TEST OF A ONE HUNDRED HORSE-POWER GAS ENGINE USING PRODUCER GAS.

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About a year ago the makers of the Otto gas engine, Messrs. Schleicher, Schumm & Co., stated that they were then completing a 100 horse-power gas engine, and that their plant was run on producer gas and the engine would be at our service to make a test to determine the amount of coal used per horse-power. Unfortunately this engine was not completed before the end of the college year, so that it was practically impossible to carry out the test at that time. Later in the year another engine of the same size was under way and was offered to us at a time that we could do the work, and we gladly undertook to make as full a test as the means then at hand would allow.

The data were taken by students of the Mechanical Engineering Department of the University of Pennsylvania under my direct supervision, and most of the results were worked out by Messrs Head and Wood for a graduation thesis.

The engine tested was nominally a 100 horse-power, two cylinder Otto gas engine, sections of which are shown in *Figs. 1, 2 and 3*. The cylinders are horizontal, one directly over the other. The general type of the engine is very much that of the ordinary Otto. The connecting rod from the upper piston takes hold of the crank pin, while the connecting rod from the lower piston is attached to the upper connecting rod, some distance back of the pin. The arrangement of the admission and exhaust valves is plainly shown in the figures. The gas and air are admitted through the pipes marked, there being a throttle valve on the gas pipe. The supply valves to the cylinders are disc valves, opening inwardly, and which are held on their seat by a light spiral spring. The exhaust valves are flat valves, which are opened by a cam, as is

usual in engines of this type. During the test the relative amounts of air and gas admitted were regulated so that there was as little loss as possible from incomplete combustion.

The engine for testing was set up on the foundation which is usually used at the works for testing large engines before sending them out. The pipe connections for this engine were so made that gas could be used either from the city supply or from the producer, and during the test the joints in the city supply pipe were broken and no gas could get to the mains except such as came from the producer. During the time of the test the engine which runs the factory was disconnected from the pipes carrying the producer gas, and was supplied with gas from the city mains.

A diagrammatic view of the producer is shown in *Fig. 4*.

The producer, which was Taylor's patent, No. 4, consists of a cylindrical shell *D'*, lined with fire brick *E*, at the bottom of which was a grate *F*, which could be turned around its centre by means of gearing *G*, extending outside the base of the producer.

Ashes filled the producer from the grate to about six inches above the top of the air pipe *H*, coming out in the centre of the producer.

The air supply for the producer is derived from the positive blower, driven by shafting in the works. The power necessary to drive it was afterwards determined. The air entered the pipe, at the point marked, from the blower and passed directly into the bottom of the first scrubber up through the wet coke, with which the bottom of the scrubber was filled, then through the air pipe *H* under the coal in the producer. As it passed through the producer it converted the carbon of the coal largely into carbonic oxide, then passed through the pipe *I* into the bottom of the top half of the first scrubber where the pipe dipped into a water seal. After passing up through the first scrubber it passed down, up through the second scrubber and then into the gasholder, the course taken by the air from the point that it entered to the point at which it was discharged into the gasholder, being shown by the arrows.

Coal was fed in through the circular box *J* on the top of the producer, the bottom of which was an inverted cone held up tight by a chain, pulley and weight. The supply of air was regulated by an escape valve *K*, which was closed by the descent of the gasholder.

All the small pipes are water pipes, except the one marked *A*.

The water comes from a tank on the roof, supplying the second scrubber, and continuing to the first, the supply for which is regulated by a float in the small tank *L*. In this manner the scrubbers are cooled and the water seal maintained.

From the small tank *L*, the water flows through the valve *B* into a circular jacket around top of the producer. The valve is governed by the motion of a piston in *C*, which opens *B*, when the temperature of the water in the producer exceeds a fixed height. This was so adjusted that a continuous flow of hot water takes place through the pipe *D* to the top of the lower part of the first scrubber, where it heats and moistens the air before entering the producer, the first scrubber being divided in the middle of its height by an air-tight partition. By this system the steam necessary for the producer is obtained by utilizing the heat which is carried from the bed of fuel by the gas, and by this means the steam boiler usually used in connection with boilers is dispensed with. This method of supplying moisture is the invention of Mr. Paul Winand, of the Otto Works, and a comparison of the following tests with those in which a separate boiler is used for supplying steam shows a decided saving in coal consumed.

During the test the explosion of the gas in the engine was caused by a spark made by the breaking of the circuit of Edison-Leland cells, a spark coil being in the circuit.

The gas pipe from the producer to the gas bag was eight inches in diameter. The gas bag was a cylinder 3 feet in diameter and 1 foot long, having loose gas-proof ends. A three and one-half inch gas pipe connected the gas bag to the engine.

The method of making the test was as follows :

The coal that was fed to the producer was weighed partly in charges of about 130 pounds, and during a portion of the time the amount used at each firing was noted. Samples of the coal used were taken and afterwards tested under the direction of Prof. Edgar F. Smith, of the University, and was found to have the following composition :

Per Cent.

4.20 moisture.

6.88 volatile and combustible, { 3.18 per cent. hydrogen.

80.41 fixed carbon. { 84.76 per cent. total carbon.

8.51 ash.

0.74 sulphur.

Samples of the gas in the holder were taken at frequent intervals and tests made of it, some of the tests being complete ones, while others simply showed that the conditions remained about constant.

The pressure and temperature of the gas as it went into the gas bag were noted at regular intervals. Indicator cards were taken from both cylinders every half hour during the test. A supplementary wheel was bolted to one of the fly-wheels of the engine, and on this a prony brake was fitted. Water was allowed to run on the inside of the rim of the wheel and evaporate, and as the details of the test will show, no difficulty was experienced in keeping the load reasonably constant.

The temperature of the water used in the jacket was taken throughout the test, and at regular intervals the quantity of water used every four minutes was run into an iron tank and weighed.

A continuous counter was used to record the number of revolutions of the engine, and a counter was fitted in such a way that the number of times the gas valve opened to admit gas was registered.

A Brown's pyrometer was fitted in the exhaust pipe to determine the temperature of the exhaust gas and provision was made by which samples from the exhaust pipe could be taken for each engine and the gas analyzed.

The test proper extended over three days, while preliminary trials were made on the two preceding days. The

condition of the fire in the producer was noted on the evening of May 4th, by pushing an iron rod from the top of the producer down to the grate, allowing it to remain long enough to become red hot, then marking the two ends of the hot portion, and measuring the thickness of the bed of ashes and of the bed of coal on the rod. The height of the holder was noted, and the plant shut down until the next morning.

On May 5th, the engine was started at 7.39 A.M. and run continuously until about 5.45 P.M. On May 6th, before starting the engine the producer was started, and the gas allowed to escape into the air, until the producer was making the gas of the proper quality for use in the engine. The engine was started at 7.44 and run until 5.40 at night. On May 7th, the same method of proceeding was taken as on the day before. The engine was started at 7.26 and run until 5.40 in the evening, great care being taken that the amount of fire in the producer at the end of the test—that is at the end of the third day, should be the same as at the beginning of the test, or on the evening of May 4th, and that the holder should be at the same height as at the beginning of the test.

The tables accompanying this paper are the records of the test as made, and *Fig. 5* graphically represents the tables.

Tables 1*a*, 1*b*, and 1*c* show the total reading of the revolution counter, the revolutions per minute, the total reading of the explosion counter, the explosions per minute, the reading of the pyrometer in degrees F., the gas pressure in inches of water, the gas temperature and the room temperature in degrees F., and the load on the brake in pounds. The total time of running the engine was determined from this table in the following way: The total time of running was made up of two parts, one of which commenced when the explosions had become uniform and the load steady, and to this was added the duration given by dividing the number of explosions before and after the time allowed above, by the average number of explosions per minute during this uniform running.

TABLE I (a).—MAY 5TH.

