fathom, the Dock engines have shorter strokes and slower piston speeds for their steam pistons than the pumps have; if their efficiency is high they present a great contrast to marine experience. Should there be anyone present who can furnish particulars about them it would be an acquisition to this discussion, for at first glance it would almost seem that some old mill engine patterns had been worked up, with large overhung discs added for driving the pumps, as a makeshift or temporary expedient. The design of the pumps themselves seem to be very good, as they seem to be fitted with pointed plungers somewhat like one of Messrs. Hudson Bros.' designs before you.

It is claimed for the Worthington High Duty Pumps that they are specially economical on account of them not wasting power to overcome the friction and air-resistance of the fly wheel, which occurs in rotary engines. What that power is can of course be easily calculated or ascertained by experiment, and if it is desirable to reduce it there is a possibility of interposing friction rollers or roller bearings to the crank shaft, to reduce that friction and carry the weight of the fly wheel partly or entirely.

The Worthington pump substitutes compensation cylinders for the fly wheel, but what the friction of the pistons, trunnions, crosshead pins, and the friction of the water in the presence of such compensating gear amounts to, has never, so far as the author is aware, been recorded. In "Engineering" of June 4th, 1889, there is an account of an elaborate test of Worthington High Duty pumps at Hampton by Professor Unwin, and about the same time the works at Stoke Newington had their new Worthington pumps tested by Mr E. A. Cooper, the duties recorded being 106 and 109 million respectively.

It must be admitted that these results, although no better, and perhaps worse, than old records, are good when compared with many very bad modern pumping engines; but unfortunately we have not, as in the case of steam vessels, the records of the regular daily and yearly work of these same pumps, which may give very different results. For instance :—

It is generally understood among those interested in this city that the Ryde engines made by Messrs. James Watt & Co. gave on trial a duty of over 122 millions with 100 lbs. of fuel exceedingly good, but that in actual work they have fallen very much below this. He hopes by the courtesy of the chairman of the Water and Sewerage Board to have official figures before replying to the discussion. Again, the duty of the Worthington pumps at Crown-street is said to be not much more than 70 millions in regular work. Of course, these pumps are at a disadvantage with the intermittent work, but still it seems that there must be something special in connection with pumping engines which makes their trial duty and regular work differ much more than is the case with marine engines.

Sufficient has now been said to answer the first query propounded by saying, – If the economy of marine engines has increased five-fold in the past half century, and pumping engines are just where they were, or a little way behind it, they have certainly not advanced with the times. Some of the reasons for this the author takes to be :—

(*a*) There has not been the competition between rival builders of pumping engines as there has been in the case of marine work.

(*b*) The carriage of coal is not required as at sea, and the storage of coal is of comparatively very small importance in the case of pumping engines.

(*c*) In relative size, or horse-power, the average of pumping engines is comparatively small when compared with marine engines. There is no necessity to reduce the weight of the machinery on shore as is the case on board ship ; and a pumping engine to indicate one hundred horse-power is often made more of than a marine engine of a thousand horse-power would be.

(*d*) Such a very high duty was obtained with low pressures and slow speeds in the early days by Cornish pumping engines that there has not been the scope for improvement, and no great inducement to go to high pressures and high piston speeds in the way which competition has compelled marine practice to advance.

(*e*) There seems to have been a prevailing opinion, or prejudice, perhaps, that pumps could not, or should not, be driven at a high velocity of piston or plunger, in consequence of the shocks of closing valves, friction of water in passages, and other causes, and such was of course actually the case with the early valves employed.

In answer to the second query as to what are the most important factors required to produce the highest duty in a pumping engine, nothing will be said about mechanical firing, as it is connected more directly with the boiler economy, but it is submitted:—

(*a*) A high grade of expansion is indispensable, and to secure the highest effective grade must mean high steam pressure, and, as a sequence, triple or quadruple expansion engines—practically bringing us to the modern marine engine.

(*b*) Increased piston speed in order to get a smaller and cheaper engine to do the work that is now done with a large one.

(*c*) The construction of the pump in such a way as to secure the minimum of friction in the waterways and passages, and also the least friction of its moving parts.

When the author first saw the designs of M. Farcot's pumps, made for the Paris Water Works, in 1876, he was so struck and impressed with their speed of 360 feet a minute, and with the logic of the principles embodied in them that on the first opportunity which occurred to him—now ten years ago—he adopted the same principles in the Botany supplementary pumps already referred to. Under such a design almost any practical piston speed of engine and plunger may be attained without producing either shock or concussion in the pumps, and thus the most economical description of engine may be designed without being tied to limited speeds, as with the ordinary class of pumps, and plunger speed being first determined, the pump can be proportioned for the quantity and lift of water it is required to raise without misgivings as to consequences.

