that is, its efficiency, is actually constant throughout. Hence these tests may be used as a model to show the knowledge that can be gleaned from the results of analysing the gases in the uptake coupled with the weight of the ashes and an analysis of the fuel. The only serious source of loss as regards the boiler, is that due to radiation, which if carefully clothed, ought not to exceed from two to three per cent.

(8) To measure these quantities, the gases must be sampled at intervals from the uptake as near as possible to the boiler ends, and for this purpose some form of Orsat Apparatus (Fig. 1) is suitable, whilst the analysis of the fuel may be done on shore, and its calorific value determined by means of a calorimeter. This last is an operation which our Institution has dealt with in such a practical manner that nothing more need be said on this occasion. It might be useful if some tests could be arranged so that the process of dealing with the flue gases could be taken up for the benefit of those members who have not had experience in this class of work. One other measurement is necessary in order to obtain the actual heat utilised in the evaporation of the feed, that is the amount of water carried over by the steam, and for this purpose a throttling calorimeter, or better still a separating (Fig. 2) calorimeter, is necessary. This instrument is very easy to manipulate and the calculations required to determine the wetness quite simple in character.

(9) For a complete balance sheet to be drawn up the losses in the steam main should be determined, and this would require the wetness to be determined again at the engine stop valve; supplemented by the weighing of the water collected in the separtor if one is fixed. It is somewhat remarkable that the losses in the steam mains are so generally ignored, frequently they are serious, and whilst lagging is very generally carried out so far as regards the pipes, yet valve bodies are often bare whilst the flanges are almost always so; why should this be? It is quite simple to cover them and every bare metal surface is

so far as heat leakage is concerned, like a cinder sieve, very porous to the flow of heat.

(10) Engine testing is a much more difficult undertaking as there are so many more openings for losses and much increased trouble incurred in their measurement. If the thermo-dynamics of the problem are referred to at the commencement, it will be more likely that the problem to be dealt with will be better appreciated, and time saved in explanations. The definition of efficiency already given holds good for the engine, and it follows that the quantities to be measured are (1) the heat supplied, and (2) the heat utilised, and, as before, these quantities so obtained will require correcting for various reasons.

(11) A few words must be devoted to the Carnot Cycle, possibly the best abused and least appreciated portion of this subject. This invention was a most valuable one, because it deals with that cycle which of all others is the most efficient conceivable. It therefore lays down precisely the utmost limits of perfection possible; and in consequence it may be inferred the exact places at which waste must incur, and therefore shows when it is useless to attempt to avoid them. From this cycle, Carnot showed that no matter what the nature of the working agent the efficiency remains the same; that the only method of heating a substance without waste is to supply the heat required at the highest temperature possible; and that if the temperature of the substance must be altered then the change must take place by the process of adiabatic expansion or compression, or waste of heat will take place. The self-styled practical man has written and spoken much nonsense about this cycle, just as in the same way it is easy to deride any other counsel of perfection such as honesty. Absolute honesty is no more attainable under present circumstances than the Carnot cycle, but the world would be the poorer if the ideal were abandoned in the same way, as some would banish the cycle under consideration.

(12) The best way to demonstrate the truth of the first statement is to calculate the work done for various substances under similar circumstances. In Appendix B the method of obtaining the following formula is given, which gives the work available per pound of the working fluid for a fall of temperature of one degree when using the appropriate constants for each individual substance considered.

$$\frac{144.dp\ (V-w)}{L\ J} = \frac{1}{T}$$

The following results of the use of this formula are quoted from Prof. Dalbys' book "Steam Power," page 157, and conclusively proves the claim made.

MOTIVE POWER OBTAINABLE PER POUND OF WORKING SUBSTANCE FOR A FALL OF TEMPERATURE FROM 30° to 29° C.

	dp.	V—w.	L.	Work done.
Steam	0·03507	528·00	579·6	0·003286
S.O.$_2$	2·1276	1·346	89·77	0·003281
N.H.$_4$	4·995	1·845	1327·0	0·003432
Ether	0·4539	6·406	90·86	0·003291
Alcohol	0·08355	92·14	240·5	0·003292
Chloroform	0·1990	10·30	64·10	0·003289
Carbon bisulphide	0·3058	9·093	86·88	0·003292
Carbon tetrachloride	0·1180	13·62	50·21	0·003293
Aceton	0·2282	18·97	135·5	0·003286

(13) The conditions for the reception or rejection of heat may be made clearer by the employment of the water wheel analogy. The energy available is that due to the water falling into the tail-race, and this to be a maximum requires (Fig. 3) that the water shall fall from the surface level of the water down to the tail-race. To achieve this, it is obvious that the water must pass on to the wheel in an exceedingly thin sheet, otherwise a part of the fall *must* be lost. Again the water must remain on the wheel until it has descended to the exact level of the tail-race when its total fall will have been utilized. If the water supply is, say six inches or more deep, then a portion of the fall will have been lost, similarly owing to the circular shape of the wheel, much of the water, if not all, will be spilled (Fig. 4) before it reaches the tail-race, thus more energy will be lost to the wheel. Now, if in these sentences, for the words "fall" or "loss of head" and "water-wheel," the words "fall of temperature," and a "heat-engine" are substituted, it will be at once realised that the reception of heat must take place at the highest limit of temperature, and conversely the rejection of heat must take place at the lower limit of temperature. But if heat is received upon a rising temperature, loss must take place, and equally so if rejected on a falling temperature.

(14) Again, if the water enters, or leaves the wheel in a state of *turbulence*, then this energy represents so much of the head uselessly expended; so far as urging the wheel forward is concerned; all the water splashed out of the bucket are illustrations of non-adiabatic conditions of expansion or compression; of

radiation; and conduction losses in the heat engine; and serve to show how far-reaching was the discovery and enunciation of Carnot's Cycle.

(15) This cycle is clearly quite unattainable in practice, and the nearest approach that so far has been discovered, is the cycle described by Rankine; and this is now generally used as the standard of reference. By ascertaining the actual amount of heat usefully converted into work, and comparing that possible if the Rankine cycle were rigidly adhered to, a reasonable figure of excellence is at once possible, and serves as a basis of comparison between different engines.

(16) The Rankine cycle is applicable to vapour engines, which includes refrigerators of the compression type, and is the closest possible approach to the Carnot when the practical limitations are considered. The indicator diagrams shown in Fig. 5 show both the Carnot and the Rankine for the purposes of comparison. The latter will be seen to differ very slightly from the usual P.V. diagram. In Fig. 5 both cycles are shown on the Theta-Phi chart, and at once reveals the differences between the two cycles. This consists in the manner in which the heat supply and compression part of the cycle is carried out. The heat is supplied to the feed water on a rising temperature instead of wholly at the upper limit of temperature, also in the fact that it is practically impossible to compress adiabatically a mixture of vapour and water, both of these points are clearly shown by the diagrams. Corresponding points in the respective diagrams are marked with the same letters to facilitate comparison.

(17) The effy. can be easily deduced from the diagram of the Carnot cycle to be

$$= \frac{T_1 - T_2}{T_1};$$

but for the Rankine cycle the expression is a little more complex, and may be stated thus:—

$$\frac{\text{Area ABCK of diagram}}{\text{Area aABCc (for saturated steam)}};$$

or in the case of superheated steam

$$\frac{\text{The area ABCLG}}{\text{Area aABCLg}};$$

or stated so that these quantities may be taken from the steam tables. An example is given in the Appendix D of the calculations involved in actual work. When the steam is wet on admission then the heat diagram must be modified as shown in Fig. 5.

(18) Next in order of importance is the tracing of losses of heat as indicated by the Theta-Phi diagram. Some of the more important of these are shown on the series of diagrams in Fig. 5 and the corresponding P.V. cards are also shown similar points, having similar letters. Small ports, constricted port passages, small steam pipes, slow opening of port to steam, port opening by valve insufficient in area, &c., all result in wiredrawing and the heat loss due to this cause is shown by the area between the horizontal line BC and the line Cc.

Losses due to deviations from adiabatic expansion is indicated by the differences between the vertical line Cc and the line Ec. The losses here are chiefly due to the exchanges of heat between the cylinder walls and the steam, all of which take place on rising or falling temperatures. This line will show what the jackets are doing if any are fitted, also the effects of superheating may be traced.

The loss due to cutting off the toe of the diagram is shown by the line FK, or MFK (Fig. 5) according to the conditions of working whilst finally the loss due to the actual method of compression is by the closing line of the diagram. These points will be referred to again later.

(19) The value of the temp-entropy diagram will be apparent now even if it has previously escaped attention, hence the method of tracing it must be sketched briefly. The data required is the mean P.V. card taken (Figs. 6, 7, 8 and 9) during the test, which must be made whilst the load on the engines is kept as constant as the circumstances will allow. As regards the engines, the exact dimensions of the cylinders must be known as well as the clearance volumes, and the dryness fraction in each cylinder at any point in the expansion period. To obtain the dryness fraction the weight of steam passing through the engine per stroke must be found, and this quantity sometimes called the "cylinder feed" compared with the indicated weight of steam present per indicator card will give the information wanted. From the data thus obtained the indicator card may be transferred to the heat chart without difficulty. When the transference is complete the area of the two diagrams should be the same; the area of the P.V. card is the work done per *stroke*, whilst that from the corresponding heat diagram is the work done per *pound* of steam passing through the engine.