Time.	Revolutions Counter.	Revolutions per Minute.	Explosion Counter.	Explosions per Minute.	Pyrometer.	Gas Pressure. Inches.	Gas Temp. F.	Room Temp. F.	Brake Load. Pounds.
7.39	689,190	—	98,773	—	—	—	—	—	—
7.52	690,890	154'	99,905	102'	490'	1 3/8	64'6	—	570'
8.00	692,460	157'	101,124	121'9	650'	1 1/2	64'7	—	820'
8.10	694,020	156'	102,413	128'9	680'	1 1/2	65'2	—	900'
8.20	695,580	156'	103,733	134'	710'	1 1/2	65'8	—	980'
8.30	697,140	156'	105,184	143'1	750'	1 1/2	66'8	—	1140'
8.40	698,690	155'	106,689	150'5	740'	1 1/2	67'8	—	1100'
8.50	700,235	154'5	108,166	147'7	745'	1 1/2	68'	—	1100'
A.M.									
9.00	701,810	157'5	109,611	149'5	755'	1 1/2	68'2	—	1170'
9.10	703,430	162'	111,222	156'2	770'	1 1/2	68'8	—	1150'
9.20	705,047	161'7	112,775	155'3	760'	1 1/2	69'2	—	1140'
9.30	706,655	160'8	114,321	154'6	775'	1 1/2	70'	—	1155'
9.40	708,290	163'5	115,870	152'9	775'	1 1/2	70'3	—	1160'
9.50	709,910	162'	117,413	154'3	780'	1 1/2	70'6	—	1145'
10.00	711,530	162'	118,958	154'5	770'	1 1/2	71'3	—	1145'
10.10	713,155	162'5	120,492	153'4	755'	1 1/2	71'8	—	1150'
10.20	714,775	162'	122,031	153'9	755'	1 1/2	71'4	—	1160'
10.30	716,400	162'5	123,566	153'5	760'	1 1/2	72'4	—	1160'
10.40	718,020	162'	125,104	153'8	760'	1 1/2	72'6	—	1175'
10.50	719,640	162'	126,654	155'	755'	1 1/2	73'	—	1125'
11.00	721,270	163'	128,161	150'	740'	1 1/2	74'	—	1124'
11.10	722,890	162'	129,681	152'	745'	1 1/2	75'4	—	1170'
11.20	724,520	163'	131,211	153'	755'	1 1/2	75'7	—	1155'
11.30	726,140	162'	132,773	156'2	755'	1 1/2	76'	—	1160'
11.50	729,390	162'	135,815	150'4	750'	1 1/2	77'	—	1162'
12.10 P.M.	731,015	162'5	137,393	157'8	760'	1 1/2	77'4	—	1150'
12.10	732,635	162'	138,981	158'8	760'	1 1/2	77'6	—	1150'
12.20	734,250	161'5	140,571	159'	760'	1 1/2	77'4	—	1130'
12.30	735,870	162'	142,141	157'	750'	1 1/2	77'1	—	1130'
12.40	737,490	162'	143,138	148'7	720'	1 1/2	78'2	—	11075'
12.50	739,125	163'5	145,122	148'4	730'	1 1/2	78'8	—	1120'
1.00	740,750	162'5	146,641	151'9	745'	1 1/2	78'8	—	1130'
1.10	742,370	162'	148,183	154'2	750'	1 1/2	79'	—	1155'
1.20	743,985	161'5	149,737	155'4	760'	1 1/2	78'3	—	1115'
1.30	745,610	162'5	151,305	156'8	750'	1 1/2	79'6	—	1100'
1.40	747,230	162'	153,841	153'6	745'	1 1/2	80'	—	1080'
1.50	748,860	163'	154,365	152'4	745'	1 1/2	80'	—	1135'
2.00	750,480	162'	155,881	151'6	745'	1 1/2	80'2	—	1095'
2.10	752,090	161'	157,451	157'	740'	1 1/2	79'	—	1085'
2.20	753,710	162'	159,021	157'	740'	1 1/2	78'8	—	1120'
2.30	755,215	160'5	160,609	157'8	745'	1 1/2	79'1	—	1115'
2.40	756,930	161'5	162,176	156'7	750'	1 1/2	79'3	—	81'
2.50	758,540	161'	163,746	157'	750'	1 1/2	—	81'	1128'
3.00	760,160	162'	165,336	159'	750'	1 1/2	—	82'	1128'
3.10	761,775	161'5	166,922	158'6	750'	1 1/2	—	—	1144'
3.20	763,370	159'5	168,513	159'1	—	1 1/2	—	—	1162'
3.30	765,010	164'	170,143	163'	765'	1 1/2	—	—	1106'
3.40	766,640	163'	171,771	163'	750'	1 1/2	—	84'	1150'
3.50	768,225	158'5	173,357	151'7	750'	1 1/2	—	84'	1160'
4.00	769,790	156'5	174,920	156'3	760'	—	—	85'	1178'
4.10	771,430	164'	176,560	164'	770'	1 1/2	—	82'	1200'
4.20	773,010	158'	178,135	157'5	765'	1 1/2	—	83'	1198'
4.30	774,580	157'	179,698	156'3	760'	2	—	82'	1192'
4.40	776,120	154'	181,245	153'7	760'	1 1/2	—	78'2	1198'
4.50	777,630	151'	182,750	150'5	760'	1 1/2	—	78'9	1162'
5.00	779,190	156'	184,318	152'8	765'	1 1/2	—	78'6	1175'
5.10	780,695	150'5	185,814	150'6	765'	1 1/2	—	78'	1190'
5.20	782,220	152'5	187,340	151'6	750'	1 1/2	—	—	—
5.30	783,820	160'	188,945	160'	760'	1 1/2	—	—	—
5.40	785,430	161'	190,549	160'4	765'	1 1/2	—	—	—
5'45	786,210	—	191,284	—	—	—	—	—	—
Mean,	—	160'76	—	155'44	752'6	1 11-16	75'5	81'3	1148'5

TABLE I (b).—MAY 6TH.

