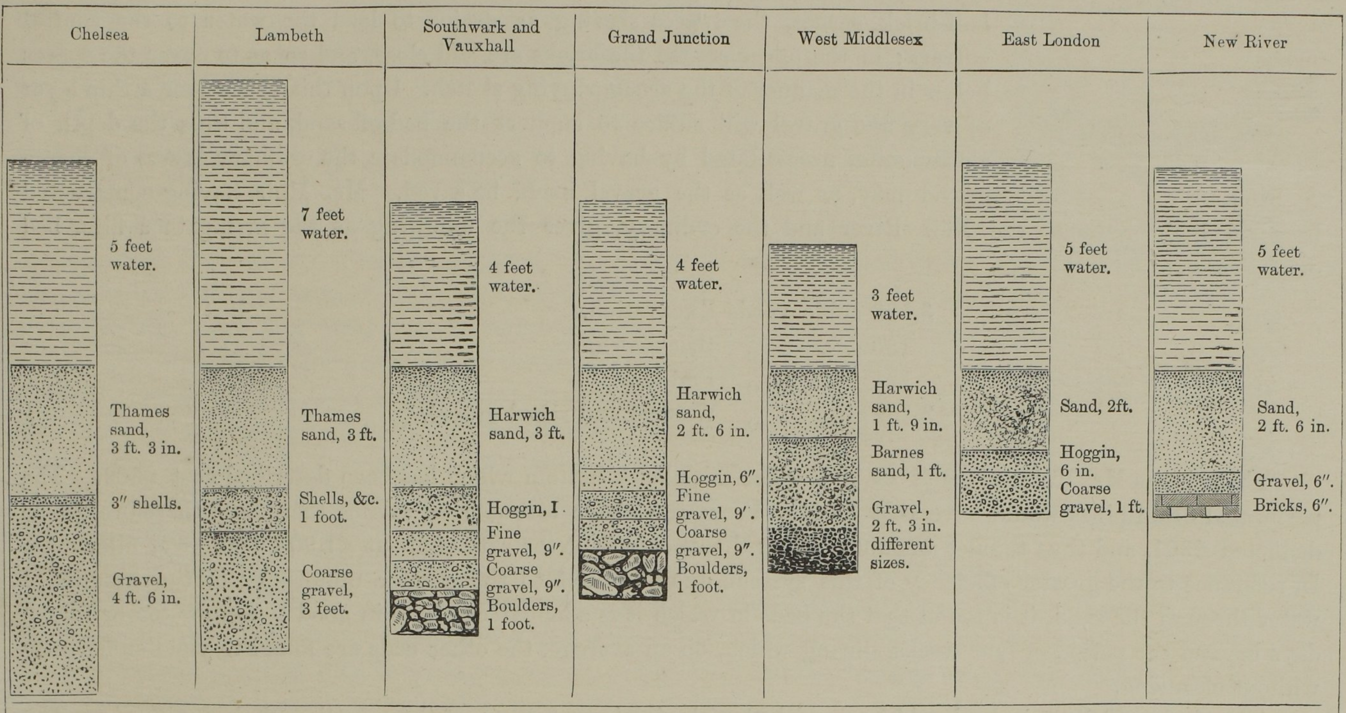
the number of hours that there are feet in depth of water on the sand. Considering also that increased depth of water means increased cost of construction, the shallow depth would appear on the whole to have the advantage. In districts exposed to very low temperatures the probable thickness of ice will have to be allowed for, as otherwise the easy distribution of water over the sand surface might be interfered with, or the sand itself might become frozen and the filtration be thereby altogether stopped. Two feet to two feet six inches would seem to be quite sufficient for this country.

FILTER BEDS OF THE LONDON WATER COMPANIES.



RATE OF FILTRATION.

Chelsea	Lambeth	Southwark and Vauxhall	Grand Junction	West Middlesex	East London	New River
6·4 inches per hour.	10·7 inches per hour.	3·0 inches per hour.	3·1 inches per hour.	2·7 inches per hour.	2·5 inches per hour.	4·5 inches per hour.