(20) It may be objected that to obtain so much data as that suggested would interfere too much with the actual working of the ship at sea to be possible, and if correct this would be a

very weighty reason against making the attempt. But the answer to this point is the very simple one that it has been done without any hindrance by the ordinary staff. The most notable instance in which the results have been collected is that recorded in the Proceedings, Institution of Mechanical Engineers for 1881, pp. 200, et. seq. The steamer in question was the well-known *Iona*, tested by the Research Committee of that Institution; the Chief Engineer, Mr. J. F. Brown, afterwards made a test at sea over a period of nine days, because the results obtained by the Committees' experts seemed to be inferior to those he had obtained at sea previously. Members interested in this work of testing would do well to read through these reports, and the discussions that followed as they contain much valuable experience in the details of the subject of engine performance.

(21) In making such a test as has been contemplated, provision must be made for the record of the following points in the boiler room. The weight of coal burned and the rate of consumption. The level of the water in the gauge glasses, the weight of the feed pumped together with notes relating to the times and the amount of supplementary feed water used. The temperatures of the air; feed water; and uptake, should each be noted as well as the air pressures in the uptake and stokehold. Samples of the flue gases should be collected in such a way as to give the average condition of the products of combustion. The Committee found the method of weighing the coal delivered to the foot-plate by means of baskets and a spring balance quite satisfactory whilst for the purpose of measuring the actual weight of feed water, two tanks were fitted in the pipe system, so that the water from the hotwell passed alternatively into each of them, thus one tank was being filled whilst the second was being emptied by the feed pump. The arrangements of these tanks is shown in Fig. 10 which has been copied from the Committee's report. The reading of the thermometers offers no special difficulty; but the taking and subsequent analysis of the flue gases requires an operator who has done the work before, otherwise the gas may probably prove to be funny stuff. The weight of the ashes can easily be weighed by a basket and spring balance like the coals.

(22) In the engine room the following work would have to be done:—Indicator diagrams from the cylinders taken simultaneously from both ends; all gauges; rev. counters; barometer; inlet and outlet temperatures of the circulating water; read at

intervals; samples of the steam tested at the boiler and engine stop valves for the amount of moisture present; the weight of water from the jacket drains as well as the separator in the steam main noted. As the engine power being developed would be practically uniform these observations noted every 30 minutes would probably suffice both in the engine and boiler-rooms. All the observations should be entered in the log of the trial with the time at which they were made and afterwards plotted upon a time base chart such as shown in Fig. 11 so that any errors may be at once detected, and if possible, corrected and allowed for when deducing the actual performance of the engines.

(23) From the data so collected the several quantities of heat required for the determination of the efficiency of the plant may be found after the manner already indicated in the previous paragraphs. The chief requisite for making such a test is organisation, each man to have certain duties allotted to him which he is capable of doing without too great a rush. The engineer in charge should give the signal first to stand-by, the second signal a minute later to make and record his observations. Thus each man can get close to his instruments and looking at them may have actually read two or three of them and only need to watch them so that at the second signal he starts writing them down and then moves off to the other points where observations have to be made.

To illustrate how a testing plant may be arranged so that one man alone can make most of the observations required, as well as to see that the supplementary work required is done at the proper time and in the proper manner; the arrangement of the plant used by the late Mr. P. W. Willans* shown in Fig. 12 and will serve to show how, if the details are carefully thought out first, the work involved is nothing like so great as one is apt to think before the business has been considered.

(24) It is probably true that the greatest help in such a matter as engine-testing, &c., is a practical demonstration; and by the courtesy of the authorities of East London College, it is possible to arrange for such of the members as may wish an opportunity of witnessing a test upon a stationary engine, and see most of the instruments mentioned actually in use. As the opportunities for observing are much reduced if a large party assembles, it has been proposed that there might be two or more demonstrations depending upon the number desiring to take part.

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* See Proc. Inst. C.E., p. 17—Vol. CXIV.

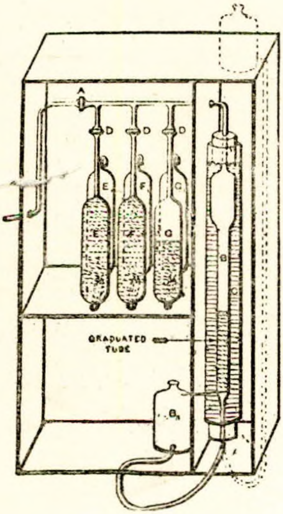


Fig. 1.

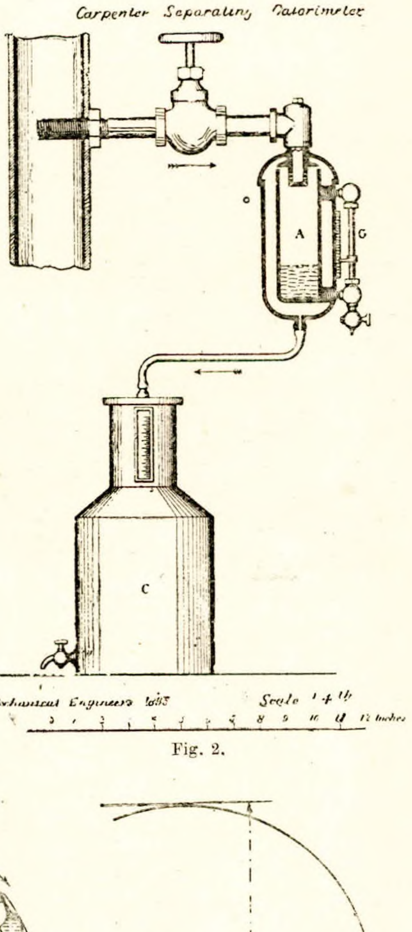


Fig. 2.

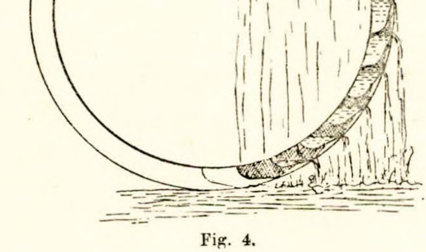


Fig. 4.

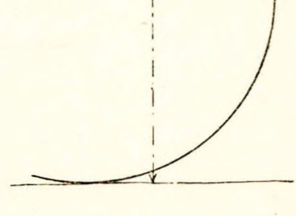
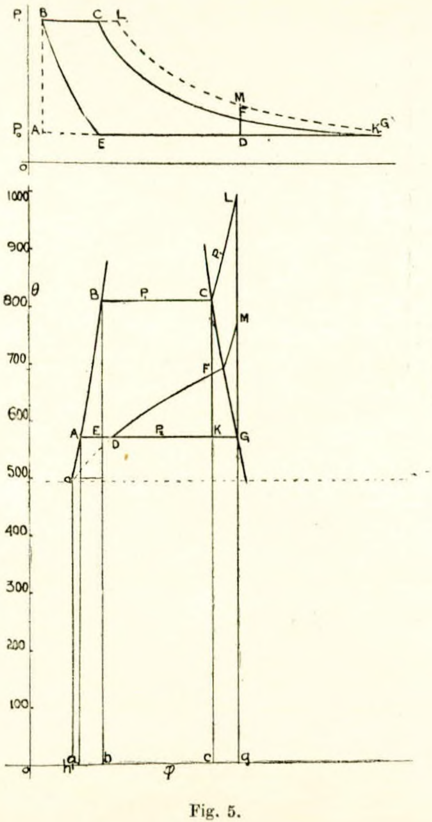


Fig. 3.


P₁
B
C
L
M
F
P₀
A
E
D
K
G
o
1000
900
800
700
600
500
400
300
200
100
θ
B
P₁
C
Q
L
M
F
A
E
D
P₀
K
G
a
b
c
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o
φ

Fig. 5.

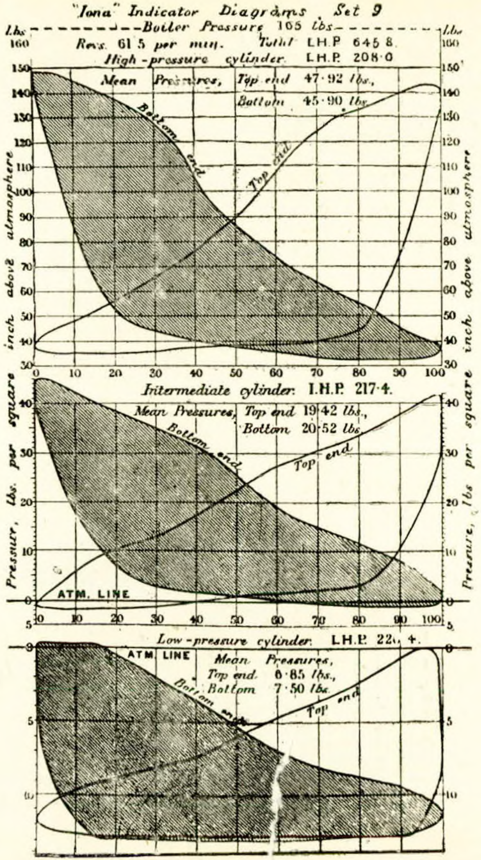

"Iona" Indicator Diagrams, Set 9
Lbs
Boiler Pressure 105 lbs
Lbs
160
Revs. 61·5 per min.
Total I.H.P. 645·8.
High-pressure cylinder. I.H.P. 208·0
Mean Pressures, Top end 47·92 lbs.,
Bottom 45·90 lbs.
Bottom end
Top end
150
140
130
120
110
100
90
80
70
60
50
40
30
0
10
20
30
40
50
60
70
80
90
100
Pressure, lbs. per square inch above atmosphere
Intermediate cylinder. I.H.P. 217·4.
Mean Pressures, Top end 19·42 lbs.,
Bottom 20·52 lbs.
Bottom end
Top end
ATM. LINE
40
30
20
10
0
5
Low-pressure cylinder. I.H.P. 22[illegible] 4.
ATM. LINE
Mean Pressures,
Top end 6·85 lbs.,
Bottom 7·50 lbs.
Bottom end
Top end
0
5
10

Fig. 6.