For example, let us take an extreme case of say an engine, 10 feet stroke, and 50 revolutions, or a piston speed of 1,000 feet per minute. It will be seen that a plunger could easily be made of such a weight as just to float in water, and thus be so perfectly balanced as to give no upward or downward strain on its guides when working horizontally, and also that if it was properly pointed or sharpened at its extremities, it could be driven into the water contained in the pump casing at that velocity (which is equal to say 12 miles an hour), just as a steam vessel, or fish-torpedo rather, is propelled. Instead, however, of the particles of water being caused, by its displacement, to travel at the same rate of 1,000 feet a minute, in order to follow the plunger or piston in and out of the barrel, as would be the case in a common plunger pump; the water in the Farcot pump need actually move only a few inches at each stroke, because it closes in, or is wedged out a maximum distance, equal to its diameter, by the withdrawal and return of the pointed plunger, just as the water acts and is acted upon by the bow and stern bodies of a ship. The area of the valves through their water ways, in such a description of pump, can of course be made as large as is required to give the minimum velocity of flow, quite apart from the general design of the pump body and plunger.

As long as beam engines held the field for pumping it was easy, as in the Brixton examples, to put the pumps near to the main centre, and to make their velocity any proportion of the speed of the steam pistons that the calculation or fancy of the designer dictated ; but with the advent of the direct acting, inverted cylinder, or horizontal machine, simplicity required that the pump pistons should travel the same speed as the steam pistons, and here the author hazards the opinion that as marine engineers have had so much greater general engineering experience than pump builders have had, and so many greater difficulties to contend with, they would (if they were suddenly compelled to make waterworks engines without having any waterworks experience to fall back upon) do a given work of pumping, with a much smaller and cheaper machine than is now common, by giving it a much higher piston speed.

Increased piston speed means increased wear and tear, and there is of course a point where reduction of first cost would cease to be ultimately economical, but when we see pumping engines crawling along at from one-fourth to one-sixth the speed of marine engines it makes one think that their limit of economical speed is yet far from being reached, and when the power required to drive the fly-wheel is complained of it seems to be forgotten that its velocity is a great factor and that much lighter fly-wheels suffice for a given power with higher velocities.

The Cornish engines in the early days appear to have made about six or seven ten-feet strokes a minute, and we know that James Watts' standard was 220 feet per minnte for the pistons of rotative engines; but such a speed seems to be much higher than most pumping engines still run, although numbers of steamers are running their engines at 600 feet a minute. The tables appended will show that there is a wide margin for the pumps to move on before they catch up to the average steamboat engine.

It must be noted that many years ago, long before either the duplex system or the high duty compensating cylinders were adopted. The well known "Worthington" firm of New

York adopted the double-ended plunger in lieu of the piston for their ordinary direct acting steam pumps, and had they been rotative pumps, with security against knocking out the cylinder covers, they would no doubt long ago have pointed the plunger and otherwise improved the design of the pump chambers to secure freedom from eddies and unnecessary friction in the passage of water, and so have got greater piston speed and smaller machines for the same work, but with the slow velocity of moving parts which seems indispensable in such direct engines without a fly-wheel, there has been no incentive to still further improve the power of these pumps beyond the introduction of the compensating mechanism.

Messrs. Auldjo and Osborne's design for the "Waverley" engines, tendered for by Messrs. Vale and Son, and others, shows a pump with very large waterways through the valves, but the piston speed is still comparatively slow, and although it may be a great improvement on the ordinary type of pumps the author must acknowledge that he has never met with any other design of pump which, to his mind, at all presents the same qualities, both theoretical and practical, as M. Farcot's, for adapting it to a modern engine with high piston speed, and he further believes there would be no practical difficulty whatever in constructing a pumping engine on the Farcot system to run perfectly smoothly at a piston speed of 500 feet a minute, the speed of the Paris engines already referred to being 360, or 30 revolutions with a six-feet stroke.

If such is the case, then nearly all the designs of pumping engines now before this meeting could be altered to do much more work than they were designed for, by simply modifying the pumps to let them get away.

It will be instructive for us to note, and it will give plenty of scope for discussion, that whereas Messrs. Mort and Co., in the accepted plan, provide two 15″ and two 30″ steam cylinders, all of 33″ stroke, to do the work. One of the other designs—No. 10—of Messrs. Hudson Bros. has only one 14″ and one 28″

cylinder x 36″ stroke to do the same work, but the piston speed is there 300 feet, as against 187 in the former one. What is most remarkable in this comparison, however, is that the tender for the smaller machine was £4,604 as against £2,855 for the one about twice its size, emphasising the remarks made at the commencement of this paper, that we should have Messrs. Mort's price for Messrs. Hudson's design, and Messrs. Hudson's price for Messrs. Mort's design, before we can really institute a proper comparison and get the maximum of information from the designs before us.

Appendix No. 1.

PARTICULARS OF PUMPING ENGINES AS TENDERED FOR CONTRACT 169.

Sydney and Suburban Water and Sewerage Board.

Hudson Brothers.

