In Fig. 8, Plate 11, A is the lower part of an air-vessel, beneath which is a chamber B. Communication between A and B is effected by means of the two pipes C D and E F, and is under control of the two cocks H K. The cock G serves to drain the chamber B, and by the cock J air can be admitted to the chamber to supply the place of the water so drained away. A contains water under pressure, and it is required to pass up into it the air from the chamber B. The cocks J and G are closed ; the cock K is then opened, and water passes down the pipe E F into the chamber, and compresses the air into the upper part of it. The cock H is then opened, and the air from the chamber rushes up through the pipe D C into the air-vessel, while water to supply its place passes down through the pipe E F. The cocks H and K are then closed, J and G are opened, and the water in B is drained off and replaced by air ready to be transferred to A as before. For this arrangement credit is due to the late Mr. W. R. Morris, of the Kent Waterworks.

For subduing the irregularities of pressure to which pumps and pumping mains would otherwise be subject, air-vessels of large capacity are now generally used in the place of expensive stand-pipes. Figs. 9 and 10, Plate 11, show a stand-pipe at Battersea, belonging to the Southwark and Vauxhall Company ; and Figs. 11 to 13 one at Kew Bridge, belonging to the Grand Junction Company. The latter is enclosed in a tower, which also contains a chimney.

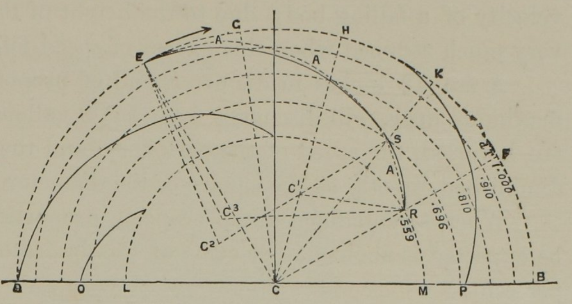
Centrifugal Pumps.—These pumps are so called because in them the principal agent in raising water is the centrifugal force created by the rapid revolution of a wheel or fan. This is the most modern kind of pump in general use; and its first introduction may be said to date from the Exhibition of 1851. It had been used long before that as an experimental machine, which had been occasionally tried in practice, but was quite unknown to the public. At the Exhibition of 1851, however, three pumps working on this principle were exhibited, and one of these, by Mr. Appold, was found to be so much superior to the others, and so well adapted for many practical purposes, that the machine immediately attained great favour and came into general use. We are indebted to a paper read by Mr. David Thomson before the Institution of Civil Engineers, in 1871, for the greater portion of the following account of the principles and rules which regulate the action and construction of this kind of pump.

The two centrifugal pumps shown in Figs. 129, 130, 133 and 134 were made by Messrs. Simpson & Co. from the designs of Mr. Thomson. The principle of action is the same in both, but the varying forms are adapted to different circumstances. The essential part consists of a revolving wheel, enclosed in a case, and similar in construction and use to the corresponding part of a ventilating or blowing fan. This wheel, W W W, in Fig. 129, is divided into two partitions by a centre plate, the clear width of each of these partitions being one-eighth of the diameter of the wheel. There are openings in the centre of each side-plate to admit the water, these openings being fully one-half of the diameter of the wheel. There are generally six curved arms or vanes to a wheel or fan. The revolution of this fan carries the water it contains along with it, and, on the centrifugal force driving the water outwards, fresh water enters by the centre openings O O, the arrows showing the direction of motion. A constant stream of water is thus created through the wheel, which, as it has no other way of escape, rises in the channel C and is discharged. The shape of the curved arms or vanes in the fan is an element of great importance in the construction of centrifugal pumps. It has been ascertained by numerous experiments that the best results are obtained with vanes curved backwards. The advantage of a curved vane over a straight one was clearly proved at a trial by the jury at the Exhibition of 1851, on the Appold pumps. This form of vane gave a maximum duty of ·68. A straight vane, inclined at an angle of 45° to the radius, gave a duty of only ·463; and straight vanes put radial, gave a duty of only ·243, all the three different kinds of vanes having been tried on one and the same pump. It is a necessary consequence of the curved shape of the vane, that the water is driven through the wheel, partly by the action of centrifugal force, and partly by the oblique pressure of the vanes on the water. The ratio which each of these forces bears to the other varies even in the same pump, according to the proportion that the speed of the pumps bears to the height of the lift.

The curve of the vanes should be such as to correspond with the path described by a particle of water in its progress from the interior to the exterior of the fan, and, if this is the case, it follows that, during its passage from the interior to the exterior end of the arm, the rotary motion of the fan must exceed that of the water by an angle equal to that subtended by the vane. In Fig. 127 the vanes are shown occupying angles of 90°, and under these circumstances it is clear that a particle of water starting at R, Fig. 127, the inner part of the vane, will make its way to E, the extremity, during the time that the fan moves with *reference to the water*, over an angle of 90°. To ascertain the intermediate points of the curve, it is only necessary to divide the space in the fan occupied by the vanes into four zones of equal area, as is done by dotted circles. The intermediate points of the curve will then be the points of intersection of these circles, with radial lines dividing the angle of 90° into four equal divisions.

In Fig. 127 are shown two methods of describing the vanes by circles, so as to make them coincide nearly with the points of the curve thus found. C is the centre of the fan, and D B the diameter of the exterior tips of the vanes. The circle L M marks the interior extremities of the vanes and also the size of the side openings in the fan for the admission of the water; L M = ·559 D B. The radii C E and C F are at right angles, and the vane E A S R subtends the angle between them.

FIG. 127.*



The approximate way to describe this vane by one arc of a circle, which is quite sufficient for small pumps, is the following: Through the points E and R, and from the centre C^3, describe the vane E A A R, with a radius = ·35 C B, as shown in dotted lines. The more accurate way to describe the same vane, as shown in black lines in two arcs of different radii, is the following:—

Draw the circle O S P, making the diameter O P = ·696 D B; then draw the radius C K so as to make the angle F C K = $\frac{1}{4}$ F C E; then through the points S and R, from centre C' draw the part of the vane R S with a radius = ·21 C B, and through the points S and E draw the remainder of the vane from the centre C^2, with radius = ·386 C B.