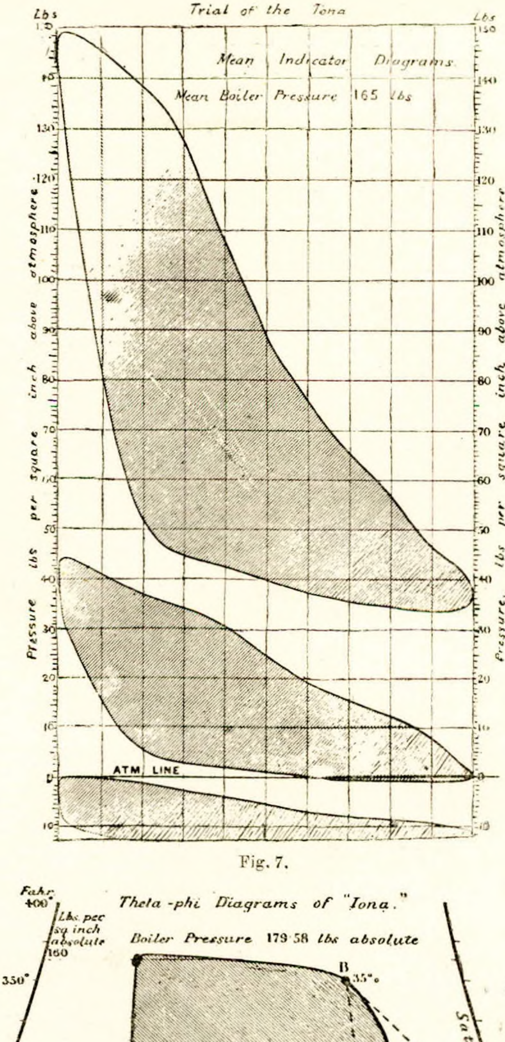

Trial of the Iona
Mean Indicator Diagrams.
Mean Boiler Pressure 165 lbs
Lbs
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
10
Pressure lbs per square inch above atmosphere
ATM LINE

Fig. 7.

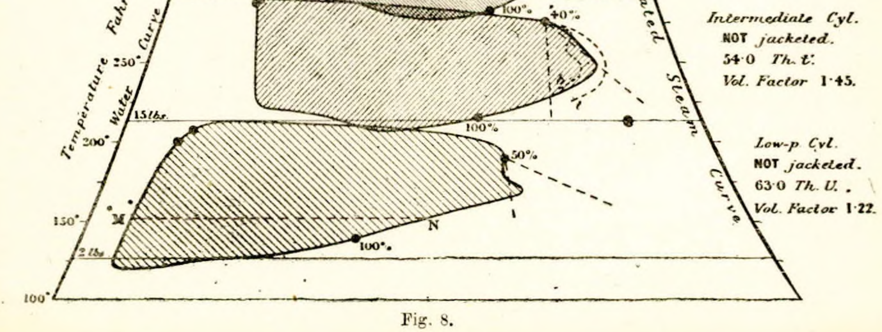

Fahr. 400°
Theta-phi Diagrams of "Iona."
Lbs per sq inch absolute 160
Boiler Pressure 179·58 lbs absolute
This square represents TEN British Thermal Units.
350°
300°
60 lbs.
250°
15 lbs.
200°
150°
2 lbs
100°
Temperature Fahrenheit
Water Curve
Saturated Steam Curve
B
35%
R
100%
40%
100%
50%
M
N
100%
High-p. Cyl. Jacketed.
44·3 Th. U.
Vol. Factor ·1·63.
Intermediate Cyl.
NOT jacketed.
54·0 Th. U.
Vol. Factor 1·45.
Low-p. Cyl.
NOT jacketed.
63·0 Th. U.
Vol. Factor 1·22.

Fig. 8.

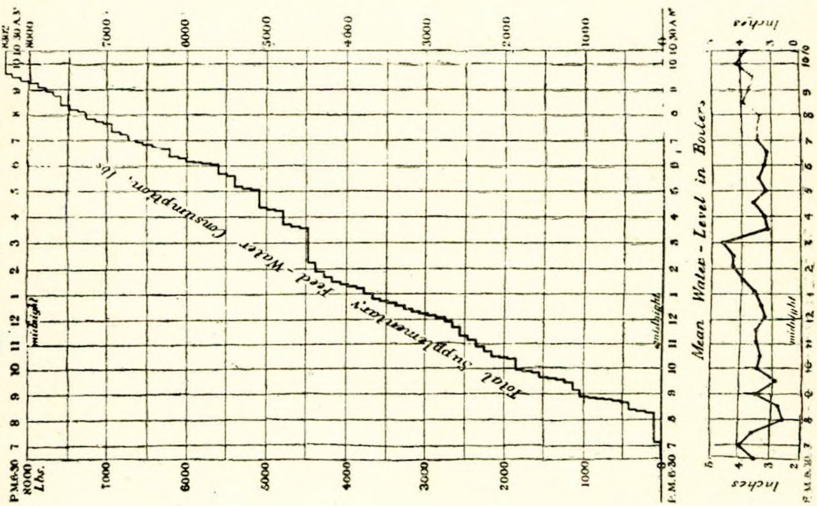

Trial of the "Iona"
Supplementary Feed Water.
Total Supplementary Feed-Water Consumption, lbs.
Mean Water-Level in Boilers
Lbs.
8000
7000
6000
5000
4000
3000
2000
1000
0
P.M.6.30 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 10.30 A.M.
midnight
Inches
5
4
3
2
0

Fig. 9.

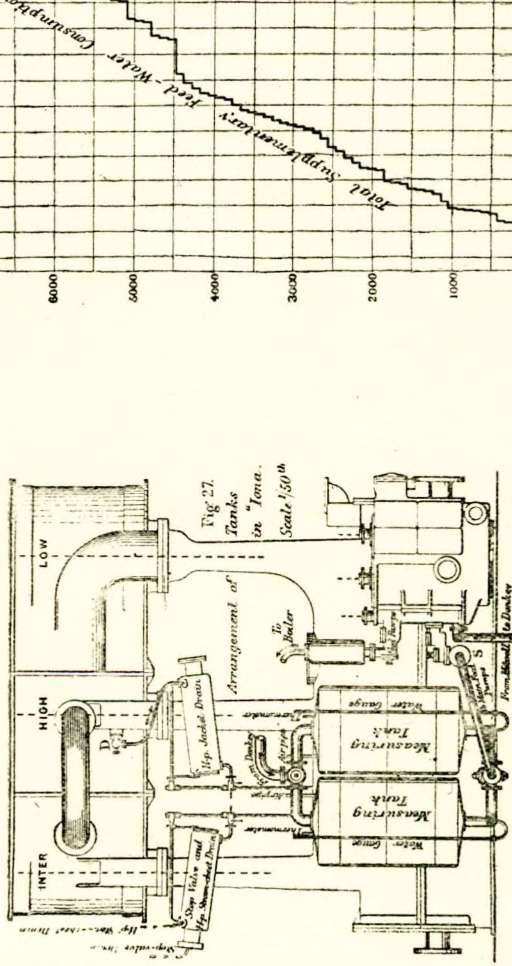

LOW
HIGH
INTER
Fig. 27.
Arrangement of Tanks in "Iona."
Scale 1/50th
To Boiler
Feed Pumps
From Hotwell
to Donkey
Main Feed Pumps
S
D
Hp. Jacket Drain
Water Gauge
Thermometer
Measuring Tank
Measuring Tank
Water Gauge
Thermometer
From Donkey
Air-pipe
Stop Valve and Hp. Steam-chest Drain
Hp. Steam-chest Drain
Stop-valve Drain

Fig. 10.

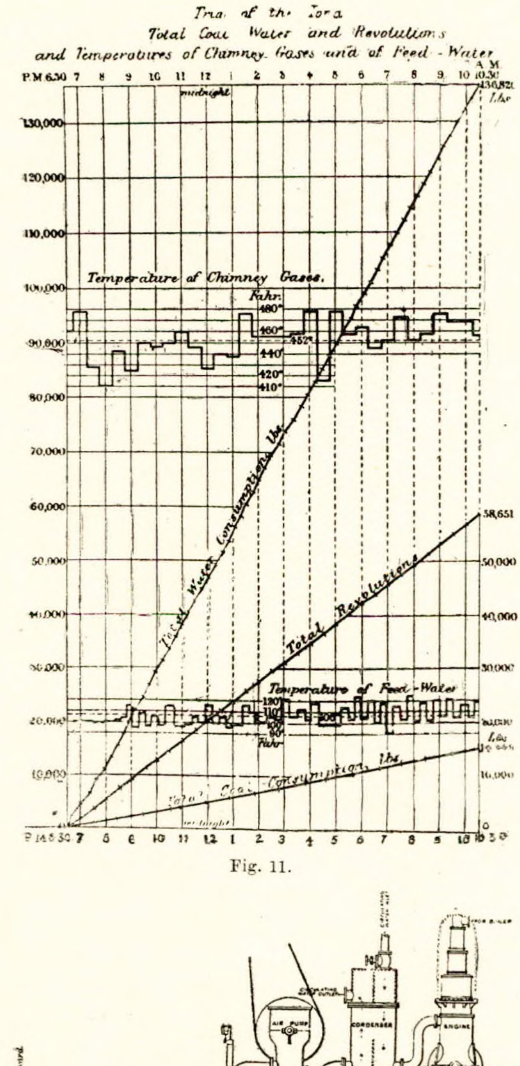

Trial of the Iona
Total Coal Water and Revolutions
and Temperatures of Chimney Gases and of Feed - Water
P.M. 6.30 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 10.30 A.M.
midnight
136,820 lbs
130,000
120,000
110,000
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
Temperature of Chimney Gases.
Fahr.
480°
460°
452°
440°
420°
410°
Total Water Consumption lbs
Total Revolutions
58,651
50,000
40,000
30,000
20,000
10,000
0
Temperature of Feed-Water
120°
110°
100°
90°
Fahr.
lbs
Total Coal Consumption lbs.
midnight
P.M. 6.30 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 10.30

Fig. 11.