Time.	Revolutions. Counter.	Revolutions per Minute.	Explosion Counter.	Explosions per Minute.	Pyrometer.	Gas Pressure. Inches.	Gas Temp. F.	Room Temp. F.	Brake Load. Pounds.
7 ⁴⁴ 7 ⁵⁰	786,210 787,130	—	191,284 191,783	—	—	—	—	—	—
8.00	788,710	158 ⁸	193,308	152 ⁵	—	—	—	—	—
8.10	790,490	158 ⁸	194,887	157 ⁹	700 ⁰	1 ³ / ₄	68 ⁸	—	1084 ²
8.20	791,890	160 ⁰	196,457	157 ⁷	750 ⁰	1 ³ / ₄	68 ⁸	—	1118 ³
8.30	793,470	158 ⁸	198,027	157 ⁷	750 ⁰	1 ³ / ₄	69 ⁹	—	1151 ¹
8.40	795,060	159 ⁰	199,615	158 ⁸	760 ⁰	1 ³ / ₄	69 ⁵	—	1160 ⁰
8.50	996,680	161 ¹	201,185	157 ⁷	760 ⁰	1 ³ / ₄	71 ⁷	—	1178 ⁸
9.00	798,300	162 ¹	202,800	161 ⁵	778 ⁸	1 ³ / ₄	70 ⁸	—	1185 ⁵
9.10	799,190	161 ¹	204,400	160 ⁰	756 ⁶	1 ³ / ₄	71 ²	—	1180 ⁰
9.20	801,470	156 ⁶	206,058	155 ⁸	756 ⁶	1 ³ / ₄	71 ⁵	—	1190 ⁰
9.30	803,030	156 ⁶	207,518	156 ⁷	760 ⁰	1 ³ / ₄	72 ¹	—	1190 ⁰
9.40	804,620	160 ⁰	209,110	159 ²	760 ⁰	1 ³ / ₄	72 ¹	—	1196 ⁰
9.50	806,254	162 ⁴	210,722	161 ²	765 ⁵	1 ³ / ₄	72 ¹	—	1189 ⁹
10.00	807,823	157 ¹	212,292	157 ⁷	770 ⁰	1 ³ / ₄	72 ¹	—	1189 ⁹
10.10	809,420	159 ⁵	213,880	158 ⁸	760 ⁰	1 ³ / ₄	72 ¹	—	1190 ⁰
10.20	810,380	156 ⁶	215,440	156 ⁶	770 ⁰	1 ³ / ₄	72 ⁴	—	1192 ²
10.30	812,580	168 ⁸	217,064	162 ⁴	780 ⁰	1 ³ / ₄	73 ¹	—	1181 ¹
10.40	814,190	161 ¹	218,673	160 ⁹	775 ⁵	1 ³ / ₄	73 ⁴	82 ⁰	1168 ⁸
10.50	815,810	162 ¹	220,272	159 ⁹	770 ⁰	1 ³ / ₄	74 ⁴	—	1181 ¹
11.00	817,423	161 ⁵	221,885	161 ³	770 ⁰	1 ³ / ₄	74 ²	—	1181 ¹
11.10	819,055	161 ⁵	223,491	160 ⁶	770 ⁰	2	74 ²	—	1179 ⁹
11.20	820,605	155 ⁰	225,039	154 ⁸	755 ⁵	1 ³ / ₄	74 ⁸	—	1182 ²
11.30	822,185	158 ⁵	226,619	158 ⁸	760 ⁰	1 ³ / ₄	76 ⁰	82 ⁰	1180 ⁰
11.40	823,730	154 ⁵	228,163	154 ⁴	765 ⁵	2	75 ⁸	—	1180 ⁰
11.50	825,235	150 ⁵	229,672	149 ⁹	760 ⁰	1 ³ / ₄	76 ⁰	—	1183 ³
12.00	826,705	147 ⁷	231,155	147 ⁷	760 ⁰	2	76 ⁸	86 ⁰	1180 ⁰
12.10	828,205	150 ⁷	232,655	150 ⁷	760 ⁰	1 ³ / ₄	76 ⁴	84 ⁰	1182 ²
12.20	829,725	152 ¹	234,185	152 ³	770 ⁰	1 ³ / ₄	76 ⁶	82 ⁰	1174 ⁴
12.30	831,350	152 ⁵	235,708	158 ⁸	765 ⁵	1 ³ / ₄	76 ²	84 ⁰	1180 ⁰
12.40	832,835	158 ⁵	237,288	156 ⁶	760 ⁰	1 ³ / ₄	76 ²	82 ⁰	1190 ⁰
12.50	834,400	150 ⁵	238,848	150 ⁸	760 ⁰	1 ³ / ₄	76 ⁶	84 ⁰	1175 ⁵
1.00	835,970	157 ¹	240,416	159 ¹	770 ⁰	1 ³ / ₄	76 ⁶	84 ⁰	1170 ⁰
1.10	837,565	159 ⁵	242,007	162 ¹	770 ⁰	1 ³ / ₄	76 ⁸	—	1156 ⁶
1.20	839,185	162 ¹	243,627	161 ⁷	770 ⁰	1 ³ / ₄	77 ¹	82 ⁰	1160 ⁰
1.30	840,815	163 ¹	245,234	162 ⁴	778 ⁸	1 ³ / ₄	77 ⁶	—	1165 ⁵
1.40	842,445	161 ¹	246,858	158 ²	755 ⁵	1 ³ / ₄	77 ²	82 ⁰	1158 ⁸
1.50	844,055	157 ⁷	248,740	157 ⁷	760 ⁰	1 ³ / ₄	77 ²	—	1179 ⁹
2.00	845,625	158 ⁸	250,010	158 ⁸	765 ⁵	1 ³ / ₄	77 ⁴	82 ⁰	1170 ⁰
2.10	847,205	163 ¹	251,590	163 ¹	760 ⁰	1 ³ / ₄	77 ²	—	1171 ¹
2.20	848,835	161 ⁵	253,220	159 ⁵	765 ⁵	1 ³ / ₄	77 ³	85 ⁰	1172 ²
2.30	850,450	162 ¹	254,815	162 ¹	770 ⁰	1 ³ / ₄	77 ¹	—	1174 ⁴
2.40	852,070	162 ¹	256,435	159 ⁸	765 ⁵	1 ³ / ₄	77 ²	85 ⁰	1165 ⁵
2.50	853,690	161 ¹	258,033	158 ⁷	760 ⁰	1 ³ / ₄	77 ⁸	—	1156 ⁶
3.00	855,300	160 ⁰	259,260	159 ³	755 ⁵	1 ³ / ₄	77 ⁸	86 ⁰	1158 ⁸
3.10	856,900	158 ⁸	261,213	156 ⁵	750 ⁰	1 ³ / ₄	78 ⁵	87 ⁰	1150 ⁰
3.20	858,480	157 ⁷	262,798	156 ²	750 ⁰	1 ³ / ₄	78 ¹	—	1165 ⁵
3.30	860,045	161 ¹	264,358	157 ⁷	740 ⁰	1 ³ / ₄	78 ⁸	88 ⁰	1158 ⁸
3.40	861,610	166 ⁵	265,920	140 ⁰	720 ⁰	1 ³ / ₄	79 ⁸	82 ⁰	1148 ⁸
3.50	863,185	161 ¹	267,490	145 ⁵	730 ⁰	1 ³ / ₄	77 ¹	—	1140 ⁰
4.00	864,795	161 ¹	269,094	140 ⁰	740 ⁰	1 ³ / ₄	77 ¹	—	1125 ⁵
4.10	866,400	161 ¹	270,494	140 ⁰	740 ⁰	1 ³ / ₄	77 ¹	—	1135 ⁵
4.20	868,070	161 ¹	271,944	155 ⁵	740 ⁰	1 ³ / ₄	76 ⁰	82 ⁰	1151 ¹
4.30	869,680	159 ⁵	273,344	156 ⁶	760 ⁰	1 ³ / ₄	76 ⁵	82 ⁰	1137 ⁷
4.40	871,235	158 ⁸	274,894	155 ³	760 ⁰	1 ³ / ₄	77 ¹	—	1149 ⁹
4.50	872,830	160 ⁵	276,474	155 ³	760 ⁰	1 ³ / ₄	77 ¹	—	1149 ⁹
5.00	874,435	158 ⁸	278,034	155 ³	760 ⁰	1 ³ / ₄	77 ¹	—	—
5.10	876,010	158 ⁸	279,587	—	—	—	—	—	—
5.20	877,590	158 ⁸	281,119	153 ²	760 ⁰	1 ³ / ₄	77 ¹	82 ⁰	1170 ⁰
5.30	879,180	157 ⁷	282,639	152 ¹	760 ⁰	1 ³ / ₄	77 ²	—	1170 ⁰
5.40	880,690	151 ¹	284,614	152 ⁵	—	—	—	—	1200 ⁰
Mean,	—	158 ⁷ 3	—	156 ⁷ 3	758 ⁵ 4	1 ⁸	75 ¹ 3	82 ⁴ 1	1162 ⁵

TABLE I (c)—MAY 7TH.