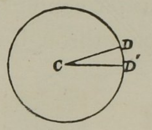
This manner of setting out the curves is better adapted for large pumps.

It has been a favourite idea with many designers of centrifugal pumps to contract the space between the sides of the fan at the circumference, so as to make the area of opening through the fan uniform, and thus preserve a uniform radial motion of the water during its whole passage through the fan. Experiments, however, made by Mr. Appold proved that this modification was productive of no increase of duty.

Looking at the matter from a theoretical point of view, it would appear to be more correct to enlarge the area of the fan towards the circumference, so that the speed of the water should be gradually diminished, as much as possible, and thus be made to part with a portion of its *vis viva*, before its discharge.

When a mass of water is contained in a wheel like the fan of a centrifugal pump, and is placed in connection with a discharge-pipe, so high that no water is discharged, the water in the wheel receives a motion of rotation, equal in speed to that of the wheel. Under these circumstances, the head of water supported at the discharge pipe will be that due to the pressure outwards of the centrifugal force of the revolving mass of water contained in the wheel, and may be thus calculated.

FIG. 128.



The cylindrical mass of water may be supposed to be divided into an indefinite number of small triangular sections, as C D D′ (Fig. 128), so small that the line D D′ may be considered straight.

Let d = diameter of the fan.

h = head of water supported by the centrifugal force.

s = speed per second of the periphery of the fan.

t = time in seconds of one revolution of the fan.

Then the radius of the centre of gravity of any small triangular section of the cylindrical mass of water will $= \frac{1}{3} d$.

It will be most convenient to express the weight of this triangular section of water, by the height of a parallel prism of equal weight, and having the area of its base equal to the area of the base of the triangular section, and in this way the weight of this section may be expressed by $\frac{1}{4} d$.

By the ordinary formula for centrifugal force

$$h = \frac{1{\cdot}2268 \times \frac{1}{3}d \times \frac{1}{4}d}{t^2}, \quad \text{or} \quad h = \frac{{\cdot}1022\ d^2}{t^2}, \quad \text{or} \quad \frac{d}{t} = \sqrt{\frac{h}{{\cdot}1022}};$$

$$\text{but} \quad s = \frac{3{\cdot}1416 d}{t} = 3{\cdot}1416 \sqrt{\frac{h}{{\cdot}1022}} = \frac{3{\cdot}1416}{{\cdot}32} \sqrt{h} = 9{\cdot}82 \sqrt{h}.$$

$$\text{Whence} \quad h = \frac{s^2}{96{\cdot}43}.$$

These formulæ give the following rules:—

I. To support any given statical height of water, without discharge, requires a speed per second of the periphery of the fan, equal to 9·82 times the square root of the given height.

II. When no water is being discharged by the fan, the statical height it will support is equal to the speed per second of the periphery of the fan, divided by 96·43.

For fans from 1 to $1\frac{1}{2}$ foot in diameter, it is found by experiment that $s = 8 \sqrt{h}$ nearly, and with large fans

* The figures at the dotted circles express their diameters in decimals of D B taken as unity.

it approaches more nearly to the theoretical value of 9·82 $\sqrt{h}$. This discrepancy between the theory and experiment is probably to be accounted for by the fact that, besides the water contained in the fan, a considerable quantity exterior to it is carried round with it.

The best duty with a centrifugal pump is obtained when the speed of the periphery of the fan exceeds the velocity of a falling body due to the height of the lift, by from 6 feet to 8 feet per second; but the duty is not very much reduced when this excess of speed falls to 4½ feet per second, or rises to 14 feet per second.

A fan 12 inches in diameter, and of proportions given in Fig. 127, when working at a speed affording the maximum duty, will discharge from 1,200 gallons to 1,400 gallons of water per minute. If the diameter of the fan is varied, the speed of the periphery, and the lift remaining the same, the delivery of water is increased or diminished directly as the square of the diameter. The proportions given in Fig. 127 are supposed to be retained.

When a centrifugal pump properly proportioned is worked by a steam engine, the *maximum* duty that may be expected is about 55 per cent. of the indicated power in the smaller pumps, rising in the larger ones to 70 per cent.

Centrifugal pumps may be most advantageously used for small or moderate lifts, and in such cases they give as good a duty as any pumps that can be made, while they are the simplest and cheapest of all. The ordinary valve-pump gives the best duty with high lifts; but for lifts of 15 feet and under, the centrifugal pump is quite equal to the valve-pump, and when the lift is reduced to 4 feet or 5 feet the centrifugal pump gives a better duty than the other.

It may be said that the larger the pump is, the greater is the lift which can be undertaken by it. An 18-inch fan has been found to work very well with a 20-feet lift, and a 3-feet fan with a 30-feet lift; but a 21-inch fan with a 40-feet lift has not given favourable results. Very high lifts are not advisable, as the speed required, together with the necessary driving power, are productive of much wear and other practical inconveniences. For temporary purposes, however, where a cheap and simple machine is required, and both these considerations are of secondary importance, centrifugal pumps may be strained beyond the limits here indicated.

The centrifugal pump is especially well adapted to such cases where the lift is both moderate in its maximum amount, and very variable. With the employment of nearly a constant amount of engine power it has a faculty of self-adaptation to a varying lift.

During the experiments made with the pumps shown in Figs. 129 and 130, the height of lift varied from 1 foot 3 inches to 12 feet 8 inches, and the discharge from 12,838 cubic feet to 7,162 cubic feet of water in 15 minutes, whilst the engine power kept very near the mean, viz. 23 H.P. (indicated) during the whole time of the trial.

Another great advantage of centrifugal pumps is, that having no valves they can without inconvenience pass water containing large quantities of solid matter in suspension. In fact, they will discharge anything they can pass through the water passages, which in the larger pumps are of considerable dimensions.

