The price quoted for the accepted design, which some of the speakers said was low, he considered quite the reverse as compared with a surface condensing marine engine of the same power, which could be built at Home for about £1,500, or, allowing for the difference in the cost of labor, could be constructed here for about £2,000, and the marine engine was certainly the more complicated machine. He made this statement subject to correction, and with a view of giving any member an opportunity of explaining what appeared to him a high price for the guaranteed power.

Mr. T. H. Houghton considered that the author had taken some extreme cases as examples of the economy of the early Cornish pumping engines, and he (the speaker) did not think that anything like that duty had been attained in ordinary work.

The author advocated separating the engine from the boiler in considering the results of engine performances. In this he was quite right. It would have added to the value of his paper had he done so in the figures he had given.

Anyone who examined the matter closely must acknowledge that there had been a great advance in pumping engines within the last half century. In 1841 the duties of 50 Cornish engines were reported, the average being 65,000,000. In 1844 the duty of 37 engines averaged 68,000,000, few, if any, rotative pumping engines at that time were giving higher results.

The Cornish engines at the East London Water Works were stated to do a duty of 90,000,000, and as the steam consumption for four engines was given at 20·25 lbs. per I.H.P. per hour, no doubt this was correct.

He had prepared a table showing, as far as he had been able to ascertain, the steam consumption of various types of pumping engines, giving the duties obtained.

DUTIES OF PUMPING ENGINES.

Compiled by T H. Houghton.

No.		Date.	Boiler Pressure.	Indicated H.P.	Actual H.P. in Water Lifted.	Efficiency.	Lbs. of Coal per I H.P. per hour.	Lbs. of Coal per P.H.P. per hour.	Duty in million foot lbs. of Water Raised per cwt. of Coal.	Lbs. of Steam per hour.	
										Per I.H.P.	Per P.H P.
1	Cornish	..	..	..	..	82	2·03	2·47	90	20·25	24·7
2	Cornish	1870	30	184·5	149	80·7	2·93	3·6	62	23·44	29·0
3	Engines	..	31	146	117	80	2·6	3·2	68·6	24·15	30·19
4		..	40	175	140	80	3·2	4·0	54·4	32·02	40·0
5		1857	..	..	150	81	1·72	2·13	103·9	..	..
6		1867	40·5	306	247	80·7	1·61	1·99	111·35	..	..
7		1869	35	..	115·2	..	..	1·88	117·9	..	..
8	Rotative	1876	..	..	..	..	..	..	..	19·3	21·0
9	Compound	1876	..	198	..	83·7	1·63	..	124·9	16·48	19·69
10	Engines	1881	60	127·4	93·7	77	1·55	2·15	103·11	14·84	19 3
11		1883	50	222	..	85	1·53	1·82	121·6	15·65	18·3
12		1883	70	121	103·8	86	..	..	124·6	15·46	18·0
13		1884	60	194	..	86	..	..	..	15·12	17·58
14	Worthington	1886	101	130	120	92·3	..	..	..	16·67	18·06
15	Engines,	1889	75	296	250	84·6	..	..	..	16·5	17·75
16	Compound	1891	90	456·7	443·15	96·4	..	..	..	16·4	17·0
17		1891	110	606	564	93	..	..	..	15·7	16·88
18	Rotative Engine	1891	130	160	140	87·5	This is a tri	ple expans	ion engine.	13·53	15·47
19	Pulsometer ..	1876	72	..	..	..	..	53·06	3·73	..	477·5

1.—Results of tests on four Cornish Engines at East London Water Works:—

72 in. diameter of cylinder, 9·625 ft. stroke
80 in. ,, ,, ,, 9·75 ft. ,,
90 in. ,, ,, ,, 10·58 ft. ,,
100 in. ,, ,, ,, 11·00 ft. ,,

2.—Cornish Engine at Hebburn Colliery, near Newcastle-on-Tyne:—

70 in. diameter of cylinder, 10 ft. stroke.

3.—Cornish Engine at West Middlesex Water Works Pumping Station at Hammersmith:—

Cylinder, 68¼ in. diameter; 8 ft. stroke.

4.—Cornish Bull Engine at West Middlesex Water Works Pumping Station, at Hampton:—

Cylinder, 64 in. diameter, by 10 ft. stroke.