Time.	Revolutions. Counter.	Revolutions per Minute.	Explosion. Counter.	Explosion per Minute.	Pyrometer.	Gas Pressure. Inches.	Gas Temp. F.	Room Temp. F.	Brake Load. Pounds.
7.26	880,690	—	284,164	—	—	—	—	—	—
7.40	882,900	170'	285,962	134'	640	1½	68.8	64	1030'
7.50	884,505	160'5	287,543	158'1	700	1½	68'2	—	1051'
8.00	886,145	164'	289,181	163'8	720	1½	70'	72	1051'
8.10	887,785	164'	290,820	163'9	730	1½	71'	—	1060'
8.20	889,420	161'5	292,424	160'4	740	1½	71'2	74	1087'
8.30	890,945	154'5	293,964	154'	740	1½	71'8	—	1139'
8.40	892,490	165'5	295,540	157'6	760	1½	71'6	71	1154'
8.50	894,108	161'8	297,130	159'	760	1½	71'6	—	1182'
9.00	895,690	158'2	298,710	158'	750	2	71'9	75	1166'
9.10	897,250	156'	300,267	155'7	750	3	71'9	80	1155'
Engine stopped at 9.11 because indicator motion string broke.									
9.30	899,049	—	301,578	—	690	1½	74'1	82	1119'
9.40	900,475	142'6	302,986	140'8	740	1½	72'8	80	1123'
9.50	902,250	177'5	304,733	174'7	750	1½	72'5	78	1151'
10.00	904,839	158'9	306,318	158'5	760	1½	72'2	78	1169'
10.10	905,455	161'6	307,995	160'7	760	1½	72'2	78	1153'
10.20	907,069	164'4	309,525	160'	760	1½	72'3	78	1200'
10.30	908,680	161'1	311,136	161'1	770	1½	72'6	73	1190'
10.40	910,315	163'5	312,785	162'0	760	1½	72'8	80	1200'
10.50	911,962	163'2	314,372	161'5	750	1½	73'1	79	1150'
11.10	915,161	159'9	317,569	159'2	740	1½	73'1	77	1110'
11.20	916,759	159'8	319,160	159'1	750	1½	73'2	76	1190'
11.30	918,374	161'5	320,774	161'4	760	1½	73'4	77	1150'
11.40	919,929	155'5	322,329	155'5	750	1½	73'3	78	1185'
11.50	921,840	155'1	323,859	155'1	760	1½	73'2	78	1165'
12.00	923,148	160'8	325,525	160'6	760	1½	73'7	77	1140'
12.10	924,668	152'	327,043	152'	760	1½	74'	77	1183'
12.20	926,278	161'	328,635	161'	764	1½	74'3	80	1181'
12.30	927,795	147'7	330,132	147'7	764	1½	74'5	78	1178'
12.40	929,548	179'3	331,924	179'2	758	1½	74'7	79	1154'5
12.50	931,110	156'2	333,485	156'1	745	1½	74'5	80	1155'
1.00	932,716	160'6	335,091	160'6	752	1½	74'4	80	1153'
1.10	934,355	163'9	336,729	163'8	760	1½	74'4	80	1176'
1.20	935,990	163'5	338,304	163'5	760	1½	74'6	77	1190'
1.30	937,610	162'	339,974	161'	760	1½	74'8	78	1160'
1.40	939,155	154'5	341,522	153'8	750	1½	75'1	79	1155'
1.50	940,740	158'5	343,096	158'4	745	1½	75'	80	1160'
2.00	942,320	158'	344,676	158'	750	1½	75'	81	1140'
2.10	943,940	162'	346,296	162'	760	—	75'	80	1150'
2.20	945,600	166'	347,948	165'2	750	1½	75'	78	1160'
2.30	947,200	160'	349,546	159'8	755	1½	74'8	82	1100'
2.40	948,860	166'	351,196	165'	750	1½	74'8	78	1113'
2.50	950,538	167'8	352,864	165'8	740	1½	74'9	78	1148'
3.00	952,193	165'5	354,504	164'	750	1½	75'	80	1163'
3.10	953,831	163'8	356,141	163'7	752	1½	75'	80	1175'
3.20	955,487	165'6	357,792	165'1	754	1½	75'	80	1117'
3.30	957,109	162'2	359,412	162'	736	1½	75'1	80	1147'
3.40	958,680	157'1	360,980	156'8	720	1½	75'2	78	1127'
3.50	960,397	171'7	362,696	171'6	727	1½	75'2	78	1129'
4.00	961,930	153'3	364,225	152'9	740	2	75'3	80	1143'
4.10	963,700	177'	365,989	176'4	740	2	75'	78	1144'
4.20	965,340	164'	367,625	163'0	742	2	75'1	80	1154'5
4.30	966,784	160'4	369,064	159'9	740	2	75'2	78	1158'
4.40	968,371	158'7	370,650	158'6	740	2	75'4	78	1169'
4.50	969,938	156'7	372,216	157'4	730	2	75'3	78	1176'
5.00	971,512	157'4	373,790	161'2	747	1½	75'4	79	1068'
5.10	973,125	161'3	375,402	157'8	721	1½	—	78	1159'5
5.20	974,657	153'2	376,929	159'7	735	1½	—	—	1155'
5.30	976,238	158'1	378,507	—	—	—	—	—	—
5.40	977,836	159'8	380,104	—	—	—	—	—	—
Mean,	—	160'9	—	160'43	747'3	1½	73'4	80'2	1138'3

Thus, on May 5th, the average explosions per minute, from 9 A.M. to 5.40 P.M., was 155.55. The number of explosions before 9 A.M. and after 5.40 P.M. amounted to 11,623, which was the equivalent of 74.73 minutes at the average above found, so that the total running time for that day is taken as 9 hours 54.73 minutes. On May 6th, from 8 A.M. to 5.10 P.M. was taken as the time from which to determine the average number of explosions per minute, and the total time for this day was 9 hours 49.96 minutes. On May 7th, as the engine was stopped during the test for the purpose of securing the indicator string, the total time amounted to 10 hours and 4 minutes, and the total time of running for the three days amounted to 1788.69 minutes, with an average number of explosions 157.57.

From this table was also worked out the brake horse-power. The prony brake was arranged with a weight on the north side and another weight on the south side, the weight on the north side resting on a platform scale and being so arranged that the pressure brought by the friction of the brake was downward on the scales. The weight on the north side averaged 628 pounds, while the weight on the south side averaged 469 pounds. The circumference of the pulley was 15 feet 3 inches, and the distance from the pulley where the circumference was measured to the knife edge to which the north weight was attached was $7\frac{3}{4}$ inches, and the distance from the pulley to the knife edge to which the south weight was attached was $7\frac{1}{2}$ inches, or of the lever arm of the south weight was 3.072 feet, and of the north weight was 3.073 feet, and the brake horse-power was determined from the following formulæ:

$$\text{B.H.P.} = \frac{6.2832 N(3.073 w - [3.073 \times 628 - 3.052 \times 469])}{33,000}$$

N being the number of revolutions per minute;
 w , the load on the scales in pounds.

The average brake horse-power for the first day, May 5th, was 92.73; for the second day, May 6th, was 92.85, and for the third day, May 7th, was 91.82, the average for the entire time was 92.49.

For the entire running time, the average number of explosions per minute was 157·57. The average number of revolutions was 160,145. The average reading of the pyrometer was 752·81. The average pressure of the gas was ·062 pounds, the barometer being 14·686 pounds. The average temperature of the gas was 74°68 F.

Table II gives the indicated horse-power for each of the cards as taken during the time of the test, and it will be noted that only those cards were put down that were taken during the time the engine was supposed to be running under uniform conditions. Indicators were fitted to both the lower and the upper cylinders, with springs in them which were good to over 300 pounds. During the preliminary tests which were made on the 3d and 4th of May, it was found that these indicators would not do the work, either the springs or the pencil bar being broken from the violence of the explosion. After repairing them, the same results occurred again, and we were obliged to use a Thompson indicator with a one-quarter square inch piston which had been in use in the works for a considerable time. It was found that if the indicator was allowed to remain on the engine between the time of taking successive cards, the heat conducted from the cylinder was sufficient to melt the solder holding the spring to the screw ends, but after the test was commenced, the indicators were removed after taking each card and there was practically no difficulty in this way. The indicator piston was not at all tight, or if reasonably tight at the beginning of the test was not so at the end. After the test the indicator was put on a steam boiler and the spring calibrated; as there was considerable leakage past the piston, a mercury column was attached to the upper side of the piston, and allowance made for this pressure in determining the scale, which was found to be practically 190 pounds to the inch. It will thus be seen that there is not a very large amount of confidence to be placed in the indicated horse-power, although the results are probably fairly correct.

TABLE II (a)—MAY 5TH.—Indicated Horse-power.

TOP CYLINDER.			BOTTOM CYLINDER.		
Card.	Time.	I. H. P.	Card.	Time.	I. H. P.
11	9.00	64'86	10	8.45	62'37
13	9.30	66'78	12	9.15	66'20
15	10.00	66'26	14	9.45	65'78
17	10.30	68'78	16	10.15	70'58
19	11.00	66'84	18	10.45	70'16
21	11.30	70'88	20	11.15	72'22
23	12.00	64'86	22	11.45	67'09
25	12.30	63'92	24	12.15	66'16
27	1.00	66'73	26	12.45	69'71
29	1.45	64'19	28	1.38	67'09
31	2.15	61'98	30	2.00	60'69
33	2.45	60'27	32	2.30	57'45
35	3.15	66'21	34	3.00	68'44
37	3.45	59'25	36	3.30	68'65
39	4.15	66'51	38	4.00	68'40
41	4.45	57'13	40	4.30	64'15
43	5.15	60'26	42	5.00	65'34
45	5.42	62'17	44	5.30	67'26
Mean,	—	64'36	—	—	66'80

Total I. H. P., 131'15

Mean brake horse-power, 92'73

TABLE II (b)—MAY 6TH.—Indicated Horse-power.

TOP CYLINDER.			BOTTOM CYLINDER.		
Card.	Time.	I. H. P.	Card.	Time.	I. H. P.
46	8.05	57'62	47	8.15	56'95
48	8.30	55'86	49	8.45	60'88
50	9.00	63'23	51	9.15	63'31
52	9.30	57'20	53	9.49	61'48
54	10.00	60'49	55	10.15	67'02
56	10.30	59'14	57	10.45	63'76
58	11.00	61'47	59	11.15	68'49
60	11.30	59'31	61	11.45	59'84
62	12.00	60'84	63	12.15	60'41
64	12.30	60'86	65	12.45	65'64
66	12.57	61'10	67	1.15	63'75
68	1.30	64'58	69	1.45	66'45
70	2.00	60'54	71	2.15	62'13
72	2.30	65'92	73	2.45	65'80
74	3.00	62'28	75	3.15	63'77
76	3.30	59'26	77	3.45	61'87
78	4.00	57'04	—	—	—
79	4.30	56'70	—	—	—
80	5.00	58'73	—	—	—
Mean,	—	59'81	—	—	63'08

Total I. H. P., 122'89

Mean brake horse-power, 92'85

TABLE II (c)—MAY 7TH.—Indicated Horse-power.