Fig. 129.

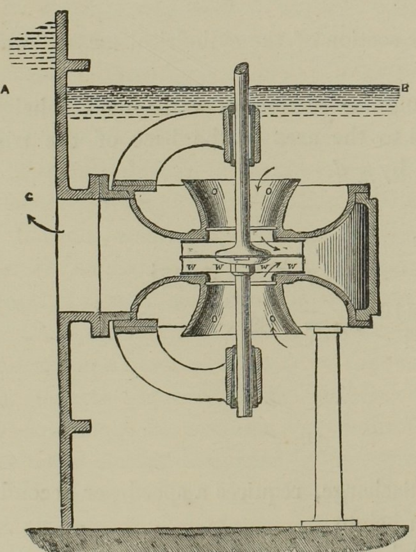
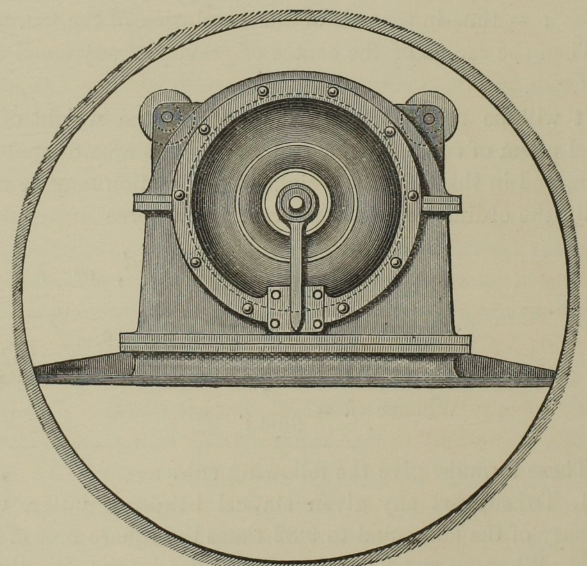


Fig. 130.



The pump shown in Figs. 129 and 130 is fixed under water; the advantages of this arrangement being that the pump is always charged. The spindle is vertical, and the fan and all the working parts under water are balanced and produce no pressure on the bearings under water, the weight being entirely taken by a grooved bearing at the top of the upright shaft, which is quite accessible. This pump is working at West Hartlepool Graving Docks.

The pumps shown in Figs. 131 and 132 are of the kind usually employed for the smaller sizes, and where portability is required. It requires a stop-back valve fitted to the bottom of the suction-pipe, and the means of charging the pump with water before starting it, as it is absolutely necessary to have it full of water to the top of the fan in starting it. The valve is rather apt to become leaky and inefficient where dirty water has to be pumped.

Fig. 131.

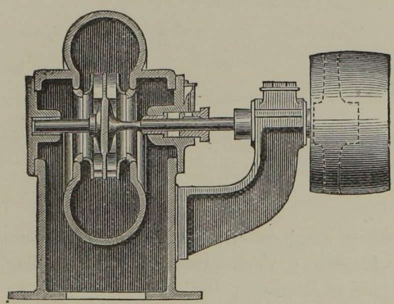
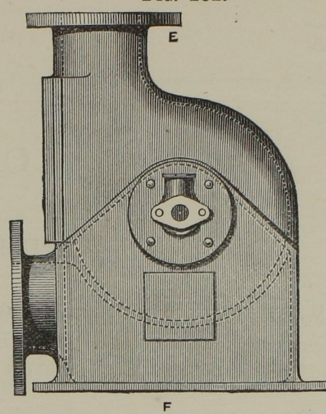


Fig. 132.



Figs. 133 and 134 show the pump at Leith, designed by Mr. D. Thomson. The fan is like one-half of a fan for the other pumps, and has an opening to receive the water at one side only. It works under water, with its spindle vertical, and discharges the water equally all round its circumference. The water then rises in spiral courses through the vertical pipe in which the fan works. All working parts, being fixed in conical seats, can be taken out at the top of the vertical pipe for repairs and replaced without excluding the water from the pump-well. The fan of this pump, being only one-half of an ordinary one, has to be made larger than in an ordinary pump, for a given amount of work. This causes a corresponding diminution in the number of revolutions per minute required for any given lift, which in ordinary-sized centrifugal pumps is a great practical advantage. A peculiar feature is the shield, *s s*, the object of which is to relieve the fan of the excess of pressure on the upper over that of the lower side, which excess of pressure tends to increase the weight to be supported on the fan spindle.

Fig. 133.

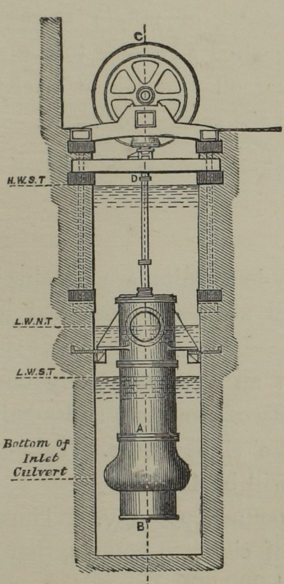
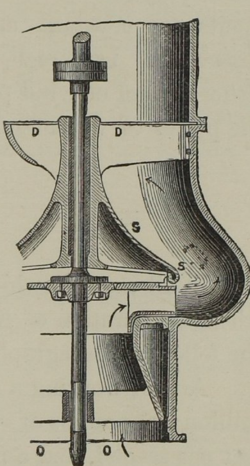


Fig. 134.



On the top of the fan there is a rim or lip, which fits a corresponding turned rim on the shield, thus enclosing a space above the fan, which is kept in communication with the suction side by having several holes drilled through the web of the fan, as shown in the figure. By making this enclosed space larger than the inlet opening below, not only can the unbalanced pressure be removed, but any required amount of pressure upwards may be obtained to neutralize the weight of the fan and the spindle, and consequently diminish the friction and wear in the working parts. The arms D D of the shield are made in a spiral or helical form to suit the motion of the water.