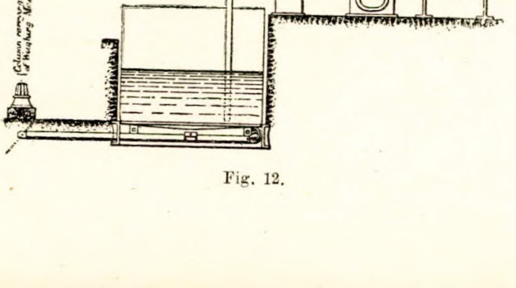

AIR PUMP
CONDENSER
ENGINE
Column carrying steel yard of Weighing Machine

Fig. 12.

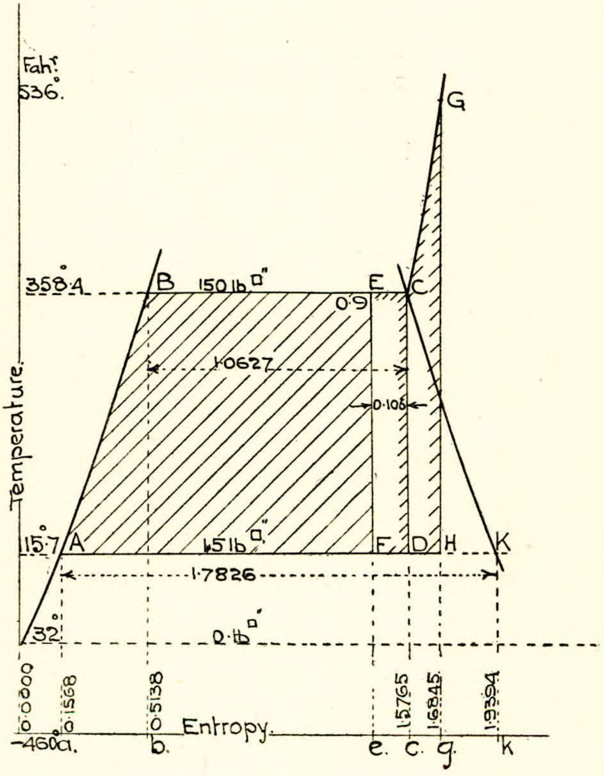

Fah.°
536°.
358°.4
B
150 lb □"
E
C
G
0·9
1·0627
0·106
Temperature.
115°.7
A
5 lb □"
F
D
H
K
1·7826
32°
0 lb □"
0·0000
0·1568
0·5138
1·5765
1·6845
1·9394
Entropy.
-460° a.
b.
e.
c.
g.
k.

Fig. 13.

APPENDIX A.

Rate of Firing in pounds of dry coal per sq. foot of Grate per hour :—

	30	50	70	90	110	130	140
Loss by formation of CO. ..	0·25	0·40	0·60	0·80	0·90	1·10	1·20
,, in Products of Combustion	18·26	15·73	14·03	12·80	11·92	11·15	10·96
,, by unburnt Coal	5·89	16·77	25·20	31·80	37·10	41·55	43·53
,, by Radiation..	3·60	3·20	2·87	2·60	2·38	2·20	2·11
Heat of Evaporation	72·00	63·90	57·30	52·00	47·60	44·00	42·20
	100·00	100·00	100·00	100·00	100·00	100·00	100·00
Smoke Box Tempes. Fahr. ..	528°	553°	579°	604°	630°	655°	668°
Deductions from above.—Furnace :—							
Losses by imperfect Combustion %	6·14	17·17	25·80	32·60	38·00	42·65	44·73
Effy. of Combustion	93·86	82·83	74·20	67·40	62·00	57·34	55·27
		Boiler as an Evaporator.					
Heat absorbed by Heating Surface							
(*a*) of Total Heat of Coal fired %	75·60	67·10	60·17	54·60	49·98	46·20	44·31
(*b*) of Heat produced by Combustion %	80·60	81·00	81·00	81·00	80·60	80·60	80·20
Weight of dry gases per lb. of Coal fired	18·3	14·8	12·6	10·9	9·8	8·8	8·4
Weight of dry gases per lb. of Coal actually fired	19·4	17·8	16·8	16·0	15·5	15·0	14·9
Weight of air actually required per lb. of dry Coal . ..	11·12	11·12	11.12	11·12	11·12	11·12	11·12
Excess air per lb. of dry Coal ..	8·28	6·68	5·68	4·88	4·38	3·88	3·78
,, ,, % ..	42·6	37·8	39·8	30·5	28·3	25·8	25·4
Total Weight of dry Prod. Combustion and Excess Air per sq. foot of grate	549	740	882	981	1,078	1,144	1,176
Vol. of do. at 75° Fahr.—cu. ft.	7,391	9,964	11,875	13,210	14,510	15,400	15,830
Velocity in feet per sec. through tubes	2·05	2·77	3·30	3·67	4·03	4·28	4·40

APPENDIX B.

From the indicator diagram, at some pressure per ℔ per sq. in. (see lantern slide) let the pressure fall a little—dp—there the shaded area is a measure of the work done during the expansion. Let V = the volume of one pound of dry steam at the pressure p, also w = the volume of a pound of water at the same temperature as the steam, there the area shaded, and therefore the work done is

$$= 144 \cdot dp.\ (V - w);\ \text{(foot pounds)}.$$

Let the fall of temperature corresponding to the fall of pressure dp be dT; the latent heat of the steam at the pressure p (℔ per sq. in.) = L; T = the absolute temperature of the steam; also J = the mechanical equivalent of heat: then it is evident that the area shaded may be written—

$$= \frac{L.\ J.\ dT}{T} : \text{ foot pounds :}$$

hence the formula given in paragraph (12)—

$$\frac{144 \cdot dp.\ (V - w)}{L\ J} = \frac{1}{T}$$

where dT is put equal to one degree. This equation is commonly known as Clapeyron's.

Example :—30°C = 86°F. Dr. Grindley has given for CO_2, at the temperature of 86°F, the following values of the physical quantities employed in this formula—8p = 12·895; (V—w) = 0·0206; and L = 27; the units being, foot, pound, and tempr. Fahr., hence—

$$\frac{1}{T} = \frac{144 \times 12{\cdot}895 \times 0{\cdot}0206}{27 \times 778} = 0{\cdot}001823$$

or in pound calories $Ø\ \frac{1}{T} = 0{\cdot}001822 \times \frac{9}{5} = \underline{\underline{0{\cdot}003279}}$

which may be compared with the quantities under the heading work done in the table quoted from Prof. Dalby in paragraph 12.

APPENDIX C.

Analysis of Coal.—Carbon	82·34	per cent
Hydrogen	5·47	,,
Moisture	1·94	,,
Ash	2·90	,,
Nitrogen, Sulphur, Oxygen, &c., by difference ...	7·35	,,
	100·00	

By calculation Calorific value = 14,830 thermal units per lb.
By experiment ,, = 14,890 ,, ,, ,,

Weight of ashes was 430 lbs. and the total weight of coal fired was 14,949 lbs. so that the ashes amounted 2·877 per cent. of the coal fired.

Analysis of Flue Gases—CO_2 12·12 $^\circ/_\circ$ by weight
CO. 0·00 „
O 12·01 „
N. 75·87 „
Dry Air per pound of fuel 24·5 pounds.
Excess „ „ 13·1 „
Heat lost in Dry Gases 16·2 $^\circ/_\circ$
Temperature in Uptake, 30 feet above Boiler = 452° F.

APPENDIX D.

Assume first that the steam is dry saturated, then the Rankine cycle is shown on the diagram (Fig. 13) by the area ABCD, and the Carnot cycle is BCDL. The efficiency on the Carnot cycle would be—

$$= \frac{358{\cdot}4 - 115{\cdot}7}{358{\cdot}4 + 460} = \frac{242{\cdot}7}{818{\cdot}4} = 0{\cdot}2965\,;$$

that is 29·65 per cent. of the heat supplied would be converted into mechanical work.

Upon the Rankine cycle the heat supplied is proportional to the area aABCc; and the heat rejected to the condenser is proportional to the area aADc. From the steam tables the heat supplied per pound of dry steam is = 1199·68 units, and deducting the heat carried into the boiler with the feed, the nett quantity of heat supplied per pound of steam is = 1199·68—83·69 = 1115·99 units; the quantity of heat rejected to the condenser is

$$= 1025{\cdot}38 \times \frac{1{\cdot}5765 - 0{\cdot}1568}{1{\cdot}7826} = \frac{1025{\cdot}38 \times 1{\cdot}4197}{1{\cdot}7826}$$

$$= 812{\cdot}2 \text{ units};$$

and the efficiency is therefore

$$= \frac{1115{\cdot}99 - 812{\cdot}2}{1115{\cdot}99} = \frac{303{\cdot}79}{1115{\cdot}99}$$

$$= 0{\cdot}2722\,;$$

that is 27·22 per cent.