Design.	Description.	Size of Cylinders.	Stroke.	Amount of Tender. £
A	Two Compound Vertical ..	Two $10\frac{3}{4}''$ & Two $21\frac{1}{2}''$ ...	36″ ...	4,851
B	,, ,, ,, ...	,, ,, ,, ,, ...	,, ...	4,851
C	One Compound Vertical ...	One $15\frac{3}{8}''$, One $30\frac{3}{4}''$.	36″ ...	4,736
D	,, ,, ,, ...	,, ,, ,, ,, ..	,, ..	4,736
E	Two Horizontal Engines ...	Two $10\frac{3}{4}''$ & Two $21\frac{1}{2}''$ ...	36″ ...	4,751
F	One Horizontal Engine ..	One $15\frac{3}{8}''$, One $30\frac{3}{4}''$ ...	36″ ...	4,676
G	One Vertical Compound ...	One 21″, One 36″ ...	36″ ..	5,075
H	Two ,, ,, ..	Two $15\frac{3}{4}''$, Two $26\frac{3}{4}''$ ...	36″ ...	5,163
J	Two ,, ,, ...	,, ,, ,, ,, ...	36″ ...	5,308
K	One Horizontal ,, ...	One 14″, One 28″ ...	36″ ..	4,601

Simpson and Houghton.

A	One Duplex Compound Horizontal	2,520
B	Two ,, ,, ,, ...	2,832
C	One Triple Expansion ,, ...	3,617
D	Two Triple ,, ,, ...	4,021
E	One Compound Duplex (High Duty)	6,857
F	Two Triple Duplex Vertical	6,695
G	One Compound Duplex Short Stroke...	3,782
J	Triple Duplex Short Stroke	6,047

Vale and Co.—Vertical Compound, One 25″ & One 42″, 30″ stroke	3,685
Morris Bros.— „ „ „ „ „	5,841
Hoskins Bros.— „ „ „ „ „	4,182
Atlas Co.—Vertical Compound, One 19″, One 32″, 42″ stroke ...	—

Mort's Dock Company.

Horizontal Compound Duplex, Two 15″, Two 30″, 33″ stroke ...	2,855

Appendix No. 2.

PARTICULARS OF PUMPS.

Ryde.

Diameter h.p. cylinder, 27 in.; l.p., 46 in.; stroke, 4 ft.

Type of pump, piston lifting double charge and discharging on down stroke.

Number of strokes per minute, 21·12 revolutions max.

Max. head, 308 ft., including friction.

Steam pressure, 85 lbs., max. 90.

Duty on trial, 112,818,000 ft. lbs. per cwt. coal.

Working duty, 79,000,000.

Length of main, $6\frac{1}{8}$ miles.

Diameter of main, $24\frac{3}{4}$ in.

Diameter of pump, 19 in.

Crown Street Pumping Station.

Worthington, No. 1.

Diameter l.p. cylinder, 43 in.; h.p., 22 in.; stroke, 4 ft.

Diameter pump plungers, 28 in.

Strokes per minute (max.), 20.

Max. head, including friction, 88 ft.

Steam pressure, 90 lbs.

Duty on trial, 100,000,000 ft. lbs.

Working duty, 63,000,000 ft. lbs.

Length of main, 1 mile; diameter, 36 in.

Type of pump, plungers.

CROWN STREET PUMPING STATION.

Worthington No. 2.

Diameter l.p. cylinder, 43 in.; h.p., 22 in.
Diameter pump plungers, 18½ in.
Strokes per minute (max.), 20.
Max. head, including friction, 162 ft. Woollahra, 255 ft. Waverley.
Length of main, 2 miles Woollahra, 3 miles Waverley.
Diameter of main, 24¾ in.
Type, plunger.

APPENDIX No. 3.

COMPARISON OF RYDE AND WAVERLEY PUMPS.

	RYDE.	WAVERLEY.
Steam pressure, boiler	90 lbs. ...	90 lbs.
„ „ engine	„	„
Diameter of steam cylinders	27″ & 46″ ...	10¼″ & 21½″
Ratio of steam cylinders in areas ...	2·9 : 1 ..	4·4 : 1
Stroke	48″ ...	36″
Combined areas of steam pistons ...	233·4 sq. in. ...	445·6 sq. in.
Pumps (piston and plunger diameter)	$13\frac{7}{16}$″ dia. ...	10¼″
„ 19″ piston = double plunger ... (Double Plunger only.)	area, 141·76 ...	area, 82·5 sq. in.
Actual height pumped	261 ft. ...	219 ft.
Frictional head	70 ft. ...	21 ft.
Total	331 ft.	240 ft.
Water head in lbs. pressure ... (2·3 ft. per lb.)	143·9 lbs. ...	104·3 lbs.
Water pressure on pump rams, each .	20390 lbs. ...	8604·75 lbs.
„ „ „ combined	40780 „ ...	17209·5 „
Steam pressure required ... ... (To balance water column.)	17·4 lbs. steam ...	19·3 lbs.
Water displaced one revolution of two pumps in cubic inches and gallons .	27,216 cu. in. .. 98·5 gallons ...	5,940 cubic in. 21·44 gallons
Delivery of engine, gallons	120,000 hour ... 2,000 min.	50,000 hour 833·3 per min.
Revolutions required per minute ..	20·3 ...	38·8
Piston speed (theoretical) per minute	162·4 ft. ...	232·8