Although the friction of the fan in the water is nearly the same as that of an ordinary fan doing double the work, the duty of this pump has been as much as 70 per cent. of the indicated power of the engine. (The lift was at that time 20 feet, discharge 43,296 cubic feet of water in 15 minutes, revolutions of fan 195 per minute, indicated H.P. 81.) In a similar pump of only a $20\frac{1}{2}$-inch fan, the duty obtained, on an average of five experiments, was $71\frac{1}{2}$ per cent., with a lift varying from 20·83 to 23 feet.

In both pumps with vertical spindles there are no footsteps at the bottom, the bearings being above water.

CHAPTER XI.

PUMPING MACHINERY.

Animal Power—Wind Power—Water Power: Vertical Wheels; Turbines; Pressure Engines—Steam Power; Single-acting Non-Rotative Engines; Double-acting Non-Rotative Engines; Double-acting Rotative Engines; Vertical and Horizontal Engines; the Cornish and the Double-cylinder Rotative Engine; Pumps worked by different kinds of Engines; Boilers.

MACHINERY used for raising water is worked by the power of either animals, wind, water (as a medium for the force of gravitation), or steam. Of these, the first is used chiefly in eastern countries for purposes of irrigation; while both for irrigation and drainage, the second is largely employed. For the supply of towns, water power is utilised considerably on the continents of Europe and America, while in England the employment of steam for this purpose is almost universal. The hindrances to the use of animal power are its great relative cost and the practical inconvenience of its application, where the quantity of water to be raised is large. The objection to the employment of wind power is that it is very irregular and uncertain, while, on the contrary, the requirements are constant and indispensable; but this may be overcome by the introduction of ample storage reservoirs. Inasmuch, however, as circumstances may arise under which it may be deemed advisable to adopt either animal or wind power, a few memoranda thereon will be here given, before passing on to consider briefly the power of water and steam, and the machines by means of which they are applied to the raising of water.

Animal Power.

In all cases in which animal power is employed it is found that the most favourable results are obtained when the duration of work is limited to eight hours per day. This time, therefore, will always be reckoned in the following paragraphs.

A man working a pump by means of a lever in the ordinary way will develop, on an average, nearly one million foot pounds of work per day. The conditions yielding the best results are a velocity of about two-and-a-half feet per second, and a resistance of about thirteen pounds, equal to 936,000 ft. lbs. for the eight hours. Taking the daily wages of the man at four shillings, the cost of raising 1,000,000 lbs. one foot will be 4*s.* 3*d.*

Working a crank, a man will exhibit more than one and a quarter million foot pounds per day. Thus with the most economical velocity of two-and-a-half feet per second, and resistance of eighteen pounds, there will be 1,296,000 ft. lbs., which duty, at the rate of four shillings per day, is equal to 1,000,000 lbs. raised one foot high for 3*s.* 1*d.*

With a capstan a man's daily performance may be reckoned at one-and-a-half million foot pounds. The velocity is two feet per second, and the average pressure 26 lbs., giving for the eight hours, 1,497,600. This, at the same rate as above, is equal to 1,000,000 lbs. raised one foot high for 2*s.* 8*d.*

The most advantageous conditions are obtained when a man raises his own weight up a ladder or stair, for then two million foot pounds will be realised. Thus with a velocity of half-a-foot per second, and a weight of 140 lbs., there will be a development of 2,016,000 ft. lbs., equivalent to the raising of 1,000,000 lbs. one foot high for 1*s.* 11$\frac{3}{4}$*d.*

A horse will exert a force of 100 lbs. on a gin or mill at a velocity of three feet per second for eight hours per day, which is equal to 8,640,000 ft. lbs. Taking the horse-hire at seven shillings per day, the cost of raising 1,000,000 lbs. one foot high will be 9$\frac{1}{2}$d.

Walking in a straight track, and drawing a cart, or hauling a boat on a canal, a horse will for eight hours exert a force of 120 lbs., with a velocity of three-and-a-half feet per second, which is equivalent to 12,096,000 ft. lbs. per day. This, compared with the performance in a gin, shows the disadvantages of working in a circular track.

Watt's standard horse power is 33,000 ft. lbs. per minute, the actual work in a gin, 18,000 ft. lbs., that is, only six-elevenths of the former.

The work of an ox may be estimated at about six millions of foot pounds per day; the velocity will be lower, but the draught will be about the same as that of the horse.

Wind Power.

The efficiency of a wind mill, constructed according to Smeaton's well-known proportions, may be found from the following formula, the speed of the tips of the sails being two-and-a-half times the velocity of the wind.

$$\text{Horse power} = \cdot 00000062\ A\ V^3$$

In which A is the area in square feet of the circle swept by the sails, and V the velocity of the wind in feet per second.

Water Power.

The only hydraulic motors which it will be necessary to consider here are wheels and pressure engines; the former of which may be divided into the two general classes of vertical wheels, and horizontal wheels or turbines.

Vertical wheels may be divided into four classes, viz., overshot, breast, undershot, and stream wheels. The first two are actuated by the weight and impulse of the water jointly. In a common undershot wheel, with radial floats, the water acts by its impulse only. In the class of undershot wheels known as the Poncelet wheels, the water acts partly by its impulse and partly by its reaction upon the curved floats or vanes.

In an overshot wheel the water is led over the wheel and discharged on to its periphery at a high point on the further side. Breast wheels are those provided with a 'breast,' or curved trough, in which the wheel works, and which prevents that spilling of water from the buckets which takes place when the wheels are not so provided. With undershot wheels the water is directed against the floats from the bottom of a sluice, whence it issues with a force due to the elevation of the still surface. Stream wheels are those actuated by the current of a river, in which they are partly immersed. They are frequently attached to boats moored in the stream.