Assume that the steam is 90 per cent. dry at admission, then the cycle will be ABEF; the heat supplied per pound of steam will be reduced by the area eECc; and = 1029·3 units. Similarly the heat rejected will be reduced by the area eFDc, and will be

$$= 1025{\cdot}38 \times \frac{1{\cdot}4197 - 0{\cdot}1063}{1{\cdot}7826}$$

$$= 1025{\cdot}38 \times \frac{1{\cdot}3134}{1{\cdot}7826} = 755{\cdot}6 \text{ units}$$

and the efficiency is now

$$= \frac{1029{\cdot}3 - 755{\cdot}6}{1029{\cdot}3} = \frac{273{\cdot}7}{1029{\cdot}3}$$

$$= 0{\cdot}2659\,;$$

or 26·59 per cent.

Lastly assume that the steam is superheated to 536° Fahr., then the total heat supplied per pound is shown by the area aABCGg, and this is equal to 1213·39 units. The heat rejected is shown by the area aAHg, and this is

$$= 1025{\cdot}38 \times \frac{1{\cdot}6845 - 0{\cdot}1568}{1{\cdot}7826}$$

$$= \frac{1025{\cdot}38 \times 1{\cdot}5277}{1{\cdot}7826} = 920{\cdot}1\,;$$

and the efficiency is now

$$= \frac{1213{\cdot}39 - 920{\cdot}1}{1213{\cdot}39} = \frac{293{\cdot}29}{1213{\cdot}39}$$

$$= 0{\cdot}2417\,;$$

or 24·17 per cent.

Collecting these results—

Initial condition of Steam.	Dry Sat.	90 % Dry.	Superheated 177°·6F.
Efficiency per Rankine's Cycle % ..	27·22	26·59	24·17

Incidentally it may be noticed that the specific heat at constant pressure for the superheat is for this case

$$= \frac{\text{area (c C Gg)}}{\text{rise of temp}^{\text{e}}.} = \frac{97{\cdot}4}{177{\cdot}6} = 0{\cdot}5484\,;$$

BOILER EXPLOSIONS ACTS, 1882 AND 1890.

REPORT OF PRELIMINARY INQUIRY (No. 2387.)

(Conducted by Messrs. S. A. HOUGHTON and P. McNEIL).

Explosion from a Main Steam Pipe.

The explosion occurred about 6.15 a.m. on the 23rd April, 1915, the vessel being then in latitude 19° 17′ N., and longitude 63° 41′ W., during a voyage from New York to Cape Town *via* St. Lucia. Seven men, all natives of India, were killed by the escaping steam; and the second engineer was slightly scalded.

The steam pipe was made of solid-drawn copper, and connected the centre main boiler to a junction-piece on the engines. It was 6 inches in internal diameter and about 14 feet 6 inches long, its shape being as shown on Plate I. A sleeve-piece, 7 inches long and $\frac{5}{16}$ inch thick, was brazed on at the boiler end, and the flanges, which were 13 inches in diameter and 1 inch thick, were also brazed on in the usual manner, and were jointed by twelve $\frac{7}{8}$ inch bolts. The thickness of the pipe varied from ·26 inch to ·32 inch near the sleeve-piece, and at other parts from ·275 inch to ·29 inch. Iron straps $1\frac{1}{8}$ inches broad and $\frac{3}{8}$ inch thick, secured by bolts, were fitted at intervals of about $8\frac{1}{2}$ inches along the pipe, and the weight was taken by a hanging stay, the top end of which rested on a spiral spring in a bracket secured to the deck above. The pipe which exploded was one of those originally fitted in the ship, and was nearly 16 years old.

In June, 1908, a crack $2\frac{1}{4}$ inches long occurred close to the boiler flange whilst the vessel was on a voyage to Bombay. The pipe was taken down, blank flanges were fitted, and on arrival at Bombay it was sent ashore to a firm whose name we have been unable to ascertain. At these works the defective part was cut off and a sleeve-piece brazed on, both flanges were rebrazed and the pipe was afterwards tested by hydraulic pressure to 360 lbs. per square inch. On the vessel's return the pipe was disconnected and again tested to 360 lbs. per square inch in order to be certain that the repairs done in Bombay were satisfactory.

In February, 1913, a crack having again occurred at the neck of the boiler flange, the pipe was sent for repair. A length of

$1\frac{7}{8}$ inches from the sleeve-piece was cut off and the flange rebrazed, making up the shortage by a brass distance-piece; the pipe was then annealed and tested to 360 lbs.

In October, 1913, the steam pipes being due for testing and annealing by the rules of the British Corporation, all the pipes were disconnected, annealed and then tested to 360 lbs.

In addition to the above repairs all the main steam pipes were tested by hydraulic pressure to 360 lbs. per square inch in November, 1907, while in place.

The steam pipe which exploded was inspected at the usual surveys, but more particularly at the times when it was tested, viz., July, 1899, when new; November, 1907, on board; June, 1908, in Bombay; August, 1908, in Birkenhead; February, 1913, in Birkenhead; and October, 1913, in Govan.

The machinery, including the pipes, is also under the control and inspection of the engineer superintendent.

The explosion was of a very violent nature, as the pipe fractured circumferentially just outside the sleeve-piece and was swung by the hanging stay bodily to starboard, drawing the other end out of the engine junction-piece flange and allowing the steam of all the boilers to escape into the stokehold.

As regards the cause of the explosion, we are not quite agreed. One of us believes that the explosion was due to the metal of the pipe in the vicinity of the place of fracture having been excessively overheated and burnt when the sleeve-piece was brazed on, the cracks thus produced being extended by the somewhat considerable movements of the engines until the pipe gave way suddenly. The other is of opinion that the explosion was caused by the metal of the pipe at its junction with the sleeve-piece being over-heated and burnt at some previous date when the pipe was being either repaired or annealed, and, probably, when the sleeve end was fitted. The excessive vibratory movement of the engine, and other stresses due to the working condition, also fatigued the metal locally at the fracture and contributed to the failure.

The steamship is a cargo vessel of the turret type, the gross tonnage being 5,855 tons. The machinery consists of a set of triple expansion engines secured to longitudinal box girders on the tank top, and supplied with steam from three single-ended boilers, placed athwartships, the safety valves of which are loaded to 180 lbs. per square inch. A separate solid-drawn copper pipe is led from each boiler stop valve to a junction-piece jointed to the engine stop valve, as shown in Plate I, and it will be seen that the pipe from the centre boiler is connected to the starboard opening, whilst the starboard boiler pipe is jointed to the centre opening. All the pipes are fitted with iron straps with a view to diminishing the danger of exploding, and the weight is taken by hanging stays connected to spiral springs in brackets bolted to the deck above.

On the 17th April, 1915, the vessel left New York on a voyage to Cape Town, it being intended to call at St. Lucia for bunker coal. All went well till the 22nd April, when a leak was observed in the starboard main steam pipe at the flange connecting it to the engine junction-piece. The leak was on the starboard side and appeared to come from the brazing, but it may be observed that when the pipe was afterwards removed, the defect was found to be a crack in the pipe itself close to the brazing. As a precautionary measure the chief engineer reduced the steam pressure at noon to 155 lbs., and orders were given to inspect the leak at frequent intervals, but no extension was observed. At 4.0 a.m. on the following day the second engineer came on watch, and about 4.30 a.m. he went on top of the boilers to examine the leak which he found unaltered, and he returned to the engine room. The engines were working steadily, and there was no racing or priming. Nothing further happened till 6.15 a.m. when, the pressure being 155 lbs. and the revolutions 55 per minute, a loud explosion occurred over the boilers, and the engine room was filled with steam. The second engineer concluded that the starboard steam pipe had failed and endeavoured to get to the back of the engines to start the donkey feed pump, but was unable to do so on account of the steam and was slightly scalded about the head. The fifth engineer, greaser, and storekeeper, had previously reached the deck, and the serang and a fireman also escaped injury by retreating to the tunnel. In the stokehold, however, the situation was much worse, and when after twenty minutes it was possible to enter it, one tindal, two donkeymen, three firemen, and one trimmer were found to be dead. On examination it was seen that the main steam pipe from the centre boiler had fractured where brazed to the sleeve-piece, and was drawn out of the flange at the engine end; the pipe itself was blown to starboard and was lying on top of the pipe from the starboard boiler. As the steam from all three boilers had escaped into the stokehold, the fires were drawn, and after the port boiler had been pumped up steam was raised in it, the openings on the junction piece to the other boilers being blank flanged. The vessel was then taken to San Juan, Porto Rico, where the necessary repairs were effected.

The exploded pipe was retained on board and we have carefully examined it. The fracture at the sleeve-piece end was of an extremely coarse crystalline character and occurred circumferentially at the end of the sleeve-piece. At the engine-end, where the pipe was drawn out of the flange, the brazing was very defective, the depth to which it held being little more than $\frac{1}{4}$ inch at the fillet for the greater part of the circumference. The question therefore arose whether the pipe did not first fail here, but, apart from the appearance of the fractured end, the position of the pipe after the explosion and the fact that it was bent to starboard and cracked where it was pulled out of the flange showed conclusively that the pipe had first failed at the boiler end.