TOP CYLINDER.			BOTTOM CYLINDER.		
Card.	Time.	I.H.P.	Card.	Time.	I.H.P.
81	7.45	44'28	82	8.00	54'43
83	8.15	66'59	84	8.35	62'23
85	8.47	60'54	86	9.00	Indicator string broke.
87	9.05	57'08	88	9.30	64'72
89	9.45	70'10	90	10.00	63'31
91	10.15	62'19	92	10.30	69'73
93	10.45	61'59	94	11.01	63'56
95	11.15	61'86	96	11.30	72'38
97	11.45	60'60	98	12.00	77'90
99	12.15	65'14	100	12.30	61'30
101	12.45	58'00	102	1.00	68'20
103	1.15	63'26	104	1.30	69'71
105	1.45	57'64	106	2.00	77'68
107	2.22	61'25	108	2.30	75'79
109	2.45	64'42	110	3.00	72'58
111	3.15	65'92	112	3.30	69'27
113	3.45	64'17	114	4.00	63'25
115	4.15	60'92	116	4.30	69'84
117	4.45	62'58	118	5.00	69'77
119	5.15	52'26	120	5.30	67'41
Mean,	—	61'10	—	—	67'96

Total I.H.P., 129'06

Mean brake horse-power, 91'82

Figs. 6, 7, 8 and 9 are the average of all the indicator cards taken. *Fig. 6* shows the average of the cards from both cylinders taken on May 5th, and *Figs. 6 and 7* for May 7th and 8th. *Fig. 9* is the average for all the cards taken. It will be noted that the average cards from the bottom cylinder are invariably larger than those from the top cylinder and an examination of Table VIII shows that the amount of air supplied to the bottom cylinder was more nearly the amount required for complete combustion than that supplied to the top one.

The size of the cylinder was practically 14½ inches diameter by 25-inch stroke. After the test the cylinder and the clearance spaces were filled with water.

Table III shows the volume of both cylinders, together with the clearances. The displacement of the bottom cylinder was found to be 4211'36 cubic inches and the clearance 1170'19, or 27'98 per cent. The displacement of the top cylinder was found to be 4247'94 cubic inches, and the clearance 1187'09 cubic inches, or 27'94 per cent. The volume as found from filling the cylinder with water, was used in determining the horse-power.

TABLE III.—*Clearance Determination.*

TEMPERATURE OF WATER, 61° TO 62° F.

No.	Before.	After.	Net.	Volume.
<i>Bottom Valve.</i>				
1	27'56	21'62	5'94	164'5974 cubic inches.
<i>Top Valve.</i>				
2	24'17	18'33	5'84	161'8264 cubic inches.
<i>Top Cylinder Clearance.</i>				
2	26'07	8'78	17'29	(38'58 — 1'58) $\times 27'71 = 1025'27$ cubic inches.
3	27'09	8'79	18'32	
4	28'63	25'66	2'97	
			38'58	
<i>Top Cylinder Displacement.</i>				
1	29'65	8'81	20'84	$153'3 \times 27'71 = 4247'943$ cubic inches.
2	27'62	8'77	18'85	
3	27'97	8'77	19'20	
4	25'66	8'80	16'86	
1	27'92	8'83	19'09	
2	28'50	8'78	19'72	
3	28'65	8'80	19'85	
4	29'98	11'09	18'89	
	225'95	72'65	153'30	
<i>Filling Pipe.</i>				
—	18'32	16'74	1'58	
<i>Bottom Cylinder Clearance.</i>				
1	30'34	8'82	21'52	(37'87 — 1'58) $\times 27'71 = 1005'5959$ cubic inches.
2	29'95	13'60	16'35	
	60'29	22'42	37'87	
<i>Bottom Cylinder Displacement.</i>				
3	26'64	10'37	16'27	$151'98 \times 27'71 = 4211'3658$ cubic inches.
4	27'57	10'91	16'66	
1	26'33	9'31	17'02	
2	27'52	9'30	18'22	
3	27'23	9'10	18'13	
4	26'96	9'23	17'73	
1	27'65	9'42	18'23	
2	27'61	9'45	18'16	
3	27'13	15'57	11'56	
	244'64	92'66	151'98	

Total clearance top cylinder, 1187'0946 cubic inches, 27'94 per cent.
 Total clearance bottom cylinder, 1170'1933 cubic inches, 27'978 per cent.

TABLE IV (a)—MAY 5TH.—*Jacket Water.*

Time.	Weight Water.	Temp. Disc.	Temp. Inlet.	Pounds C.	B.T.U.
		°C.	°C.		
8.05	664	37°33	16°91	13,280	5976°
8.50	611	46°58	28°83	10,845	4880°25
9.22	645	53°75	32°5	13,775	5171°75
10.10	678	55°5	35°	13,900	6255°
10.58	680	56°	36°	13,600	6120°
11.54	680	57°66	36°5	13,710	6169°5
12.45	687	56°33	37°75	12,768	5746°2
1.52	686	57°25	38°25	13,034	5865°3
3.06	673	60°00	32°33	18,642	8388°9
4.43	700	40°00	23°66	11,666	5250°

TABLE IV (b)—MAY 6TH.—*Jacket Water.*

Time.	Weight Water.	Temp. Disc.	Temp. Inlet.	Pounds C.	B.T.U.
		°C.	°C.		
8.25	664	46°66	30°	10,762	4843°
9.25	801	39°	21°	14,418	6488°
10.25	427	59°	29°66	12,518	5633°
11.25	531	64°	34°	10,620	4779°
12.25	631	57°	36°	13,261	5967°
1.25	698	56°33	36°92	13,551	6098°
2.25	524	59°33	34°92	12,787	5758°
3.25	520	63°	38°	13,000	5850°
4.25	691	56°66	37°13	13,941	6273°
5.25	697	57°5	28°	12,894	5802°

TABLE IV (c)—MAY 7TH.—*Jacket Water.*

Time.	Weight Water.	Temp. Disc.	Temp. Inlet.	Pounds C.	B.T.U.
		°C.	°C.		
8.50	521	50°33	32°	9,550	4297°
9.50	700	49°06	32°	12,361	5562°
10.50	703	54°5	33°	15,116	6802°
11.50	703	53°03	34°33	13,729	6178°
12.50	701	53°00	34°	13,360	6021°
1.50	532	61°66	34°	14,715	6622°
2.50	769	41°66	22°	15,119	6803°
3.50	694	50°5	32°	12,819	5817°
4.50	519	61°	33°	14,529	6538°
5.35	696	52°	33°83	13,347	6006°

Mean B.T.U., May 5th, 5904°9. May 6th, 5742°5. May 7th, 6218°1.

Table IV, *a*, *b* and *c*, shows the records of the water used in the jacket. The first column gives the time when the water began to fill the tanks. The second column gives the weight of water in pounds that flowed into the tank in four minutes. The third and fourth columns give the temperatures of the inflowing and discharge water in degrees C., each number being the mean of three readings. The fifth column gives the result in pound degrees found by multi-

plying the temperature change by the pounds discharged, and the sixth column gives the number of British thermal units carried away per minute, being nine-twentieths of the fifth column.

Table V gives the quantity of coal that was used each day of the test, amounting to 1069.6 pounds on May 5th, 1324.2 on May 6th, 1263.6 on May 7th, a total of 3157.4 pounds for the entire time.