The gross horse-power of any fall of water may be expressed as—

$$H\ P = \frac{qh}{8 \cdot 8}$$

q being the number of cubic feet of water available per second, and h the height of fall in feet, measured from the surface of the still water above. The proportion of this power available in practice varies with the kind of wheel. Overshot and high breast wheels yield from 0·6 to 0·8 of the total power; undershot and low breast wheels from 0·3 to 0·4; Poncelet wheels 0·6 to 0·8; stream wheels 0·4. Such efficiencies are of course to be obtained only with the best wheels of their respective kinds. At the Geneva Waterworks is an example of pumping by a vertical water wheel. 'An undershot water wheel 33ft. 6in. diameter, and 20ft. face, drives a pair of double-acting pumps of a collective capacity of $6\frac{5}{8}$ gallons, at four times the speed of the wheel itself, the gearing being 4 to 1. At two and a quarter revolutions of the wheel per minute, 120 gallons are thus pumped per minute. Including friction and all resistances, the pumps work against the great resistance of 472 feet of water. The usual speed of the water wheel is however $1\frac{5}{8}$ turns per minute, and the corresponding head, including friction, is 380ft.'

Turbines.—In horizontal water wheels or turbines, the water acts either by impact, pressure, or reaction, but never immediately by its weight. Of the various kinds of turbines, that which has been longest in use is Fourneyron's. It consists of a cylindrical vessel in which the head water is received, and from which it is let out at the bottom between fixed curved vanes or guide blades. These impart to the water a circular motion, and direct it against the inside of a wheel, which encircles them, and which is provided with vanes curved backwards so as to be nearly radial at their inner, and nearly tangential at their outer extremities. The water thus passes horizontally and outwards through the wheel to the tail race.

Another class of turbine is that in which the water is directed by curved vanes or guides against the outside of a wheel which they encircle, and which is provided with curved vanes differing somewhat in their form from those just described. The water in this case flows inwards towards the centre of the wheel, whence it is permitted to escape in both an upward and a downward direction. The machines known as the Francis turbine, Professor Thomson's, and Schiele's, are of this class.

The next class includes Fontaine's and Jonval's turbines, in which the water is led on to the upper side of the drum or wheel, by guides fixed above it. Thus the water flows neither towards nor from the centre of the wheel, as in the former cases, but downwards through it to the tail race below.

Reaction wheels, or Whitelaw's turbines, are a kind of turbines in which there are no guide blades, the apparatus being simply an improved form of 'Barker's mill.' The lower end of the supply pipe is turned upwards, and the wheel or drum revolves over the aperture, the water being received into the wheel through a central opening on its lower side. This arrangement permits of the weight of the wheel being perfectly counterbalanced by the pressure of the water upon the area of the opening. The flow from the wheel takes place tangentially through apertures in the periphery.

With high falls the head-water is conveyed to the receiving chamber of a turbine by means of pipes. Sometimes the machine is placed above the level of the tail race, in which case the water is led from the wheel in a pipe, which thus becomes a suction pipe ; the fall from the wheel to the tail race, if not exceeding the height due to the pressure of the atmosphere, may thus be utilised, and the moving parts at the same time kept above water, so as to be always easily accessible.

The efficiency of turbines varies from 60 to 80 per cent., the kind first described, Fourneyron's, yielding about 70 per cent; inward-flow turbines or vortex wheels nearly 75 per cent ; Jonval's and Fontaine's, or 'parallel flow' turbines, 75 to 80 per cent; reaction wheels 60 to 65 per cent.

At the Fairmount extension of the Philadelphia Water Works are three Jonval turbines, each 9ft. in diameter, working from an average head of 11 feet. Each wheel drives two double-acting pumps 18 inches in diameter, and 6 feet stroke, the total lift being 115 feet. The pumps are worked at about 12 double strokes per minute.

At the works of the Îles des Meldeuses, near Meaux, about 9,000,000 gallons of water per day, for the supply of Paris, are raised from the river Marne into the Canal de l'Ourcq, by means of four double-acting pumps driven by a pair of vertical wheels, worked however after the manner of an outward-flow turbine. (See fig. 18, Plate 8.)

Water Pressure Engines.—The admission and discharge of the water is controlled by piston valves worked by the engine itself. These engines are well adapted for pumping purposes, having the same velocity and kind of motion as are necessary for the efficient working of pumps. The pump-rods are connected directly with the piston-rod.

Water pressure engines are only employed with advantage at a fall of about 60 feet and upwards; and they yield an efficiency of 65 to 80 per cent.

Steam Power.

The history of the steam pumping engine commences with the atmospheric engine, which is known as the Newcomen type. It is single-acting, the steam raising the piston, and the atmosphere forcing it down when a vacuum is formed by condensing the steam below the piston. This was improved upon by Watt, who substituted for it his single-acting engine without a crank.

Table showing the duty of Watt's Pumping Engine, as manufactured by Messrs. Boulton & Watt.

Description of Engine	Quantity of water raised per diem	Net Lift	Cost of raising 1,000 gallons 100 feet high	Number of gallons raised 100 feet high for one penny
	Gallons.	Feet.	*d.*	
One single-acting engine, in 1809, working $10\frac{1}{2}$ hours per diem, 6 days per week, mean power, $29\frac{1}{2}$ horse power, average of two years' working . .	612,360	100	·543	1,841
Two single-acting engines, in 1809, working 24 hours per diem, 7 days per week, mean power of each engine $30\frac{1}{2}$ horse-power, average of 10 years' working	2,922,480	90	·358	2,793
Two single-acting engines, in 1816, and one in 1828, working 12 hours per diem, 7 days per week, mean power of each engine 76 horse-power (average 10 years' working) . .	3,601,116	100	·333	3,000

This type of engine was in general use until the Cornish people began to work at it. They reversed the process, by making the steam lift the weight (as described at length in this chapter) which enabled them to carry the expansion to a much greater extent than Watt had done, as will be seen by the following data, taken from a single-acting pumping engine by Harvey & Co., upon the expansive principle, in 1837.