In dealing with failures of this nature it is necessary to consider strains due to the movement of the engines which in this case was chiefly in a fore and aft direction and was of considerable amount, owing to the engines being secured to fore and aft box girders placed on the tank top. The superintendent engineer supplied particulars of repairs made to those vessels in which this method of construction was adopted, and from this list there is no doubt that it causes a marked want of stiffness in the engines, and the following repairs have had to be effected at this part:—

> August, 1908.—80 rivets renewed in main engine seating. Holding-down bolts tightened and plate washers fitted to take heads.
>
> January, 1909.—110 rivets renewed in main engine seating. All holding-down bolts tightened.
>
> October, 1913.—36 rivets renewed in engine seating.
>
> March, 1914.—Engine room tank top patched. Main engine chocks renewed.
>
> January, 1915.—H.P. and L.P. engine holding-down bolts refitted.

In addition to these special repairs, it was the custom for the fifth engineer to go round the holding-down bolts once a week when at sea, and they were also overhauled in harbour. The last occasion before the explosion that the latter was done was on the 6th and 7th April, when the vessel was in New York. On arrival at San Juan the bolts were again tested, but could be tightened very little.

After the commencement of this inquiry the chief engineer was requested to measure the fore and aft movement of the cylinder tops whilst the vessel was proceeding from London to Dundee. He did so and states that this movement was $\frac{1}{2}$ inch, with the engines running at 61 revolutions, the weather being fair. It is therefore evident that this amount would be considerably exceeded in rough weather, and would be an important element in producing the failures which occurred in the steam pipes. Three of these have been of a normal type, *i.e.*, small cracks which did not develop quickly and consequently allowed precautionary measures to be taken. In the fourth case (which forms the subject of this Inquiry) it is clear that the pipe failed suddenly, as any leak would have been noticed by the second engineer when inspecting that in the starboard boiler pipe less than two hours before the explosion, especially as the pipe was not lagged.

With a view to ascertaining the cause or causes of this peculiarity, the following methods of investigation were adopted:—(i) The pipe was carefully gauged, and (ii) tensile and bend tests, (iii) a chemical analysis of the copper, and (iv) microscopical examinations were made. The results of these are now given.

(i) *Gaugings.*—Measurements were taken at places marked A and B, and at the place of fracture:—

	Top. Inch.	Bottom. Inch.	Starboard. Inch.	Port. Inch.
A	·275	·294	·29	·282
			Forward.	Aft.
B	·268	·284	·27	·3
At fracture ..	·294	·27	·247	·318

There was also one place at the fracture where the thickness was only ·243 inch. It will be seen that there was a considerable variation in thickness at the fracture, partly due to the pipe being slightly bent at this point, but taking the minimum thickness at ·25 inch this would only give a stress of 2,075 lbs. under working conditions.

(ii) *Mechanical Tests.*—A fairly complete series of tensile and bend tests was carried out. These consisted of four longitudinal and two transverse tensile test specimens from each end of the pipe, together with four longitudinal bend tests. The position of those at the boiler end is shown on Plate II., and those at the engine end were cut in a precisely similar way, the longitudinal test-pieces being stamped EL and BL, according to which end of the pipe they were taken from, and the transverse tests ET and BT. The latter specimens were straightened at a very low red heat as it was considered that in view of the recent annealing of the pipe the effect of such heat would be negligible, whilst if straightened cold some mechanical effect would be produced.

Mark.	Thickness. Inch.	Tons. Per sq. Inch.	Elongation in 2ins. per cent.	Contraction of area per cent.	Appearance of Fracture.	Remarks.
BL1	·3	12·7	20	36·9	Medium	Broke $\frac{3}{16}$ inch inside mark
BL3	·26	13·7	21	36·8	Medium	Broke on mark
BL5	·27	13·4	49	48	Medium	Broke on mark
BL7	·32	13·1	33	34	Coarse	Broke on mark
BT1	·275	8·6	3	24·1	Coarse	Broke outside mark
BT2	·275	10·1	18	30·7	Coarse	Broke $\frac{5}{8}$ inch inside mark
EL1	·28	14·3	48	47·3	Fine	Broke $\frac{5}{8}$ inch inside mark
EL3	·29	16·5	40	34·5	Fine	Broke 1 inch inside mark
EL5	·29	14·2	49	49·1	Fine	Broke $1\frac{1}{8}$ inches inside mark
EL7	·28	14·3	52	57·1	Fine	Broke $1\frac{1}{8}$ inches inside mark
ET1	·28	14·0	27	34·7	Fine	Broke on mark
ET2	·29	14·5	15	26·1	Fine	Broke outside mark

All the bend test-pieces bent close without sign of fracture. The machined parts of the tensile and bend test-pieces were about 1 inch wide. It will be seen that the tensile strength at the engine end is very uniform, with the exception of EL3, and that the elongation and contraction of area of the longitudinal tests are good. As regards the transverse tests, one broke on the mark and the other outside it, and if allowance is made for the difference thus caused, the results are also fairly satisfactory. At the boiler end of the pipe more variation exists, the tensile strength being about one ton less than at the other end; and in the longitudinal tests, BL3, BL5 and BL7, which broke at the end nearest to the fracture of the pipe, slight surface cracks were developed. These cracks were much more evident in the transverse tests, and the results obtained were unsatisfactory in consequence of these defects.

As has already been stated, the thickness of the pipe was not uniform, and this fact tends to depreciate the results of the tensile tests; on the whole, however, they may be considered to be good, except those of the metal near the place of fracture.

(iii) *Chemical Analysis.*—A very complete analysis has been obtained, the results of which are as follows:—

Copper	99·663
Arsenic	·014
Sulphur	·01
Lead	·225
Iron	·023
Total Oxygen	·065
Oxygen as Cu_2O	·025
Tin	Nil.
Antimony	Nil.
Zinc	Nil.
Bismuth	Nil.
Manganese	Nil.
Aluminium	Nil.
Vanadium	Nil.
Nickel	Nil.

The outstanding feature of this analysis is the percentage of lead, which is considerably greater than the maximum usually allowed. In this case, however, it cannot be definitely asserted that the lead produced any distinct inferiority, for although the pipe cracked at the boiler flange when nine years old, the sleeve-piece supplied in Bombay cracked at the same place after five years, and it will be seen from the report of the microscopical examination that both coppers had surface cracks, indicating that the metal of the pipe was not specially red short.

As regards the oxygen, the total amount is probably what would produce "tough pitch," although no records have been available of copper containing so much lead, but it will be noticed that only ·025 per cent. existed as cuprous oxide. This is an important point which as a rule seems to be overlooked. In all the analyses of copper to which access has been obtained the total oxygen only is given, it being apparently assumed that, owing to its great affinity for copper, the whole is in the form of cuprous oxide. It is difficult therefore to state definitely whether the actual amount of cuprous oxide in this copper is in accordance with that in good quality tough pitch copper, though *prima facie* it seems low. The subject seems one which is worthy of further investigation.

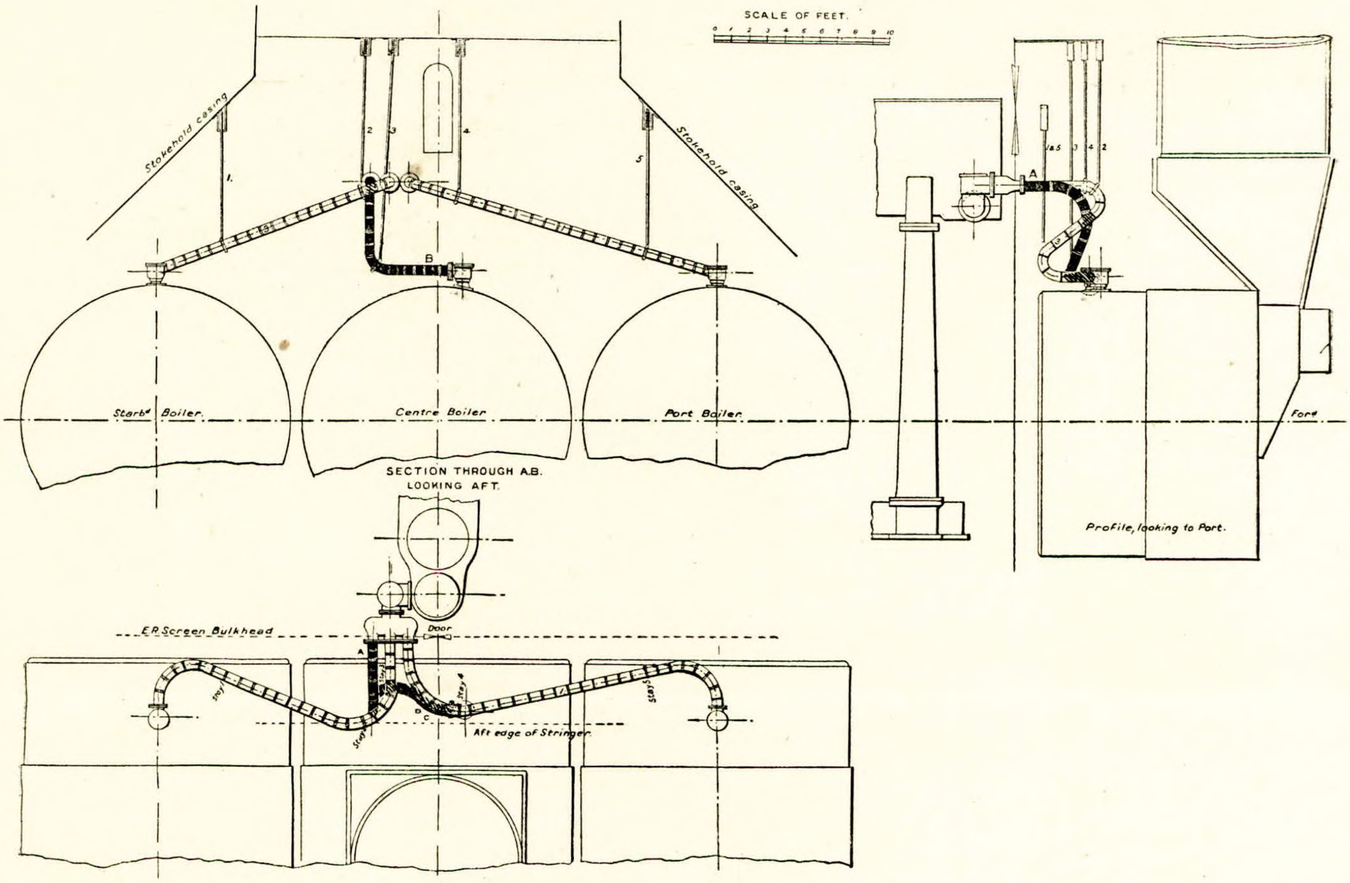
From the results of the various investigations it appears that although the thickness of the pipe varied, yet even at the thinnest part it possessed a factor of safety of about 15 when cold, taking the tensile strength at 14 tons per square inch. This would give an actual factor of about 10·7 under working conditions, as the strength of the copper would be reduced to about 10 tons per square inch at the temperature of steam at 180 lbs. pressure. The mechanical tests indicate a deterioration of the metal near the place of fracture, but as it is impracticable to take tensile tests close to that point, the results of the microscopical examination are by far the most valuable and important, as is usual in cases of this description, owing both to the local character of the conditions producing failure and to the fact that this is the only method of investigating the effect of heat treatment on metals. In this instance it appears that the metal was most grossly over-heated and burnt during the process of brazing, thereby producing huge crystals and surface cracks, the latter being extended by fatigue action due to the motion of the engines until the pipe gave way. The instantaneous nature of the failure is therefore explained, and considering the serious deterioration of the metal it is a matter for surprise that the pipe lasted so long without fracturing. It may be mentioned in this connection that my experience in the case of steel seems to show that annealing tends to augment fatigue cracks, and if this is correct the failure of this pipe would have been accelerated by being twice annealed in 1913.