In designing the vertical sections of a filter bed to pass a given quantity of water at a given rate, the dimensions upon which the effective area depends should be taken at the level where the sand is most contracted, for here the velocity of filtration will of course be at its maximum. It will be rightly inferred from this that the additional area of a filter bed having sides sloping or battering considerably is useless for the purpose of filtration, although it may sometimes permit more economical construction. Where, however, the cost of the land is high, the latter consideration will probably be set aside. In Fig. 1, Plate 5, beds No. 5 and No. 6 have each one acre of efficient sand. The difference in the gross areas they occupy is due to the difference between the methods of construction shown respectively in Figs. 4 and 7.

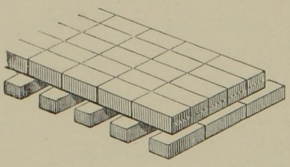
The inlet arrangements should be such as to allow of the filter being charged, after emptying for cleaning, without extensively disturbing the sand. Where it is convenient so to do, a good plan is to allow filtered water from an adjacent bed to flow up the drains of the filter to be charged until it has covered the sand to the depth of 6 or 8 inches. In many cases the water is admitted into a long trough, closed at the farther end, and over the two sides of which the water flows in a gentle current; in others, the inlet pipe is carried to the centre of the bed and turned upwards; and at the Chelsea Company's filters, and elsewhere, the admission of water to the beds is through a wall of gravel contained between two concentric semicircles or horizontal arches, as it were, of brickwork, laid with open vertical joints. This arrangement affords the water a preliminary screening or rough filtration.

For drawing off the filtered water, drains of one kind or another are laid on the bottom of the bed in the stratum of gravel. Perhaps the simplest method consists in the employment of perforated stoneware drain pipes, or ordinary pipes laid with open joints, as illustrated on Plate 18. In larger works the pipe drains generally lead into a brick culvert traversing the filter bed. This culvert may very conveniently be made to support the distributing trough, as illustrated in Fig. 8, Plate 34. Frequently the small feeding drains are formed with bricks laid dry, as shown in Figs. 2 and 3, Plate 2, and Fig. 6, Plate 38.

In Figs. 7 and 8, Plate 6, are shown the lines which Mr. Spencer supposes the water will be caused to follow in its descent by the introduction of the stoneware 'regulators' forming part of Mr. Spencer's system. It can scarcely be supposed, however, that the water in passing through the medium will take such a circuitous course instead of following the line of least resistance, and making to the drains, of whatever kind they be, the easiest passage it can trace out.

In the filters of the Lambeth Company at Ditton, the gravel is supported by a flooring of slate slabs resting on dwarf walls, and having half-inch open joints through which the water drains. But that which may perhaps be considered on the whole the best method of draining a filter is Mr. Muir's, of the New River Company. It is illustrated by Figs. 8 to 10, Plate 5, and consists in the disposal of two courses or layers of bricks laid flat and dry. In the lower course the bricks are placed end to end in rows alternating with half-brick spaces, the spaces serving as drains to lead the water to the central culvert; in the upper course the bricks are laid close, and so as to cover the spaces below in the manner of the accompanying sketch. Upon this brick floor a thin layer of very fine gravel will suffice to support the bed of sand, and thus the depth of construction necessitated by having to accommodate the ordinary layers of coarse gravel may, as well as the gravel itself, be saved. Mr. Muir, having constructed beds on both systems, the New River and the ordinary, gives the following as the saving in a filter bed of one acre:

FIG. 99.



3,528	cubic	yards	Excavation.
155	,,	,,	Brickwork.
121	,,	,,	Puddle.
3,332	,,	,,	Washed and sifted gravel.