TABLE V.—*Coal.*

Time.	Weight.	Time.	Weight.	Time.	Weight.
<i>May 5th.</i>		10 40	29.5	<i>May 7th.</i>	
A.M.		11.06	50.6	A.M.	
7.00	129.8	11.25	48.4	8.25	134.4
9.45	136.3	11.40	33.0	10.00	118.4
10.40	127.6	11.55	54.6	11.00	127.2
11.44	131.1	P.M.		P.M.	
P.M.		12.20	48.7	1.00	125.1
1.15	146.3	12.35	27.2	1.30	32.7
2.30	139.3	12.40	53.5	1.45	51.2
3.45	135.2	1.23	42.1	2.13	28.8
5.22	130.1	1.48	34.1	2.32	22.3
Total, . . 5-5 =	1069.6	2.05	56.2	2.47	59.1
		2.23	49.1	3.01	61.3
		2.39	32.3	3.15	65.6
		3.03	45.2	3.35	55.1
<i>May 6th.</i>		3.24	54.8	4.05	54.6
A.M.		3.43	34.0	4.30	59.1
7.38	42.7	4.00	49.8	4.51	20.7
8.28	47.5	4.15	50.1	5.18	59.1
8.56	40.2	4.30	34.1	5.22	31.1
9.15	49.1	5.00	50.4	5.30	28.5
9.26	50.1	5.19	49.7	5.35	34.4
9.48	34.1	5.40	30.1	5.40	75.1
10.09	54.7				
10.20	48.9	Total, . . 5-6 =	1324.2	Total, . . 5-7 =	1263.6

Table VI shows in the first column the time at which the sample of gas was taken. The apparatus used was the Elliott, in which the readings before the explosions indicate the differences between 100 cubic centimetres and the quantity of gas in the apparatus. In the explosion tube the numbers represent the total volume used. The second column in the table indicates the reading of the original gas. The third column, headed KOH, is the reading after potassic hydrate has been added, and the difference between that column and the one preceding is the amount of CO₂ which was present in the gas. The fourth column represents the reading after the oxygen has been removed; the fifth column the reading after the carbonic oxide has been removed. The sixth column represents the quantity of the

remaining gas that was taken for explosion. The next column represents the quantity of gas after a certain proportion of air has been added, and the difference between the last two columns is the quantity of air added. The next column represents the quantity of gas after the mixture has been exploded, the hydrogen having disappeared. The last column is the quantity of gas after the carbonic acid has been taken out, and practically represents nitrogen. The remaining columns represent the number of cubic centimetres of the different constituents of the original gas.

TABLE VI.—Gas Analyses.

Time.	READINGS.				CUBIC CENTIMETRES.											
	Orig. Vol.	KOH.	Pyro.	Cu ₂ Cl ₂ .	Before exp.	Air Added.	After exp.	KOH.	Gas.	CO ₂ .	O.	CO.	Rem.	Before exp.	Contraction.	CO ₂ .
May 5th.																
8.55	11'2	14'2	14'2	36'1	12'2	25'2	—	—	—	—	—	—	—	—	—	—
9.27	4'3	6'9	6'9	24'5	16'7	38'2	—	—	—	—	—	—	—	—	—	—
11.10	4'4	6'3	6'3	29'6	22'3	48'1	44'5	44'3	96'1	2'3	0	23'3	70'3	22'3	3'5	1'2
2.05	8'5	12'6	20'7	36'5	11'1	25'4	—	—	—	—	—	—	—	—	—	—
4.34	8	4'9	5'1	22'5	16'2	42'4	39'5	38'8	99'2	4'1	2	17'4	77'5	16'2	2'9	7
May 6th.																
8.04	5'9	10'1	10 1	36'1	15'6	36'	—	—	—	—	—	—	—	—	—	—
9.02	4'1	6'1	6'2	36'1	11'	20'5	—	—	—	—	—	—	—	—	—	—
11.25	5'5	7'5	7'5	35'9	21'5	28'7	25'5	24'5	94'5	2'	—	28'4	64'1	21'5	3'2	1'
1.41	11'5	14'9	14'9	39'8	24'8	33'2	29'9	—	88'5	3'4	—	24'9	60'2	24'8	3'3	—
3.15	10 8	14'3	14'8	39'7	24'2	33'1	30'	—	89'2	3'5	5	24'9	60'3	24'2	3'1	5
May 7th.																
7.00	10'2	14'5	14'5	38'7	—	—	—	—	89'8	4'3	—	24'2	—	—	—	—
8.25	10'4	13'5	13'3	39'5	32'	45'2	40'	39'	89'6	2'9	—	26'2	60'5	32'	5'2	1'
10.45	7'4	10'4	10'4	36'2	43'1	56'7	51'2	—	92'6	3'	—	25'8	63'8	43'1	5'4	—
2.03	10'4	15'4	15'8	38'8	37'3	50'2	44'4	43'8	80'6	5'	—	23'1	61'2	37'3	5'8	6
3.55	6'4	12'7	13'3	34'8	47'7	61'6	58'	57'5	93'6	6'9	—	21'5	65'2	47'7	3'6	5

The work is continued beyond this in only those cases in which the readings were completed. The other cases are here given to show that those used were about mean values.

Table VII is a continuation of those portions of Table VI, in which a complete analysis was made, and reduces the gas into its percentage by volume.

Table VIII gives the analysis of the top and bottom exhausts, the headings of the columns sufficiently explaining the quantities entered. The Elliott apparatus was used

on part of the work, and on the balance the readings beginning at 100 or 72 being the latter.

TABLE VII.—*Gas Analyses continued.*

PER CENT. VOL.

	CO ₂	O	CO	H	CH ₄	N
<i>May 5th.</i>						
11.10	2'40	—	24'27	7'46	'66	65'21
4.34	4'13	'20	17'54	4'78	3'40	69'95
<i>May 6th.</i>						
11.25	2'12	—	30'05	2'58	3'16	62'09
3.15	3 92	'56	27'92	3'91	1'40	62'29
<i>May 7th.</i>						
8.25	3'23	—	29'24	4'51	2'10	60'92
2.03	5'58	'45	25'65	5'60	1'10	61'62
3.55	6'73	'64	22'97	2'71	'73	66'22
	4'02	'26	25'38	4'51	1'79	64'04 = 100

Weight in 100 Pounds Gas.

	% Vol.	% Wt	C	O	H	N
CO ₂ ,	4'02 × 22 = 88'41	6'50	1'77	4.73	—	—
O,	'26 × 16 = 3'16	'23	—	'23	—	—
CO,	25'38 × 14 = 355'32	26'08	11'18	14'90	—	—
H,	4'51 × 1 = 4'51	33	—	—	'33	—
CH ₄ ,	1'79 × 8 = 14'32	1'05	'79	—	'26	—
N,	64'04 × 14 = 896'56	65'81	—	—	—	65'81
		1362'31	100'00	13'74	19'86	'59
						65'81

Table IX gives on the left-hand side the average composition by weight and volume of the exhaust gas, and on the right-hand the composition of enough of the gas by weight to include 13.74 per cent. of carbon and .59 per cent. of hydrogen, which was the amount in 100 parts of the original gas; that is, each 100 parts of the original gas required 126.64 parts of air by weight, making 226.64 pounds of exhaust gas. The oxygen and nitrogen added, are in the proportion of 22.5 : 77.5, which is about the proportion they should have had in the air added.

Table X shows the variation in condition of the fire during the time of the test; the first column showing the time at which the reading was taken; the second the distance

from the bottom of the rod to the bottom of the fire; the third the distance from the bottom of the rod to the top of the fire, and the fourth the thickness of the fire. The gas meter was attached to the pipe leading to the second scrubber, as shown in *Fig. 3*, by means of which the attendant noted the condition of the gas. The total quantity of gas used in this meter was 2,530 cubic feet. The power necessary to run the blower was found to be .085 horse-power on one inch of water, .28 for $6\frac{1}{2}$ inches of water and .431 for 9 $\frac{1}{4}$ inches of water.