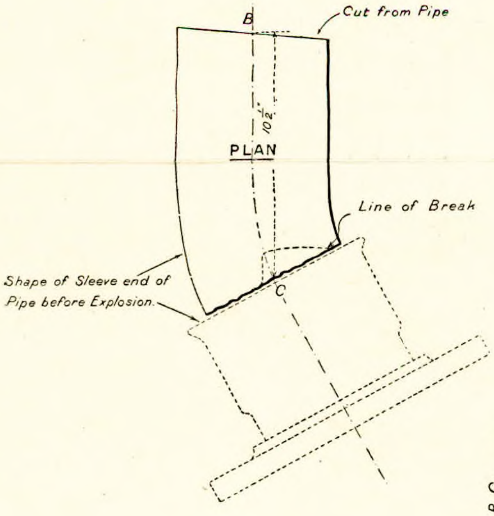
The brazing of the pipe which resulted in the metal being burnt was, as stated above, done in Bombay, and it is noteworthy that the brazing of the engine flange done at the same time was very defective. It appears therefore that the work was very badly executed, and to this cause the lamentable loss of life is due.

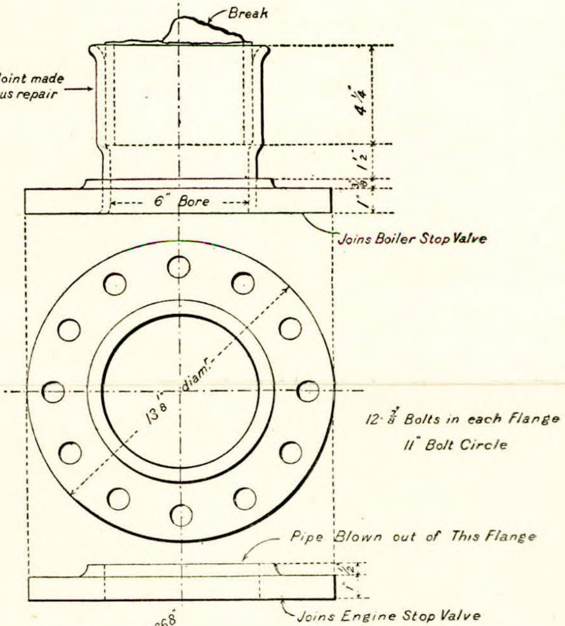
The question arises whether the defective condition of the pipe should have been detected afterwards, especially as the pipe was tested and inspected after the repairs, also on the vessel's return, and on two occasions in 1913. From the appearance of the pipe after the explosion I am of the opinion that defects in the copper could not have been seen by ordinary inspection, but it was found, by filing the metal and carefully examining the surface, preferably with a magnifying glass, that the surface cracks could be distinguished. Owing to their minute character, however, it is doubtful whether anyone without special experience would have recognised the serious nature of the defect and condemned the pipe.

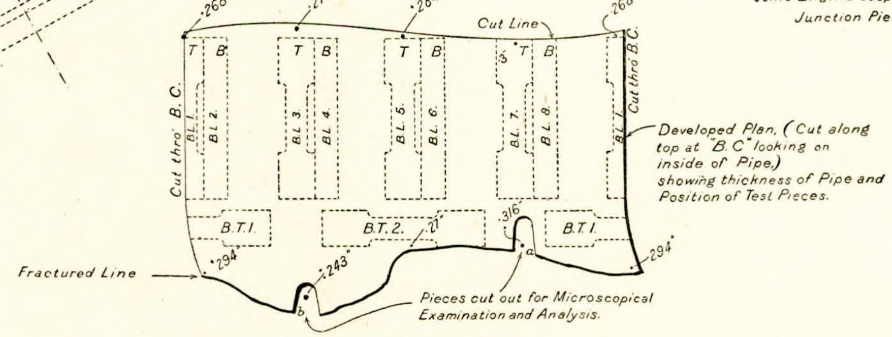
It may therefore give rise to some feeling of alarm that a copper pipe may exist in so dangerous a condition without being

EXPLOSION FROM MAIN STEAM PIPE.









Diagrams kindly lent by The Shipbuilder and Shipping Record.

detected by the usual inspection, but, whilst there is no doubt that a great many failures of copper pipes are due to bad workmanship during the process of brazing, yet in almost every case a small leak develops at first giving sufficient warning to allow repairs to be made. In the present instance although the metal was grossly burnt yet the pipe lasted seven years in spite of considerable fatigue action arising from the excessive movement of the engines. It is improbable that conditions such as these will coexist in another pipe, but as a safeguard the practice adopted by at least one well-known firm of shipbuilders of fitting ferrules in the ends of copper pipes is one which appears to be satisfactory, and likely to prevent serious accidents.

It has been stated by Mr. J. T. Milton that, owing to the local softening of the metal when the flanges are brazed on, deformations tend to concentrate at these parts, which then harden up and cause the flexure to occur a little further along the pipe, hence it is desirable to anneal the pipe at intervals. It may, however, be pointed out that as copper, unlike iron and steel, has no critical points of crystallisation the crystals tend to grow at each annealing operation, and it is therefore desirable to keep the temperature of this as low as possible. Fortunately it has been ascertained that ordinary commercial copper is annealed almost at once by heating it to about 450° C., a temperature which is described as being just visible in the dark; if, therefore, the pipe is at a just visible red in the coppersmith's shop the annealing may be considered satisfactory, and the growth of the crystals would under these conditions be slight.

In conclusion I desire to express my thanks to Messrs. William Beardmore and Company, Parkhead, for the chemical analyses, the experiments in the heat treatment of copper and the mechanical tests.

S. A. Houghton.

APPENDIX.

(iv) *Microscopical Examination.*—Sections containing the fractured edge were cut at opposite ends of the same diameter. Another section was cut at 11 inches from the place of fracture, and another through the sleeve-piece, brazing, and original pipe in juxtaposition to the sections. All the sections were cut longitudinally, and the face examined was at right angles to the surface of the pipe. From these sections microphotographs were taken, these being all at the same magnification—50 diameters—and having the top of the photograph nearest to the outside surface of the pipe. The structure of the metal from the fracture may be taken as approximately that of the copper of the pipe, as it is far enough away from the sleeve joint to be unaffected by the heat of the brazing operation. The crystals are distinctly large for the thickness of metal, this being probably due to the annealing operations the pipe has undergone. There is a considerable number of small impurities, comparatively few of which can be identified as copper oxidule CuO_2), and it is suggested that the others may contain the lead constituent.

At the fracture the structure is very different, the crystals being of relatively immense size, and the etched surface forms a fine macrostructure. An exception to this occurs at the outside of the sections where the crystals are only moderately large, owing probably to the metal having been hammered at this part when hot.

Before etching it was observed that both the outside and inside surfaces were covered with cracks similar to those in burnt metal. These were rather deeper on the outside and tended to form in places a layer of defective metal, which also seemed porous, the depth of which was approximately $\frac{1}{16}$ inch. One photograph shows this appearance, but the layer is more shallow at this part. Another photograph shows some of the deteriorated surface metal after etching. The cracks follow the outlines of the crystals and there is an extensive one, parallel to the surface. The sections near the brazing were etched with hot 50 per cent. aqua regia, which reagent was ineffective on the normal metal and the photographs were taken by oblique light. Some of the crystals were fully ·05 inch across, and, as shown by the photographs, there is a good deal of twinning.