5.—Rotative Compound Woolf Beam Engines, at Chelsea Water Works, Surbiton:—

H.P. cylinder, 28 in. diameter; 5 ft. 6 in. stroke.
L.P. ,, 46 in. ,, 8 ft. ,,

6.—Rotative Compound Woolf Beam Engines, at Chelsea Water Works, Surbiton:—

H.P. cylinder, 28 in. diameter; 5 ft. 4 in. stroke.
L.P. ,, 46 in. ,, 8 ft. ,,

7.—Rotative Compound Woolf Beam Engine at the Berlin Water Works:—

H.P. cylinder, 40 in. diameter; 5 ft. 4 in. stroke.
L.P. ,, 60 in. ,, 8 ft. ,,

8.—Rotative Compound Engine, with cranks at right angles, at the Brixton Pumping Station of the Lambeth Water Works:—

H.P. cylinder, 22½ in. diameter; 5 ft. 6 in. stroke.
L.P. ,, 45 in. ,, 5 ft. 6 in. ,,

9.—Rotative Beam Compound with inclined cylinders, at the Lawrence Water Works, U.S.A.:—

H.P. cylinder, 18 in. diameter by 8 ft. stroke.
L.P. ,, 38 in. ,, ,, ,,

10.—Rotatve Compound Beam Engine, with cranks at right angles at the Ditton Pumping Station of the Lambeth Water Works Co.:—

H.P. cylinder, 21 in. diameter; 5 ft. 6 in. stroke
L.P. ,, 36 in. ,, ,, ,, ,,

11.—Rotative Beam Woolf Engines, at the Hammersmith Pumping Station of the West Middlesex Water Works Company :—

H.P. cylinder, 29 in. diameter ; 5 ft. 5 in. stroke.
L.P. „ 47½ in. „ 8 ft. „

12.—Vertical Rotative Engine, with cranks at right angles, at the Eastbourne Water Works :—

H.P. cylinder, 20 in. diameter ; 3 ft 4 in. stroke.
L.P. „ 38¼ in. „ „ „ „

13 —Rotative Woolf Beam Engine, at the Surbiton Pumping Station of the Lambeth Water Works Company :—

H.P. cylinder, 22 in. diameter ; 4 ft. 7 in. stroke.
L.P. „ 37 in. „ 6 ft. 6 in. „

14.—Worthington High Duty Pumping Engine :—

H.P. cylinder, 18 in. diameter ; 2 ft. stroke.
L.P. „ 36 in. „ 2 ft. „

The tests of this engine are described in Vol. 86, *Proceedings, Inst., C.E.*

15.—Worthington High Duty Pumping Engine, at the Hampton Pumping Station of the West Middlesex Water Works Company :—

H.P. cylinder, 27 in. diameter ; 3 ft. 6 in. stroke.
L.P. „ 54 in. „ 3 ft. 6 in. „

See *Engineering*, January 4th, 1889.

16.—Worthington High Duty Pumping Engine, at the Memphis Water Works, U.S.A. :—

H.P. cylinder, 30 in. diameter ; 4 ft. stroke.
L.P. „ 60 in. „ „ „

17.—Worthington High Duty Pumping Engine, used for pumping oil. See *Building and Engineering Journal*, September 24th, 1892 :—

H.P cylinder, 33 in. diameter ; 5 ft. 6 in. stroke.
L.P. „ 66 in. „ „ „ „

18.—Rotative Triple Expansion Vertical Marine Type Pumping Engine, at the East London Water Works :—

Cylinders, 18 in., 30½ in., and 51 in. diameter, by 3 ft. stroke.

He had excluded from this list the very high duty at Fowey Consols, and also some of the American results, for instance, Mr C. T. Porter, in 1883, when testing the pumping engine built by the Gaskill Co., for the Saratoga Springs, reported a duty of 142·4,000,000 for the first 12 hours of the test, and in 1882, Mr. S. M. Gray, City Engineer of Providence, as the result of a six days test of a Corliss pumping engine, at the Pettaconset Water Works, reported that after deducting the fuel used for banking fires and getting up steam, a duty of 154·6,000,000 was obtained.

He, however, preferred to take the steam consumption as the true test of an engine's economy, for, after all, it was only the coal that could be varied on a trial, the steam consumed per horse power was usually the same whether a special trial was being made or not.

In the table the examples were under four different heads.

Nos. 1, 2, 3, and 4 engines were Cornish, No. 1 being the results of tests made on four engines at the East London Water Works. No. 2 was the result of tests made on a large Cornish engine, near Newcastle-on-Tyne. Nos. 3 and 4 were tests made of engines at the West Middlesex Water Works, London.