	Quantity of water raised per diem	Height to which the water is raised	Cost of raising 1,000 gallons 100 feet high	Number of gallons raised 100 feet high for one penny
	Gallons	Feet	*d.*	
Working 24 hours per diem, 7 days per week, mean power 95⅓ horse-power (average 4 years' working).	4,107,816	110	·150	6,666

In the above cases the coals are taken at 12*s.* per ton, and the charges of working the engines, materials and labour, are included, but not the interest for outlay or repairs of machinery. Simultaneously with the efforts of the Cornish people in this direction, there was a great deal done in applying the Watt double-acting engine to pumping, which Watt himself had done only to a limited extent.

The duty obtained by the Cornish single-acting engine was greater than that derived from Watt's double-acting engine, and it is only within the last 25 years that the double-acting engine has been made to equal and to surpass the Cornish engine in duty, and this has been done principally by the use of compound engines. The system of pumping by compound engines may be considered the most advanced now in use, and that by which the largest duty is obtainable, as will be presently shown.

The following table, compiled from the evidence given before the Royal Commission on Water Supply, gives the cost of raising a million gallons of water to the height of 100 feet at some of the largest waterworks, the cost of coals, oil, tallow, and ordinary repairs being included, but not interest on capital.

Waterworks	Authority	Cost of raising 1,000,000 gallons 100 feet high	Cost of raising 1,000 gallons 100 feet high	Number of gallons raised 100 feet high for one penny.
		£ *s.* *d.*	*d.*	
Grand Junction	Mr. Bateman	1 2 6	·27	3,703
East London	do.	1 1 0½	·256	3,910
Manchester W.-W. Gorton Engine	do.	1 11 7	·379	2,638
Liverpool. Green-Lane Engine .	do.	0 19 11	·239	4,184
Do. Windsor . . .	do.	1 4 1	·289	3,460
Do. Audley-Street . .	do.	1 3 5	·281	3,558
	Mr. James Simpson	1 0 3	·243	4,115
	Mr. Hawksley	1 0 10	·250	4,000
Southwark and Vauxhall . .	Mr. Quick	0 13 10	·166	6,024
Average of above		1 1 11¼	·263	3,798

In the mechanical arrangements of their parts modern steam pumping engines are of almost endless variety, and they are naturally capable, therefore, of many different classifications.

For the purpose of this work, however, they may perhaps be most conveniently grouped into three classes ; first, single-acting non-rotative ; second, double-acting non-rotative ; third, double-acting rotative.

Each of these, again, may be subdivided into direct-acting and indirect-acting ; in the former the pump-rod is continuous with the steam piston-rod, in the latter either a beam, crank, rocking-shaft, or other mechanism intervenes. Existing examples of the different types are illustrated on Plate 8.

Of the *single-acting non-rotative* class, No. 2 and No. 4 are *direct-acting* or Bull engines. The former is one of a pair at the Leipsic Waterworks, and has a cylinder 48 inches in diameter, working a plunger pump with a stroke of 8 feet, the diameter of the plunger being 21 inches. The plunger is provided with a hollow head, in which the necessary balance weights are placed. The valves of each engine are controlled by means of two cataracts, which will be presently described. The piston-rod, by means of a short link, works a beam which again works the cold water pumps, the air pump, and the feed pump.

At the up or steam stroke of the engine the plunger with its balance weights is raised, and the pump makes its suction stroke, delivering no water. The entire delivery is made on the down stroke by the weight of the loaded plunger, that is to say, unassisted by the steam, which during this time is simply passing through the equilibrium valve from the under to the upper side of the piston, and thence, subsequently, to the condenser. Each engine raises 196 cubic feet of water per minute against a dead lift of 142 feet, the number of double strokes per minute being $10\frac{1}{2}$, and the boiler pressure 45 pounds per square inch.

The engine numbered 4 on the plate is at work pumping water from a mine in Cornwall. It is similar in its leading features to that last described. The cylinder is 100 inches in diameter, and works with a stroke of 11 feet. The piston-rod is in a vertical line with the pump-pole, to which it is directly connected. The water is raised from a considerable depth by the weight of the pump-pole or 'spear' acting on the plunger of the pump. In the Leipsic engine weight is expressly added to the plunger; in the present case the weight of the spears upon the plunger would be in excess of that necessary to raise the water to the required height, but that it is counterbalanced by a weight at the opposite end of a beam linked to the piston-rod, as shown in the sketch. From this beam the air-pump &c. are worked, as at Leipsic.

Figs. 14 and 15 represent *indirect* single-acting, non-rotative engines, the piston-rod being at one end and the pump-rod at the other of their respective beams. The latter engine works a similar pump to that of fig. 4. The water is raised by the descent of the pump-rod, and the rods are raised by the steam stroke, in this case the down stroke of the piston.*

The West Middlesex Waterworks engine (fig. 14) has an 80-inch cylinder, and works with a 10 feet stroke, the pump being 24 inches in diameter and of the same stroke as the steam cylinder. It differs from those already described in the fact of its working a double-acting pump. A heavy cast-iron balance is connected with the pump-rod, and at the steam or down stroke of the piston not only has this weight to be raised, but the pump barrel has also to be discharged; on the return stroke the contents of the pump barrel are again discharged, but this time by the weight of the balance box alone.

Notice will hereafter be taken of the important difference between the application of single-acting engines to single-acting and to double-acting pumps.

This engine is supplied with steam at 40 lbs. pressure, cut off at $\frac{1}{3}$ stroke. The pumps deliver against a pressure of 200 feet, including friction.

The second class of pumping engines, namely the *double-acting non-rotative*, is illustrated by fig. 1, simple direct acting; figs. 7 and 8 combined direct and indirect acting, and fig. 3 simple indirect acting. Fig. 1, the engine at the Cincinnati Waterworks, has a cylinder of 100 inches diameter, with a 12 feet stroke, working a double-acting pump, 45 inches diameter, the stroke being the same. The air-pump is also double-acting, and is worked direct from the piston-rod. It is to be observed that in each of the engines previously noticed the air-pump is worked from a beam, and has a stroke only half that of the cylinder. The arrangements in the present case are exceptional. The water pumped is from the River Ohio, which rises and falls to the extent of 60 feet, the maximum lift is 170 feet. This engine is capable of delivering 800,000 gallons per hour.