These items Mr. Muir values at £2,260. The false brick bottom which has been described cost £502. The perforated drain pipes would have cost £141. From the above estimate of saving there has, therefore, to be deducted £361, and thus the net amount of effected economy is at the rate of about £1,900 per acre of filter area. In reference to the greater efficiency of this system, due no doubt to the greater uniformity of the draught of water through the sand, it is found that the beds in which it is adopted continue in good action for ten or fifteen days beyond the period of four weeks, during which, on an average, the other beds are found to yield sufficiently without cleansing.

The drains of filter beds should be furnished with air pipes, to prevent them getting choked with air. The overflows to filter beds are best arranged at or near each angle, and should be commanded by sluices, so that the scum, especially that which with some waters is so prevalent in hot weather, may be readily cleared off by opening the leeward sluice when there is a breeze. Drains should be provided, also, for drawing off the water from both above and below the sand, without passing it through the clear-water well or tank.

Filter beds will require cleaning out after they have been in operation for a length of time, varying from one week to six or eight, but which will depend generally upon the fineness of the medium, and the quantity and quality of the water that has passed through it. When clean, an ordinary sand filter will require only two or three inches head to yield water at about the ordinary rates; but, as the sand becomes clogged, this loss of head will increase, or, if the head be maintained constant, the yield will gradually diminish. Filter beds, especially those worked at a slow rate, will often be found to require cleansing before the yield becomes greatly reduced. This will occur mostly with bright water containing suspended organic matter which accumulates in the bed, and, in time, has an injurious effect even on the quality of the filtered water itself.

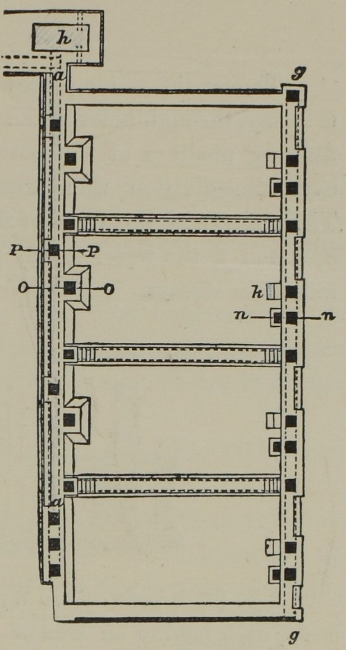
The process of cleaning, as ordinarily practised, consists in the removal of a film of sand of from a quarter to half an inch in thickness; in this thin layer the suspended impurities will be found collected. The clean sand remaining in the bed should then be loosened with a fork to the depth of six or seven inches, and in this state allowed to lie exposed to the air as long as possible. Before the filter is again charged, the sand should be smoothed over. This process may be repeated until from nine inches to a foot of sand is left, when the bed should be re-made.

For washing the sand previously to its replacement in the filter beds, various contrivances are used. One is an iron box or cylinder open at the top, and having a false bottom perforated with small holes. The box is charged with the sand to be washed, and water under high pressure is admitted underneath the false bottom, through the holes in which, it rises with great force, boiling up as it were through the sand. The agitation thus caused effectively loosens the dirt from the sand, and the former is carried away with the water, leaving only the clean sand behind.

In some works the dirty sand is placed in a heap on the sloping bottom of a shallow chamber about 10 feet long, 5 feet wide, and 2 feet deep. Water under high pressure is then directed against the heap of sand from a hose pipe by the man in charge, until it flows away clear over a small weir at the lower end of the chamber. Two chambers are used, placed side by side, so as to be worked alternately.

At the Chelsea Company's works, Seething Wells, the sand is washed in a 'squirrel cage,' or double-screening cylinder of coarse wire gauze, the axis of which is inclined to the horizon, and consists of a perforated pipe. The sand falls from a hopper into the internal cylinder, and is washed by jets of water under pressure issuing from the holes in the central pipe. Water is also allowed to play upon the sand from pipes on the outside. The cylinder is caused to revolve; and, while the sand falls through the meshes of the gauze, any gravel that may have been mixed with it is rolled out, washed, at the lower end. The sand passes into troughs, where it is allowed to deposit, the dirty water flowing away to the drains.