TABLE VIII.—*Exhaust Analyses.*

TIME.	READINGS.				VOLUMES.				PER CENT. VOLUMES.				
	Orig. Vol.	KOH	Pyro.	Cu ₂ Cl ₂	Gas.	CO ₂	O	CO	Gas.	CO ₂	O	CO	N
Top Exhaust													
May 5th.													
10.20	3'	16'4	19'7	22'7	97'	13'4	3'3	3'	100	13'6	3'4	3'1	
5.15	1'6	17'1	19'1	18'7	98'4	15'5		—	100	15'7	2'1	—	
May 6th.													
10.55	7'	20'5	23'	23'	93'	13'5	2'5	—	100	14'5	2'6	—	
2.55	100'	84'6	81'6	100'	15'4	3'		—	100	15'4	3'	—	
4.47	72'	19'9	24'4	92'8	12'2	4'8	—	—	100	13'1	5'2	—	
May 7th.													
9.10	100'	84'8	81'	81'	100'	15'2	3'8	—	100	15'2	3'8	—	
10.15	9'8	21'9	24'8	24'8	90'2	12'1	2'9	—	100	13'4	3'2	—	
11.45	9'3	23'8	25'5	25'5	90'7	14'5	1'7	—	100	15'9	1'8	—	
1.20	12'4	25'1	28'7	87'6	12'7	3'6	—	—	100	14'5	4'2	—	
2.55	12'	25'5	28'2	88'	13'5	2'7	—	—	100	15'3	3'1	—	
5.30	10'2	24'	27'8	27'7	89'8	13'8	3'8	—	100	15'4	4'1	—	
Bottom Exhaust.													
May 5th.													
11.35	4'5	19'5	29'1	27'	95'5	15'	8'6	—	100	15'7	9'0	—	
12.25	2'1	17'3	20'1	16'2	97'9	15'2	2'8	—	100	15'5	2'9	—	
4.00	8'1	21'2	22'	21'7	91'9	13'1	1'	—	100	14'2	1'1	—	
May 6th.													
10.55	100'	83'2	83'2	82'7	100'	16'8	—	'5	100	16'8	—	'5	
1.08	10'4	25'1	26'0	26'2	89'6	14'7	'9	'2	100	17'5	1'0	'2	
2.55	4'6	21'0	21'7	22'9	95'4	17'4	'7	1'2	100	18'2	'7	1'2	
May 7th.													
9.10	9'9	25'	26'4	26'4	90'1	15'1	1'4	—	100	16'7	1'5	—	
11.45	100'	82'8	81'6	82'2	100'	17'2	1'2	'6	100	17'2	1'2	'6	
12.30	9'	23'3	24'5	24'5	91'	14'3	1'2	—	100	15'7	1'4	—	
3.25	11'3	25'7	26'5	26'5	88'7	14'7	'8	—	100	16'6	'1	—	
4.47	100'	82'	82'	82'	100'	18'	—	—	100	18'	—	—	
4.55	3'8	18'6	22'7	22'	96'2	14'8	4'1	—	100	15'4	4'2	—	
Mean of top and bottom,									100	15'60	2'24	'23	81'93

TABLE IX.—*Weight of Exhaust Gas Corresponding to One Hundred Pounds of Producer Gas*

	Per Cent. Volume.	Per Cent. Weight.	WEIGHT IN 100 POUNDS GAS.			WEIGHT CORRESPONDING TO 100 POUNDS ORIGINAL GAS, OR 13.74 C + .59 H.			
			C	O	N	C	O	N	H
CO ₂ ,	15.60	22.44	6.12	16.32	—	13.54	36.11	—	—
O ₂ ,	2.24	2.34	—	2.34	—	—	5.18	—	—
CO,	.23	.22	.09	.13	—	.20	.20	—	—
N,	81.93	75.00	—	95.00	95.00	—	—	165.94	—
	100.00	100.00	6.20	18.79	75.00	—	—	—	—
						5.38 H ₂ O	—	4.79	—
								165.94	.59
From 100 pounds original gas we have = 226.64 exhaust =							13.74	46.37	165.94
									.59

TABLE X.—*Height of Fire and Ash in Producer.*

Time.		Depth of Fire.		
		inches.	inches.	inches.
May 4th.				
5.45 P.M.	Bottom of rod to top of ashes, .	14½	39½	25'
May 5th.				
6.50 A.M.	.....	14'	34½	20½
8.35	.....	—	—	Fire raked.
10.00	.....	—	—	Fire raked.
10.07	.....	12'	32'	20'
1.55 P.M.	.....	—	—	Fire raked.
2.00	.....	18'	30'	12'
5.00	.....	19.5	40'	20.5
6.00	.....	19'	40'	21'
May 6th.				
7.30 A.M.	.....	13.5	24'	10.5
10.30	.....	18'	32'	14'
12.40 P.M.	.....	19'	43'	24'
4.30	.....	20'	41'	21'
5.40	.....	22'	41.5	19.5
May 7th.				
7.15 A.M.	(Note—Blast was on 15 minutes.)	20'	25'	5'
11.00	.....	18.5	37'	18.5
12.30 P.M.	.....	20'	41'	21'
1.30	.....	18'	33'	20'
2.30	.....	20'	38'	18'
3.30	.....	12.5	36.5	24'
4.30	.....	16'	42'	24'
5.30	.....	18'	43'	25'
5.50	.....	18'	44'	26'

At the end the distance from the top of producer to top of fire was 3 feet 6 inches.

GAS METER—CONNECTED TO BURNER.

	<i>Cubic Feet.</i>
May 5th, 7 A.M.,	500
6th, 7 A.M.,	1,340
7th, 7	2,190
7th, 6 P.M.,	3,030
Total	2,530
Average	84.8 cubic feet per hour.

The following will give the calculations to determine the efficiency of the plant and the different portions of it, together with the amount of coal used per horse-power :

Total coal used,	= 3657.4 pounds.
Time,	= 1788.69 minutes.
Explosions per minute,	= 157.57
Total carbon, $3657.4 \times \frac{84.76}{100}$	= 3100.01 pounds.
Gas used in meter,	= 2,530 cubic feet.

	<i>Volume.</i>		<i>Weight.</i>	
Comp. of gas by vol. and wt. =	CO ₂ , 4.02	C = 15.60	6.5	total C = 13.74
	O, .26		.23	
	CO, 25.38		26.08	
	H, 4.51		.33	
	CH ₄ , 1.79		1.05	
	N, 64.04		65.81	

Mean barometer 29.90 in. mercury, = 14.686 pounds.

Meter pressure, gas, = .062 pounds.

Temperature gas, = 74° 68 F.

Total absolute pressure gas, = 14.748 pounds.

Weight of carbon in one cubic foot of gas at 14.748 pounds, 74° 68 F.

$$= .071128 \times \frac{14.748}{14.7} \times \frac{492.66}{535.34} \times .1560 = .0102446 \text{ pounds.}$$

[Haswell, p. 215.]

Total carbon weight used in meter = .0102446 $\times$ 2,530 = 25.92 pounds.

Carbon chargeable to engine = 3100.01 — 25.92 = 3074.09 pounds.

Coal used for engine

$$= \frac{3074.09}{.8476} = 3,626 \text{ pounds.}$$

	<i>Per Cent.</i>
Composition of coal, } 4.20 moisture,	
6.88 volatile and combustion { Total carbon 84.76 per cent. { 5.80 C H ₄	
80.41 fixed C. or approximately { 1.78 H	
8.51 ash.	

Heat obtainable from one pound of coal (containing .8476 pounds carbon).

$$\begin{array}{rcl}
 .0580 \text{ CH}_4 & \times 23,883 & = 1385.214 \\
 .0173 \text{ H} & \times 62,032 & = 1073.154 \\
 .8041 \text{ C} & \times 14,500 \text{ [Wilson, p. 251.]} & = 11659.450
 \end{array}$$

Total 14117.818 B.T.U.

COMPOSITION OF GAS IN PRODUCER CONTAINING .8476 POUNDS C.

	<i>Per Cent. Weight.</i>			
CO ₂	= 6.5	$\left. \begin{array}{l} \\ \\ \\ \\ \\ \end{array} \right\} \times \frac{.8476}{13.74} = \left\{ \begin{array}{l} \\ \\ \\ \\ \\ \end{array} \right.$	$\begin{array}{l} \\ \\ \\ \\ \\ \end{array}$	$\begin{array}{l} \\ \\ \\ \\ \\ \end{array}$
O	= .23			
CO	= 26.08			
H	= .33			
CH ₄	= 1.05			
N	= 65.81			
	<hr/> 100			
CO ₂	.404			
O	.014			
CO	1.609			
H	.020			
CH ₄	.065			
N	4.060			

$$\begin{array}{rcl}
 \text{CO}_2 & . & .404 \\
 \text{O} & . & .014 \quad \text{[Wilson]} \\
 \text{CO} & . & 1.609 \times 4.328 = 6963.75 \\
 \text{H} & . & .020 \times 62,032 = 1240.64 \\
 \text{CH}_4 & . & .065 \times 23,883 = 1552.40 \\
 \text{N} & . & 4.060
 \end{array}$$

Heat in producer gas per pound coal, 9756.79 B.T.U.

Amount of carbon per explosion approximately

$$= \frac{\text{total C received}}{\text{exp.} \times \text{time}} = \frac{3074.09}{157.57 \times 1788.69} = .010907$$

Gas per explosion

$$= \frac{100}{13.74} \times .010907 = .07938$$

Air per explosion

$$\frac{126.64}{13.74} \times .010907 = .09963$$

TO DETERMINE WEIGHT OF 1 CUBIC FOOT GAS AT 14.748 POUNDS, 74° 68 F.