Direct double-acting non-rotative horizontal pumping engines, with steam-worked valves, are fast becoming very popular, and have indeed been applied in engines of large size to the drainage of mines, working at the bottom of the shaft against heads of 1,000 feet and upwards. Engines of this kind are in use at the Slough and the Tottenham Waterworks.

Fig. 8 is a diagram of an engine at the Brooklyn Waterworks, working two single-acting pumps of peculiar arrangement, one directly from the piston-rod, which is for this purpose extended through the bottom of the cylinder, and the other from the further end of the beam. To each of the pump-rods a counterbalance is attached, and a vibrating balance also is connected with the mechanism, their total weight being 46 tons. The cylinder is 90 inches in diameter, and of 10 feet stroke. The pumps, which are duplicates of each other, are 36 inches in diameter, working against 170 feet head of water, including 10 feet friction.

The engine (fig. 7) at the Shortlands Station of the Kent Waterworks is of peculiar design. The cylinder is 40 inches in diameter, and 8 feet stroke, and is inverted. The piston-rod is connected directly to the plunger of a double-acting pump of the piston-and-plunger class, the piston being 12 inches diameter, and the plunger 10 inches; it is also connected by a pair of short links to one end of a beam, which at the other end works a common lift pump of 26 inches diameter. By the latter water is drawn from a well sunk in the chalk, and delivered into a cistern in which the surface condensers are placed. Having passed the condensers, the water is taken up by the piston and plunger pump and forced into the main. The supply of water is so large in proportion to the steam condensed, that the accession of temperature which the water undergoes in the performance of this duty is a very unimportant one.

Fig. 3 is a diagram of a double-acting engine employed for pumping water from a well in the chalk into an elevated tank on the top of the flag-tower of Dover Castle—a total height of 430 feet. In the arrangement of

* See 'The Engineer,' July 27, 1866.

the mechanism it is not far removed from a direct-acting engine of the type of fig. 2. It will be seen, however, that the cylinder is here placed at one side of the mouth of the well, so as to offer no obstruction to the removal of material from the latter. The piston-rod is connected to a beam of the third class, to the extremity of which the pump-poles are attached. From the bottom of the well the water is raised by a common lift pump, through a height of about 80 feet, into a tank from which, by means of a simple plunger pump, it is drawn and forced for a further height of 370 feet. The diameter of the cylinder is 29 inches, and the stroke 6 feet, the engine being worked with a boiler pressure of 60 lbs. The pumps have a stroke of 7 feet, the diameter of the plunger is $11\frac{9}{16}$ inches, and that of the bucket of the lift pump $11\frac{1}{8}$ inches. The engine makes about 7 strokes per minute, thus raising 10,000 gallons per hour.

The third and last class of pumping engines, namely *rotative* or fly-wheel engines, is a very large one. One of the most important differences between rotative and non-rotative pumping engines is that with the former the number of strokes made in a given time is necessarily proportional to the actual velocity of the piston and pumps, whereas with the latter the number of strokes made in a given time may be varied at pleasure, and yet the same actual velocity of the piston and pumps at each stroke be maintained. This and other differences will be discussed presently.

There are still in use at some of the metropolitan and other waterworks, a few old *single*-acting fly-wheel or rotative engines; but the manufacture of such engines has long been discontinued.

Direct-acting Rotative Engines are illustrated by figs. 5 and 6, Plate 8, and by Plate 9, showing vertical engines, and by figs. 16 and 17, Plate 8, showing horizontal engines. Fig. 5 is a small non-condensing engine, one of a pair at an auxiliary station of the Folkestone Waterworks. The cylinder is of 12 inches diameter working a 10-inch bucket and plunger pump, with a 2 feet 3 inch stroke.

The Eastbourne engine, Plate 9, is a condensing engine, and differs further in its design from that just noticed in having an inverted cylinder. The cylinder is 29 inches in diameter, and 2 feet 6 inch stroke, the barrel of the pump (a bucket and plunger) being 17 inches diameter. The pump delivers into a service reservoir with a lift of 270 feet, and occasionally into another service reservoir, with a total lift of 400 feet.

Fig. 6, one of a pair of coupled condensing engines of the Chicago Waterworks, is direct-acting as far as the pumps are concerned, the piston-rod being extended through the bottom of the cylinder, and connected directly with the pump bucket. The fly-wheel, which is 24 feet in diameter and common to the two engines, is worked by means of a beam and connecting rod, the ordinary parallel motion however being replaced by vertical guides as shown in the diagram. The cylinders are 44 inches in diameter, and of 8 feet stroke; the pump barrels are 28 inches in diameter. They are capable of delivering 750,000 gallons per hour, against a head of 125 feet, with a boiler pressure of 25 lbs.

Fig. 16 shows a direct-acting horizontal engine at the Sandown Station of the Isle of Wight Waterworks, having a 13-inch cylinder, with an 18-inch stroke, working an $11\frac{3}{4}$-inch piston-and-plunger pump, with a total lift of 148 feet, including friction, and delivering 400 gallons per minute.

Fig. 17 shows a pair of direct-acting horizontal *compound* or *double-cylinder* condensing engines, each working a pair of pumps, 14 inches diameter, with the common stroke of 4 feet. The diameter of the smaller or high-pressure cylinder, into which the steam is first admitted, is 18 inches; and that of the larger or low-pressure cylinder, the piston of which is driven by the exhaust steam from the smaller cylinder, is 32 inches. There are two fly-wheels to each engine, and the two piston-rods, two pump-rods, and two connecting-rods of each engine are attached to one cross-head, working in guides. These engines deliver 37,800 gallons per hour against a head of 215 feet.