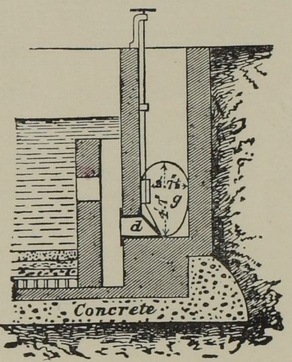
Fig. 100.



The apparatus illustrated on Figs. 5 and 6, Plate 24, is worked similarly to that first described; but the pressure used in this case is only that of a few feet of water.

The filter beds of the Dunkerque Waterworks, recently constructed from the designs of M. Parvels, are specially arranged with a view to being cleansed by a reverse current in the manner to be described. There are four compartments, shown by the plan, Fig. 100, each 52 feet 5 inches long and 26 feet 3 inches wide. The unfiltered water is supplied to the beds from an egg-shaped culvert *g g*, formed in one of the side walls of the filter bed, as shown by the section, Fig. 101. The supply is controlled by a valve *d*. In the opposite wall, *a a*, Fig. 100, are three culverts, shown at *a*, *b*, and *c*, in the sections, Figs. 102 and 103. When the beds are in ordinary operation the filtered water flows from the bottom of the bed through the opening *e*, Fig. 102, into the culvert *b*, and thence into the pump-well *h* (Fig. 100). If it be required to lead unfiltered water to the pump-well, this may be done by means of culverts formed in the transverse wells and communicating between the culverts *g* and *b*. When it is necessary to cleanse the filtering medium the valves *d* and *e* are closed, the valve *f* (Fig. 103) is opened, and so also is a communication (at *k*, Fig. 100) between the culvert *g* (Fig. 101) and the channels beneath the medium. The water from the culvert *g* is caused to rise rapidly through the media, so as to dislodge the foreign matters accumulated there, and is then drained away, through the valve *f* and culvert *a*, into a well from which it is pumped into the sewers of the town. The beds can be drained or scoured out at any time through the culvert *c* by means of a communication not shown in the figures. It would appear that the filtering medium might be readily cleaned, and often, no doubt, with fewer disadvantages, by means of filtered water, from one of the other compartments. Thus, if the two passages communicating with the culvert *g* be closed, and the valves *e* and *f* opened, filtered water will pass from the culvert *b* upwards through the media, and away through the valve *f* and the culvert *a*, as before.

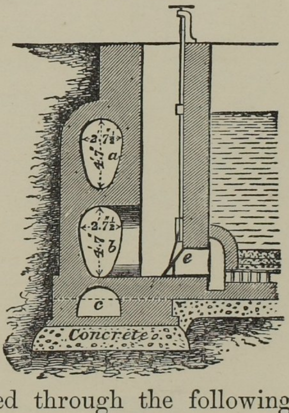
Fig. 101.
SECTION N N.



The beds of these works are formed of the following materials:—

Sand		7·8 inches.
Washed Coke-dust, very fine	2 inches	6.0 ,,
,, ,, fine	2 ,,	
,, ,, moderately coarse.	2 ,,	
Calais pebbles		5·9 ,,
Perforated tiles set in Portland cement		1·18 ,,
Bricks laid open on edge		5·12 ,,
		26·00 inches.

Fig. 102.



Filtration is allowed to take place at the rate of more than 24 inches per hour, and for this an effective head of from 1 foot 4 inches to 2 feet 8 inches is required.[*]

Fig. 104 shows the filtering arrangements at the Leghorn Waterworks. The water from the supplying conduit is first led into a semicircular chamber, *a'*, through holes, *a*, *a*, *a*, in the side of a trough or channel which runs round it. Here it is filtered through the following media:—

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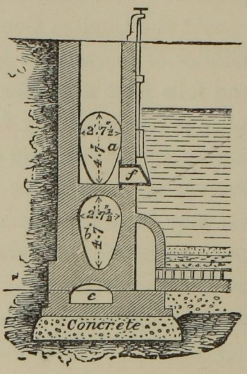
[*] Engineering, vol. xiv. page 206.