Moisture in gas, pressure .8579 inch mercury = .4214 pounds per square inch.

[Stewart, p. 436.]

Pressure of dry gas = 14.3166 pounds temperature, 74° 68 F.

1 cubic foot H at 14.7 pounds, 32° F. = .005594 pound. [Haaswell, p. 215.]

1 cubic foot H at 14°31'66 and 74°68 weighs

$$.005594 \times \frac{14.316}{14.7} \times \frac{492.66}{535.34} = .0050133$$

1 cubic foot of gas weighs

$$\text{CO}_2, \dots \dots \dots 4.02 \times 22 = 88.44$$

$$\text{O}, \dots \dots \dots .26 \times 16 = 4.16$$

$$\text{CO}, \dots \dots \dots 25.38 \times 14 = 355.32$$

$$\text{H}, \dots \dots \dots 4.51 \times 1 = 4.51$$

$$\text{CH}_4, \dots \dots \dots 1.79 \times 8 = 14.32$$

$$\text{N}, \dots \dots \dots 64.04 \times 14 = 896.56$$

$$\underline{1363.31}; \text{ sp. grav. (H = 1)} = 13.6331$$

Weight 1 cubic foot gas = $.0050133 \times 13.6331 = .06835$ pounds.

Cubic feet gas used per explosion

$$= \frac{.07938}{.06835} = 1.1614 \text{ cubic feet} = 2006.90 \text{ cubic inches.}$$

Cubic feet occupied by air per explosion. Assuming that the composition of the air is 23 parts O and 77 parts N, its specific gravity is 14.46 as compared to H, and

$$1 \text{ cubic foot air} = .0050133 \times 14.46 = .72492 \text{ pounds.}$$

Cubic feet of air used

$$= \frac{.09963}{.07249} = 1.3744 \text{ cubic feet} = 2374.96 \text{ cubic inches.}$$

Or the total volume of gas and air fed to the cylinder per explosion equals $2374.96 + 2006.90 = 4381.86$ cubic inches.

As this charges all coal to engine, including leakage and that used for blowing off in the morning, this amount should be greater than that required to fill the cylinder at atmospheric pressure.

From cards the average volume filled at atmospheric pressure was approximately 4012.673 cubic inches.

WEIGHT OF MOISTURE IN GAS AND PER EXPLOSION.

$$\text{Cubic inches,} \dots \dots \dots = 2006.9 = 1.1614 \text{ cubic feet.}$$

$$\text{Pressure,} \dots \dots \dots = 4214 \text{ pounds per square inch.}$$

$$\text{Temperature,} \dots \dots \dots = 74^{\circ}68 \text{ F.} = 23^{\circ}71 \text{ C.}$$

$$\text{One cubic metre,} \dots \dots \dots = 21.18 \text{ gramme [Kohlrausch,] p. 220.}$$

$$35.3161 \text{ cubic feet} = \frac{21.18}{2.205 \times 1,000} \text{ pounds.}$$

$$1.1614 \text{ cubic feet} = \frac{21.18 \times 1.1614}{2.205 \times 35.3161} \text{ pounds} = .0003159 \text{ pounds.}$$

ENTERED CYLINDER PER EXPLOSION.

Weight.		Pounds Gas.	Heat Units.
CO ₂ , . . . 6.50	$\times \frac{.07938}{100} =$	.005159700	
O, . . . 0.23		.000182574	
CO, . . . 26.08		.020702304	$\times 4,328 = 89.60$
H,33		.000261954	$\times 62,032 = 16.25$
CH ₄ , . . . 1.05		.000833490	$\times 23,883 = 19.91$
N, . . . 65.81		.052239978	
100.00		.07938	
Moisture,		.0003159	
Air, . . . 126.64	$\times \frac{.07938}{100} =$	.100526832	
Total weight per explosion, .		.180222732	
Total heat per explosion,			125.76

DISCHARGED FROM CYLINDER PER EXPLOSION.

Weight.		Pounds Gas.	
CO ₂ , . . . 49.65	$\times \frac{.07938}{100} =$	.039412170	
O, . . . 5.18		.004111884	
CO,49		.000388962	$\times 4,328 = 1.68$
H ₂ O, . . . 5.38		.004270644	
N, . . . 165.94		.131723172	
226.64			
Moisture,		.000315900	
Total weight per explosion, .		.180222732	
Heat obtained from each explosion,			124.08

HEAT CARRIED OUT EXHAUST FOR 1° DIFFERENCE OF TEMPERATURE.

CO ₂ ,	.0394	$\times$	.2169*	=	.0085
O,	.0041	$\times$	.2175	=	.0009
CO,	.0004	$\times$	.2450	=	.0001
H ₂ O,	.0043	$\times$	.4805	=	.0021
N,	.1317	$\times$	.2438	=	.0321
Moisture,	.0003	$\times$	.4805	=	.0001
					.0438

Difference between temperature of gas and of exhaust = $752.81 - 74.68 = 678.13$, and the heat accounted for in the exhaust per explosion = $.0438 \times 678.13 + 4.46\dagger = 34.16$, and assuming that the exhaust for those

* Stewart's Heat, p. 295.

† Heat of vaporization of H₂O.

times during which no explosion takes place, carries off the same amount of heat, we have

$$34.16 \times \frac{160.145}{157.57} = 34.72$$

heat units accounted for in exhaust.

Heat carried away in jacket water, . . . = 5988.5 B.T.U. per minute.

Heat carried away per explosion

$$= \frac{5988.5}{157.57} = 38.005 \text{ B.T.U.}$$

Heat per explosion turned into power (indicated),

$$\frac{127.7 \times 33,000}{157.57 \times 778} = 34.375 \text{ B.T.U.}$$

Brake H.P. per explosion

$$= \frac{92.49}{157.57}$$

Heat units equivalents

$$= \frac{92.49 \times 33,000}{157.57 \times 778} = 24.889 \text{ B.T.U.}$$

Heat in one pound coal, = 14117.818

Heat in equivalent gas, = 9756.79, eff. producer 69.1

Heat units available per explosion, = 125.76

Heat units used per explosion, . . = 124.08, eff. explosion 98.7

Heat units for exhaust, = 34.721

Heat units for jacket, = 38.005

Heat units for power, = 34.375

Heat units not accounted for, . . . = 16.98

Heat turned into I.H.P., = 34.375, eff. of transformation 27.7

Heat turned into B.H.P., = 24.889, eff. of machine, 72.4

Eff. of plant, $69.1 \times 98.7 \times 27.7 \times 72.4 = 13.66$ per cent.

Coal used per I.H.P. per hour

$$= \frac{3.626 \times 60}{127.7 \times 1788.69} = .9511$$

Coal used per B.H.P. per hour

$$= \frac{3.626 \times 60}{92.49 \times 1788.69} = 1.315$$

Combustible used per I.H.P. per hour = $.8729 \times .9511 = .8302$

Combustible used per B.H.P. per hour = $.8729 \times 1.315 = 1.148 +$

A large part of the 16.98 heat units not accounted for is partly due to the fact that the pyrometer in the exhaust shows a temperature which is less than the true temperature of the gases because of the short time of the exhaust, and partly to the fact that all the gas from the coal is charged to the engine, whereas part of it was discharged in putting the producer into operation.

The low mechanical efficiency was partly due to the fact that the engine was new, as it had just been completed when it was tested.

The results obtained include all the fuel used during the three days of the test and are therefore a fair indication of the amount of fuel that would be used in actual practice.

RESISTANCE TO SHIP'S MOTION : A NATURAL LAW NEWLY DISCOVERED.

BY F. M. F. CAZIN.

[*Concluded from p. 350.*]

Vendors of mathematical apparatus have a tool called burette, which is a glass tube, the inner transverse section of which is one centimetre square, this is of a diameter as $\sqrt{4/\pi} = 1.1848$ centimetre.

Then there are marks on the tube beginning at the open end of the tube, the other end being closed by a stop-cock, and these marks are distant the first from the open edge, and one from another just one centimetre, which leaves the inside (volume) spaces between marks to each measure just one cubic centimetre. And of necessity the water contained in the tube between each set of successive marks measuring one cubic centimetre weighs one gramme.

Besides this burette there should be procured three more objects, viz: a solid cylinder of the precise section to fill the tube and when inserted therein to (easily) slide therein without allowing any water to pass between it and the inner wall of the tube, the cylinder being just one centimetre long and in consequence in volume just one cubic