Fig. 19 is a diagram of both a direct and indirect-acting engine, at the Crayford Station of the Kent Waterworks. The cylinder is of 24 inches diameter and 4 feet stroke, and the piston-rod is extended through both cylinder covers. The well pump is worked from one end of the piston-rod, through the intervention of a bell crank. The distributing pump is worked directly from the other end of the piston-rod. The well pump is that already shown by fig. 125, page 151, the plunger being 6 inches diameter. This pump delivers the water into a cistern containing the surface condenser, and from this cistern the distributing pump takes its suction, the arrangement being similar, in this respect, to that at the Shortlands Station (fig. 7, Plate 8). The distributing pump is of the piston and plunger class, the piston being 15 inches in diameter; it forces the water to a height of 300 feet. The slide-valves, air-pump, and feed-pump are each driven by a separate eccentric on the fly-wheel shaft; the engine is supplied with steam at 40 lbs. pressure.

Of the class of rotative engines, those in which the pumps are not worked directly from the piston-rod are illustrated on Plate 8, by figs. 9 to 13, and also on Plates 10, 40, and 47.

Fig. 12 shows an engine of a very useful type. The bed-plate is cast in one piece, and contains the condenser and cold-water cistern. The pump-rods are connected to the beam at a point as near its extremity as practical, thus giving the pump the benefit of a long stroke. The particular engine illustrated has a cylinder of 20 inches diameter, and works a 13-inch bucket and plunger pump, with a 36-inch stroke, against a head of nearly 200 feet.

Fig. 10 is one of a pair of compound engines at the Altona Waterworks, the small cylinder being 20 inches in diameter, with a stroke of 5 feet 3 inches, and the large cylinder 35 inches, with a stroke of 7 feet. The main pump, which is of the piston and plunger class, of 20-inch diameter, is worked with a stroke only half that of the crank and large piston, namely, 3 feet 6 inches. Each engine has an independent fly-wheel. The head against which the pumps work is 300 feet.

Fig. 9 represents one of four single-cylinder engines, which, though not used for the purposes of a water supply, yet are well-known pumping engines, being employed to raise all the sewage of the south of London. They have cylinders of 48 inches diameter, and 9 feet stroke, and beams 40 feet 6 inches long. There are two pump barrels to each engine, 12 feet in diameter, and in the cover of each barrel work four 54-inch plungers in two pairs. The two pairs nearer the main centre have a stroke of 2 feet 3 inches and the other two pairs have a stroke of 4 feet 6 inches. The air-pump and cold-water pump, with strokes of 4 feet 6 inches and 2 feet 3 inches, respectively, are worked from a counter beam.

Fig. 13 shows one of a pair of double-cylinder engines at the Berlin Waterworks. The large cylinders are 60 inches diameter, and of 8 feet stroke; the small or high-pressure cylinders are 40 inches diameter, and of 5 feet 4 inches stroke. Each engine works a 33-inch plunger pump, with an 8 feet stroke, supplying the filters with river water ; and also a 30-inch double-acting piston pump, with a 4 feet stroke, for pumping the filtered water against a head of 130 feet. The two pumps are worked from a parallel motion at the fly-wheel end of the beam; and the air, cold-water, and feed-pumps are on the other side of the main centre.

Fig. 21 shows one of a pair of pumping engines at the Gorlitz Railway Station. Each engine drives a pair of $3\frac{3}{4}$-inch plunger pumps, with a stroke of 14 inches, by means of a bell crank, the vertical arm of which is coupled to the steam piston-rod. The two engines have a common fly-wheel; the cylinders are 10 inches in diameter and of 14 inches stroke. These engines raise the water from the level of the river to a height of 144 feet.

The pumping motion shown in fig. 20, Plate 8, consists of two bell crank levers centered one above the other, each working a pump bucket. The vertical arms of the levers are slotted, and are both actuated by the same crank pin working in the slots. On the revolution of the cranks a vibratory motion is given to the two levers, as shown by the dotted lines. The double-bucket pump, which is worked by this motion, is shown in detail in fig. 126. The upper bell crank lever is attached to the lower bucket by a solid pump-rod, and the lower bell crank lever is attached to the upper bucket by a hollow pump-rod, the hollow rod admitting of the solid rod passing through it.

The reciprocating motion of the levers causes the buckets to move always in opposite directions, excepting during a short interval ; so that the top bucket is descending while the bottom bucket is rising and delivering its water through the top bucket. The top bucket, in rising, lifts the water above it while the bottom bucket is descending, the space between the two buckets being filled with the water rising through the descending bottom bucket. In this way the effect of a double-acting pump is produced.

In the revolution of the crank, the dead point of one of the levers is passed before that of the other is reached, so that the bucket which first comes to rest at the end of its stroke is started into motion again before the second bucket comes to rest. On each turn of the stroke, therefore, both buckets are simultaneously lifting during the time occupied by the passage of the crank through the interval between the dead points of the two bell crank levers; so that by the time one of the buckets ceases lifting, the other is already doing its work. A steady continuous flow of water is thus obtained, without any pause occurring in it, and no shock or vibration is produced at either end of the stroke.

Several of the pumps driven by horizontal engines, coupled to them by means of gearing, are now at work with lifts from 150 to 200 feet, and have been in operation for five or six years without the makers being once called upon to repair them; the same plan of pumping has also been applied to deep wells.

The engines illustrated on Plates 40 and 41 have high-pressure cylinders of 27 inches diameter, and 5 feet 4 inches stroke, and low pressure cylinders of 54 inches diameter and 8 feet stroke. A lift pump is worked from each end of each beam, with a stroke of 10 feet 8 inches. Those at the fly-wheel end are $15\frac{1}{2}$ inches diameter. They lift the water from the well and deliver it to the pumps worked at the other or cylinder end of the beam. These latter are 15 inches diameter, and deliver the water into the service reservoir adjoining the engine-house.

Having thus given some general ideas of the mechanism of various kinds of pumping engines, attention will now be bestowed upon their relative merits in point of efficiency and economy.