Coarse gravel	8 inches.
Wood charcoal	12 ,,
Coarse gravel	8 ,,
Fine gravel	12 ,,
Total	3 feet 4 inches.

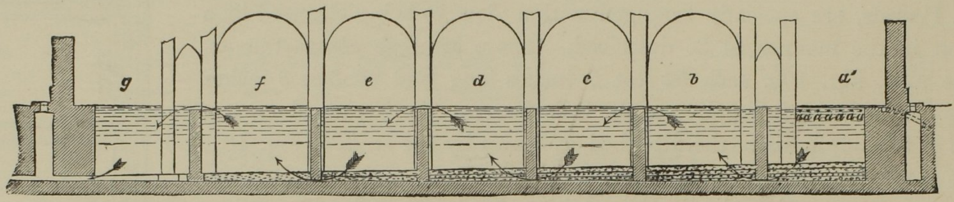
Fig. 103.

SECTION P P.



Thence the water passes into the second chamber *b*, as shown by the arrow, that is to say, through holes in the bottom of the division wall, and then upwards through the filtering medium at the bottom of the chamber. It then flows into the chamber *c*, over the division wall, there being no holes in the bottom as in the first wall. These alternate processes of filtration and aeration are continued through the chambers *d*, *e*, and *f*, the water finally passing into the chamber *g*. The source of supply is a mountain stream.

Fig. 104.



The filter beds of the Wakefield Waterworks are formed as shown on Plate 6, Figs. 7 to 10. There are two beds, each having an area of 650 square yards, one bed being exposed to the air while the other is being worked. They are designed to filter at the rate of between three and four inches per hour.

The cost of the filtration of water through sand, as ordinarily conducted by the Lambeth, Chelsea, and Southwark and Vauxhall Companies, is found to be from five to six shillings per million gallons—exclusive of interest on capital.

CHAPTER X.

PUMPS.

Valve Pumps—Lift and Force Pumps—Bucket Pumps—Plunger Pumps—Double-acting Pumps—Bucket-and-Plunger Pumps—Piston-and-Plunger Pumps. Pump Valves—Flap Valves—Pot-lid, Double-beat and Four-beat Valves, and various India-rubber Valves. Points to be regarded in designing Pump Work—Air Vessels and Stand Pipes—Centrifugal Pumps—Form of Vanes—Practical examples of Centrifugal Pumps.

PUMPS are machines for raising water, and have been used in various forms from time immemorial. In modern times their form and construction have been infinitely varied to suit different purposes, or to secure real or imaginary advantages; but in a practical work it is unnecessary to notice more than those which are in general use in modern engineering works of reputation.

These may be divided into two classes—1st, pumps working by means of pistons and valves; 2nd, centrifugal pumps.

Valve Pumps.—In engineering works for the supply of towns with water this is by far the most numerous and important class. The simplest form is the old 'bucket' pump, as it is called, which is still in universal use for shallow wells, or other moderate lifts, where the water is raised by hand-power. It consists simply of a piston P (Fig. 105), with a passage for the water through it, covered by a leather flap or valve admitting of the water passing upwards through the piston, but not returning; and a suction valve or 'clack,' as it is called, below the piston, fitted with a similar valve. This pump is very simple, and can raise the water from a depth not exceeding about 28 feet below the piston or bucket. Below this the pressure of the atmosphere cannot be depended on to force the water into the pump barrel. When such a pump is required to raise the water above H, one of two things has to be added. Either the piston-rod has to be passed through a stuffing-box, as in Fig. 106, or a rising pipe has to be added above the pump barrel in which the piston works, as shown in Fig. 107. Another kind of pump in very general use is the plunger pump, as shown in Figs. 108 and 109, in which a plunger, passing through a stuffing-box, is adopted instead of a water-tight piston. This kind of pump is in very general use both for large engineering works and for small pumps, and it possesses this advantage,—that the gland or packing that makes the plunger work water-tight is of easy access, and can be packed with fresh packing or screwed up externally, which cannot be done with the piston.