Nos 5, 6, 7, 10, 11, and 13 were rotative engines built by Jas. Simpson and Co.

No. 8 was an engine built by Easton and Anderson.

No. 9 was an engine designed by Mr. E. J. Leavitt.

No. 12 was an engine built by R. Moreland and Sons.

Nos. 14, 15, 16, and 17 were compound Worthington engines.

No. 18 was a triple-expansion rotative engine at the East London Water Works.

From the table it would be seen that even allowing as high a duty as 90,000.000 in 1841, there had been, in the 50 years, a reduction in the consumption of steam per pump horse power per hour of 37½ per cent., and it must be remembered that 50 years ago the pumping engine was far ahead of the marine engine in economy.

The author's selection of the Brixton engine as a sample of the pumping engine of 1884 was rather unfortunate, as there were several causes which prevented a higher duty being obtained, and if he had taken No. 13 on the list it would have been better.

He did not agree with the author's remarks that the three Botany engines were of a standard English type. He would find very few single cylinder engines of that size, and fewer still with that type of valve gear. A duty of about 60,000,000 would be expected from such engine.

During a temporary interruption to the Potts Hill supply main, in 1890, he saw the small horizontal engine at Botany, designed by the author, working at 65 revolutions per minute, quite quietly, except in one pump valve box which had gun-metal valves in it, the others having rubber ones. This pump had, he believed, conical-ended plungers, but there was no great advantage in this form, for it had been tried by making the plunger with loose ends so as to ascertain if any difference was caused by this form, and none could be discovered, nevertheless he believed it was almost always done where practicable, it looked better even if it did no good.

The Worthington engines at Crown Street worked under great disadvantages, and, in considering the duty of them, it must be remembered that there was a large amount of ash in the coal. In 1891 he tested the boilers for a period of $30\frac{2}{3}$ hours continuous work, and found that only $7\frac{1}{2}$ lbs. of water was evaporated per lb of coal, from and at 212°. The coal contained 20·4 per cent. of ash and clinker.

He was pleased to be able to give the result of a month's continuous working with a Worthington engine of about the same size as Crown Street, and it would be seen that a duty of almost 90,000,000 was obtained.

WORTHINGTON PUMPING ENGINE AT NEW RIVER WATER WORKS, LONDON.

Days.	Hours of Work.	Gallons of Water Pumped.	Head of Water in feet.	Coal Used. Tns.	cwt.	qrs.	Pump H.P.	Pounds of Coal per P.H.P. per ton.	Remarks.
1888.									
Nov. 7	8¾	3,127,000	147·0	2	4	0	264·8	2·1	Average duty 109,070,000 Large coal.
,,	12	4,415,000	147·25	3	4	0	272·1	2·1	
,, 8	12	4,415,000	147·00	3	0	0	271·5	2·0	
,,	12	4,415,000	146·0	3	0	0	269·7	2·0	
,, 9	12	4,562,000	147·0	3	0	0	281·2	2·0	
,,	11¾	4,488,000	145·5	3	0	0	278·5	2·0	
,, 10	6½	2,612,000	147·25	1	8	0	..	..	
,, 28	1	368,200	156·00	4	4	0	..	..	Small coal used all the time. 7 cwt. of ash and clinker in each 12 hours. Percentage of ash and clinker in coal = 9·0. Duty = 38,750,000 = 2·5lbs. pr P.H.P. pr hour.
,,	12	4,455,000	156·00				..	..	
,, 29	9	3,129,700	156·00	7	4	0	..	..	
,,	12	4,528,860	156·00				..	..	
,, 30	11½	4,234,300	156·00	7	8	0	..	..	
,,	12	4,418,400	156·00				..	..	
Dec. 1	11½	4,271,120	156·00	7	8	0	..	..	
,,	12	4,492,040	156·00				..	..	
,, 2	12	4,418,400	147·75	3	12	0	..	..	
,,	12	4,418,400	148·75	3	16	0	..	..	
,, 3	12	4,455,220	147·75	3	12	0	..	..	
,,	12	4,455,220	148·60	3	16	0	..	..	
,, 4	12	4,455,220	147·00	3	12	0	..	..	
,,	12	4,555,220	146·75	3	16	0	..	..	
,, 5	12	4,492,040	146·25	3	16	0	..	..	
,,	12	4,492,040	144·60	3	16	0	..	..	
,, 6	12	4,492,040	144·75	3	12	0	..	..	
,,	12	4,418,400	153·50	3	16	0	..	..	
,, 7	12	4,455,220	148·25	3	12	0	..	2·5	
,,	12	4,455,220	147·33	3	16	0	..	2·5	
,, 8	12	4,418,400	153·00	3	16	0	..	2·5	
,, 9	12	4,418,000	..	3	12	0	..	..	Small coal per pump horse power per hour = 2·56 pounds. Duty, 86,600,000 inclusive on ash and clinker.
,,	12	4,234,300	..	3	16	0	..	..	
,, 10	12	4,455,220	..	3	12	0	..	..	
,,	12	4,234,300	..	3	16	0	..	..	
,, 11	12	4,528,860	..	3	16	0	..	..	
,,	12	4,528,860	..	4	0	0	..	..	
,, 12	8½	3,240,160	..	2	16	0	..	..	
,,	12	4,528,860	..	4	0	0	..	..	
,, 13	12	4,528,860	..	3	16	0	..	..	
,,	12	4,528,860	..	4	0	0	..	..	
,, 14	12	4,528,860	147·25	3	12	0	..	..	
,,	12	4,528,860	146·67	3	16	0	..	..	
,, 15	12	4,528,860	146·83	3	12	0	..	..	
,,	12	4,528,860	147·00	3	16	0	..	..	