One photograph is specially interesting as it shows one of the surface cracks (at right angles to the surface), which has been extended by fatigue action, and it is to effects of this nature that the failure of the pipe was due. Comparatively few examples of the action of fatigue on the crystals of metals from actual practice have been published, and probably none in copper. This case is therefore of peculiar interest. The fracture as extended by fatigue action passes in parts along the boundaries of the crystals, but it must be remembered that the latter were on the verge of separation through overheating. In other parts it follows a plane of cleavage, and there is also a certain amount of crushing along the edges due to continual opening and closing. The total depth of this crack was exactly $\frac{1}{8}$ inch from the outside surface.

There were several points of importance in the section through the end of the sleeve-piece, especially with regard to the copper of that part. This was of a different quality from that of the pipe, judging by the microstructure, but it also showed cracks on the surface, indicating that those in the pipe were not specially due to any peculiarity in the composition of the copper. A singular feature in this section was that surface cracks showed below the surface of the brazing both in the sleeve-piece and the pipe itself. This may have been due to a shortage of spelter during the brazing operation, or to the pipe being such a bad fit as to allow the molten spelter to run through at the first attempt, this latter view being supported by the fact that a wedge-shaped piece of copper had been placed at the bottom of the socket to prevent leakage of the spelter. The latter was of variable structure; a small part near the surface was of the structure of 60 per cent. copper to 40 per cent. zinc, but the remainder indicated a percentage of copper exceeding this amount. According to M. G. Charpy* the melting point of brass composed of 70 per cent. copper to 30 per cent. zinc is 945° C., that of 60 to 40 per cent. is 880°, and of 50 per cent. to 50 per cent. (which is the composition of brazing spelter) about 850° C., whilst copper itself melts at 1,054° C. It follows therefore that the brazing of the sleeve-piece was completed at an unnecessarily high temperature. In this connection it may be pointed out that owing to volatilisation of the zinc in the spelter during brazing and the solution of the surrounding copper (which produces "guttering"), the percentage of copper and consequently the melting point of the spelter is continually rising, so that if the operation is at all prolonged the temperature is probably at least 900° C., even if the spelter is maintained only a few degrees above melting point.

As to the actual means by which copper is burned, Professor E. Heyn, of Charlottenberg, has stated that when copper is heated to within 18° C. of its melting point it absorbs oxygen which locates itself as copper oxidule between the crystals. In another paper he states that hydrogen produces surface cracks when copper is heated to above 800° C. in that gas.† Mr. J. T. Milton and others agree with the latter result by stating that the burning effect is produced by heating copper in a reducing flame, which frequently occurs when the blast is shut off at the conclusion of the operation of brazing.

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* Contribution á l'Etude des Alliages, Société d'Encouragement pour l'Industrie Nationale, 1901. † Zeitschrift des Vereins Deutscher Ingenieure, 1890.

An analysis of the oxygen in the copper at the point of fracture was therefore made, but the results obtained were almost identical with those of the unburnt copper, both for combined and total oxygen. To investigate the matter further the following experiments were made: Pieces from the flat parts of bend test-pieces Nos. 2, 4, 6 and 8 from the engine end of the pipe were heated in a reducing atmosphere (coal gas) for ten minutes to the temperatures given below, and the pieces were afterwards bent with the results indicated below.

No. of Test Piece.	Temperature to which it was heated.	Result of Bend Test.	Remarks.
2	700° C.	Close double.	Transverse cracks on bent surface.
4	800° C.	,, ,,	Transverse cracks on bent surface.
6	900° C.	180°. Sides parallel. ½ inch apart.	Bent surface badly cracked.
8	1,000° C.	90° broke.	Granular fracture.

The cracks mentioned were fairly straight and were not much more marked in No. 4 than No. 2. There were several rough excrescences on the surfaces of No. 8 which were filed flush before the piece was bent. Sections were cut from each test-piece, and on examination revealed the fact that the cracks were not caused by the heat treatment, the effect of which was to produce porosity at the surface of the metal. The depth to which this action extended increased with the temperature, until at 1,000° C. it extended in places right through the metal. This result was unexpected, but is in accordance with Professor Heyn's research, in which he states that there is a marked lowering of the specific gravity of copper after heating in hydrogen. It also explains the layers of defective metal in the pipe at the place of fracture. Pieces of the pipe were also heated to the melting point in an oxidising flame (a smith's fire) and by the oxy-acetylene flame without producing cracks, but in the former there was a marked occlusion of oxygen near the surface resulting in the formation of the copper-oxygen eutectic in places, and in layers of copper oxidule between the crystals.

Taking into consideration the results of these experiments, I am of the opinion that the pipe at the place of fracture was heated during brazing to a temperature of about 1,040° C. in an oxidising flame, causing the formation of copper oxidule between the crystals at the surface. The flame was afterwards changed to a reducing one by shutting off the blast, with the result that the copper oxidule was reduced and a layer of cracked and defective metal formed on the surfaces of the pipe. In none of the experiments mentioned were the crystals as large as those at the place of fracture, and it is therefore evident that the metal at that part must have been maintained at a perilously high temperature for some time, possibly owing to the first attempt proving a failure as previously suggested.

S. A. Houghton.

Observations of the Engineer Surveyor-in-Chief.

This was a serious explosion which involved the death of seven men and injury to another. The cause of the pipe's failure is attributed to the over-heating of the metal, the movements of the pipe due to the vibrations of the engines being a contributory factor. As to when the overheating occurred, one of the surveyors who collaborated at the Inquiry believes that it was effected when the sleeve-piece was added to the pipe, but the other is less emphatic, and considers that, while it is probable that the damage arose at that time, it may have been caused when the pipe was subsequently rebrazed or annealed. It is, however, significant that the pipe gave way near a part which had cracked previous to the operation either of brazing or annealing at which it is suggested the material may have been overheated, and that the pipe lasted for nearly seven years after the sleeve-piece was fitted, although it had again given trouble during this period; and it would seem probable that, while the overheating to which the pipe had been subjected was responsible for the suddenness of its rupture, fatigue had an equally if not more important bearing on the ultimate failure.

A. Boyle.

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ELECTION OF MEMBERS.

The following were elected at the special meeting of Council, held on Monday, July 3rd, 1916:—

As Members.

Westcott Stile Abell, 71, Fenchurch Street, London, E.C.
Archibald Crooks, 34, Newington Street, Belfast
Henry Keddey Fletcher, Messrs. Fletcher, Son & Fearnall, Ltd., Union Docks, Limehouse, E.
Jas. Herbert Wainwright Gill, The Windmill, Heacham, Norfolk.
George Hast, Bluff, New Zealand.
James McFarlane, 2, Jane Street, Bellahouston, Glasgow
John Pickering, 33, Cheltenham Road, North Shore, Blackpool
Arthur Theophilus Thomas, 1403, Rockfeller Buildings, Cleveland, Ohio, U.S.A.

As Associate-Member.

Henry Fyffe, Club Road, Port Swettenham, Federated Malay States.

As Associate.

Robert Bradley Clark, 2, Thrift Street, North Shields.

TRANSFERS.

From Associate-Member to Member.

H. P. Scott, 14, Bedford Street, Poplar, E.

From Graduate to Associate.

Cyril H. Kelly, 37, Locksley Street, Limehouse, E.

Essay Competitions.

SUBJECTS FOR SESSION 1916-17.

SIR ARCHIBALD DENNY AWARD, value £4, in books or instrument. This is open to competition to sea-going Members.

TWO STEPHEN AWARDS, value £2 each, in books or instruments, or towards payment of class fees, in the option of the successful candidates. These are open to competition to the Associate Members and Associates.

AWARDS, value £2, in books or instruments, or towards class fees. This is open for competition to the Graduates.

OPEN COMPETITION AWARD, value £2, in books or instruments, or towards class fees. This is open for competition to Graduates of the Institute and Apprentice Engineers throughout the Kingdom who are eligible for the position of Graduates.

These awards will be granted to the writers of the best papers—if deemed of sufficient merit—as undernoted, or the amounts may be divided if the merits of the papers are such as to render a division desirable.

SEA-GOING MEMBERS.—"Hints and Deductions from practical experience, which may be useful towards improving ship and engine design. Reports upon consumption of coal and/or water per I.H.P. per hour."

ASSOCIATE MEMBERS.—"The Sequence of Cranks in Multiple Expansion Engines, and the balancing of powers."

ASSOCIATES.—"The Internal Combustion Engine for marine purposes. The various fuels which may be used and their comparative merits."

GRADUATES.—"The Main Engine Shafting from and including the crank shaft, how lined off and fitted into a new vessel to the propeller; also the Stern Tube, with detailed description of the latter."

OPEN COMPETITION.—"The Refrigerator. Different systems and their adaptability for various services on ship-board," not competed for.

The Paper to be the certified sole work of the competitor, to consist of approximately 2,000 words, to be signed with a *nom-de-plume* (the name and address of the writer being also enclosed in a sealed envelope with the *nom-de-plume* written on the outside), and to be delivered addressed to "The Secretary, Institute of Marine Engineers, The Minories, Tower Hill," London, E.," not later than October 30th. The wrapper containing the paper should be endorsed "Sea-going Member," "Associate Member," "Associate," "Graduate," or "Open Competition" as the case may be.

Associates and Graduates are allowed the option of selecting the subject and competing in the class above them, but no candidate can compete for more than one award.

The above appeared in our March issue, and is now brought to the notice of members again in the hope that some of the subjects may be dealt with.

In connection with the appeal which is being issued for donations to admit of the debit balance remaining on the new premises being cleared off, responses of a gratifying nature have already been received from members and friends, and it is desirable that everyone connected with the Institute should contribute as it may be convenient, however small the amount, it will be satisfactory to everyone to give a helping hand.

Jas. Adamson, *Hon. Secretary.*