FIG. 105.

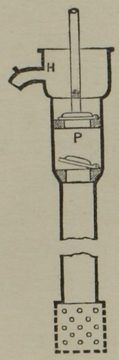


FIG. 108.

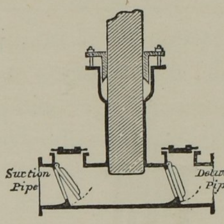
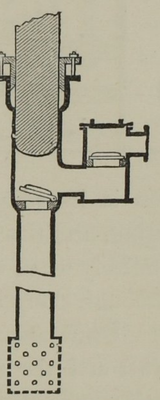


FIG. 109.



Pumps constructed on the plans illustrated in Figs. 106 to 109 are in constant use in large engineering works, and it will be observed that they deliver water on either the up or the down stroke only; hence they are called Single-Acting Pumps. The measure of the water they raise in a double stroke,* that is, a complete up stroke and a complete down stroke, is the capacity of the working barrel,† or, in other words, the area of the working barrel multiplied by the length of the stroke of the piston. Pumps of the type of Fig. 107 are illustrated in detail on Plates 42 and 43.

FIG. 106.

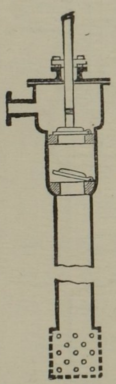
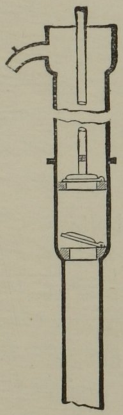


FIG. 107.



Another very usual form of valve-pump is the double-acting pump which, as commonly made, has four valves and delivers the water equally on the down and up strokes of the piston. Different forms of the double-acting pump are illustrated in the Figures 110 to 113.

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* When the stroke of a pump is mentioned in connection with the quantity of water delivered or the number of strokes made in a given time, a double stroke, or the up and down stroke taken together, is always meant unless the contrary is stated.

† In the case of the plunger pumps, of course the area of the section of plunger must be taken instead of that of the working barrel.

Fig. 110 shows a pump with four *flap* valves ; while Figs. 111 and 112 show pumps with four conical valves, arranged in different ways. Fig. 113 shows a double-acting pump with all the four valves placed in one box, and accessible by removing one cover. This is an arrangement that is sometimes convenient for small pumps, but is not generally adopted in engineering works.

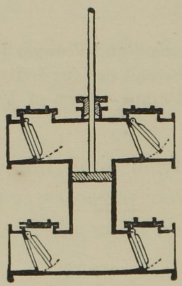
FIG. 110.

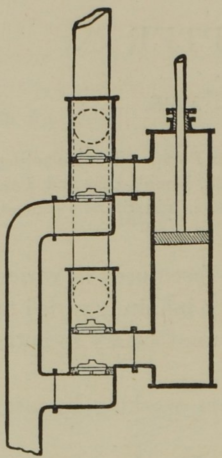
FIG. 111.

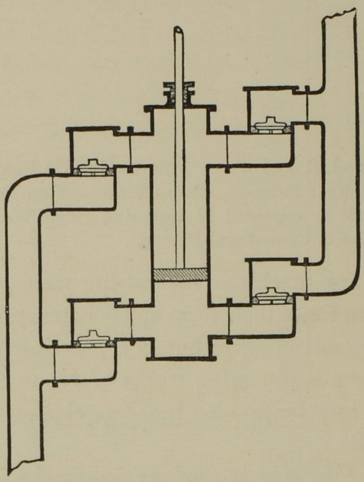
FIG. 112.

It requires only an inspection of the figures to see how each of these pumps operates in raising water, and in all of them shown in Figs. 110 to 113 it will be observed that the pump-barrel discharges its whole contents at each up stroke and also at each down stroke, so that the measure of water discharged by each double or complete stroke is the area of the pump-barrel multiplied by *twice* its length of stroke.