WORTHINGTON PUMPING ENGINES AT NEW RIVER WATER WORKS, LONDON—*Continued.*

Days.	Hours of Work.	Gallons of Water Pumped.	Head of Water in feet.	Coal used.	Pump H.P.	Pounds of Coal per P.H.P. per ton.	Remarks.
1888.				Tns. cwt. qrs.			
Dec. 16 ,,	12 12	9,020,900	149·83	7 12 0	..	..	Small coal per pumphorse power 2·47 pounds. Duty, 89,780,000
,, 17 ,,	12 12	8,947,260	150·08	7 12 0	..	..	
,, 18 ,,	12 12	8,947,260	150·17	7 12 0	..	..	
,, 19 ,,	12 12	9,057,720	149·25	7 12 0	..	..	
,, 20 ,,	12 12	9,057,720	150·75	7 8 0	..	..	
,, 21 ,,	12 12	9,057,720	148·08	7 8 0	..	..	
,, 22 ,,	12 12	9,057,730	147·60	7 4 0	..	..	

The average results of over three weeks continuous work, burning small coal containing 9 per cent. of ash and clinker was 88,400,000.

One great advantage of the Worthington and other direct acting engines was in the large amount of useful work (over 90 per cent.) that could be obtained, as against about 83 or 84 per cent. with rotative engines.

As regarded the speed of pump plungers he might mention that the 8 ft. stroke pump at the West Middlesex Water Works had a pump piston speed of over 320 ft. per minute, and many engines had been made with a pump speed of from 360 to 480 ft. The tendency was to greatly increased piston speeds, and consequently smaller engines to do the same work, and also to getting all the strains self-contained, so as to lessen the cost of foundations and buildings.

If pumping engines were judged on their steam consumption, he thought it would be found that there was no very great falling off from the results found on tests. He was acquainted with many water works where most accurate accounts were kept of the engine performances, and where the engines ran on from one week to another without a stop; the trial duty was generally found to be kept up as long as everything was tight.

An engine for pumping, however, must, in addition to being economical in steam consumption, require very little for repairs, and the absence of any heavy moving parts in most of the direct acting pumping engines made to-day rendered them peculiarly free from repairs.

Professor Thurston found, as the result of numerous experiments, that about a half of the total friction was due to the crank shaft and connecting rod bearings.

FRICTION—ROTATIVE ENGINES.

Connecting rod ... ... } Crank shaft ... ... }	6 per cent.
Air pumps	3 „ „
Pistons	2 „ „
Pump valves and pistons	4 „ „
	15 „ „
Effective work	85 „ „
	100 „ „

DIRECT ACTING.

Air pumps	3 per cent.
Pistons	2 „ „
Pump valves, &c.	4 „ „
	9 „ „
Effective work...	91 „ „
	100 „ „

Mr. R. Pollock said that in the author's very interesting paper were two salient points:—

1st. The economy of fuel.

2nd. The piston speed per minute, compared with the marine engine.