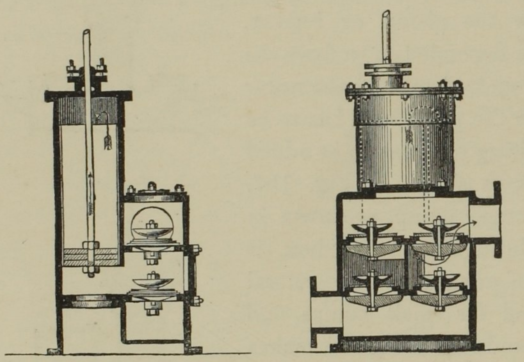
FIG. 113.

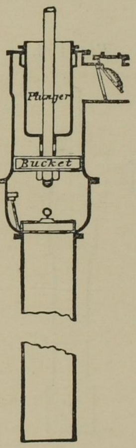
FIG. 114.

That the same sized pump barrel should be able to discharge twice as much water per stroke as in a single-acting pump is a considerable advantage that the double-acting pump has over the single-acting ones; but an inspection of the figures will show that it is gained at the cost of a very considerable increase of bulk and complication in the valves, valve boxes, and water passages. So much is this the case that a single-acting pump to raise the same quantity of water as a double-acting one can generally be made to cost less and to occupy less space, and with the further advantage that, there being only two valves instead of four, they are easier of access and are less troublesome and costly to keep in repair. In selecting the best form of pump, however, it frequently happens that a principal consideration is its adaptation to the kind of power that is to work it. Cornish engines are single-acting, and therefore the pumps used in connection with them are generally single-acting ; and similarly when double-acting engines are used they are generally fitted with double-acting pumps, although there are frequent exceptions to both these rules.

Until about twenty-five years since, most large pumping engines, following the practice of Watt and the Cornish engineers, were single-acting engines ; but from about that time double-acting engines began to be more frequently used, and their use has continued to extend, owing to their greater compactness and convenience. This led about that time to the adoption of a kind of double-acting pump, which possesses many of the advantages of the single-acting one, and of which a diagram is shown in Fig. 114. It is a combination of the plunger and bucket pumps above described. If the plunger is removed it is an ordinary bucket pump,* and raises the water at the up stroke only ; but by the addition of the plunger, which is made about half the area of the barrel, it becomes double-acting, because half the water raised by the bucket at the up stroke is absorbed in filling the space occupied by the plunger, and the other half only is delivered through the delivery-pipe, and on the down stroke the descent of the plunger expels the water formerly absorbed : thus an equal quantity of water issues at the delivery-pipe on the down and the up strokes. This is one of the best forms of double-acting pump, possessing

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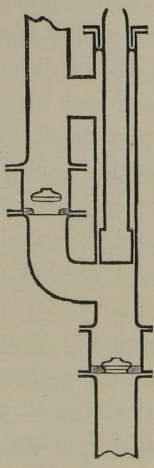
* The delivery valve shown in the figure is not required for the working of the pump, and is only of use in stopping the return of the water when the pump is out of action.

as it does nearly all the simplicity of the single-acting pump and being free from the complicated water passages of the four-valved pumps. It was invented and patented many years ago by Perkins; but had never been used in engineering works until revived by Mr. D. Thomson and introduced at the Richmond Waterworks in an engine made by Simpson & Co., about 1848. A pump on a principle similar to that just described, is the *piston-and-plunger* pump shown in Fig. 115, from which it will be seen that the pump, as before, has only two valves. The section of the plunger is only half that of the barrel, and half the water that would otherwise be discharged by the piston on its up stroke is absorbed in occupying the place of the plunger. On the return stroke the plunger expels this, and thus the pump is made double-acting as far as the delivery is concerned.

FIG. 115.



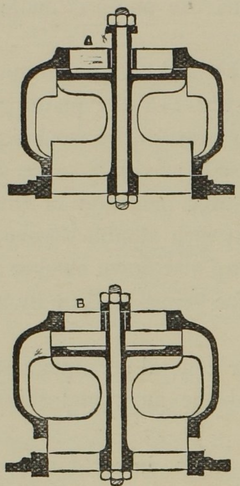
The form of pump shown in Fig. 114 is generally called the *bucket-and-plunger* pump, and it will be observed that in it, as well as the modification shown in Fig. 115, the quantity of water raised at each double stroke of the pump is measured by the area of the working barrel multiplied by the length of stroke, which is exactly the same as it would have been had the plunger been omitted and the pump been single-acting. The addition of the plunger, therefore, does not increase the quantity of water delivered at each double stroke, but merely causes its delivery to be equally distributed between the up and down strokes; the stream of water is more constant, and the pump is adapted for being worked by a double-acting engine.

Having briefly described the principal kinds of pumps in common use, so far as their general arrangement or construction is concerned, attention will next be directed to some of the details, and the most important principles or practical rules that should be observed in their construction.

Of the separate parts of pump-work that thus deserve notice, by far the most important are the valves. The first general idea of a pump-valve is very simple, being only that of a door or lid that opens freely and allows the water to pass in one direction, while it closes as soon as the water attempts to change its direction and move backwards; and for small laboratory pumps this description includes all that need be attended to in the construction of pump-valves, except perhaps that they must be readily kept water-tight when closed. When, however, the engineer constructs pumps on a larger scale, he soon finds that there are many other considerations that must be taken account of, and other requirements that must be provided for. The valves must be made as durable as possible, and to close with as small shock or concussion as possible; and as in these days it is always required that every machine should do as much work as can be got out of it, pump-valves must with this object be made so as to impede the motion of the water through them when open as little as possible, that no time shall be lost in an operation which has to be so often repeated that the least additional time required on each occasion seriously diminishes the work that the pump can do. It is, however, only during the last thirty or forty years that these points have received the attention they deserve, and before that period the pump-valves almost universally used were the primitive leather flap or door, covered by a plate of wrought iron to give it the necessary strength; and the hinge was generally formed of the leather itself, which, when softened by the water, is sufficiently flexible for that purpose.

Valves so constructed are constantly subject to having the leathers cut away, or destroyed by the heavy blow with which the pressure of the water causes the flap to fall on its seat, and also to having the leather torn in two at the hinge; and then the valves required in the technical language of the olden times 'to be fresh geared.' The leathers for this purpose were kept always ready, and this was a constant item of expenditure to be provided for. Then the flaps required in large pumps were, of course, of considerable dimensions, and in opening they had to move over a large angle, and this required time; and hence one reason why Watt, and for a long time his successors, made their large pumping engines single-acting, and with the steam-valves worked by cataracts, so as to cause a definite pause to take place at the end of each single stroke, thereby giving the valves time to close. Even then the valves frequently did not get time to close completely before the current of the water was reversed, and consequently a certain proportion of the water passed backward through the valve before it was completely closed, and by so much diminished the useful work of the pump. This was not the only evil arising from the return of the water before the closing of the valve, for the return current acting on the large area of the valve caused it to close with such a strong concussion as materially to hasten the destruction of the valves, and cause an intolerable noise and jarring in the working of the machinery. The only cure for this was to cause the engine to make a longer pause at the end of the stroke so as to give more time, and, of course, this diminished the number of strokes per minute, and the work that the engine could perform. It was, however, the excessive blow or concussion caused by the working of the old-fashioned valves at the East London Waterworks, where the first Cornish engine was erected in London with pumps of a then unusual size, that caused sufficient attention to be attracted to this subject to produce the first effectual efforts at improvement. These were successfully made by Messrs. Harvey & West, the makers of the engine, who produced their patent double-beat valves, and introduced them in place of the old flaps in the Cornish engine at the East London Waterworks. The improved valve was found to be a great advance, and almost entirely did away with the noise and concussion that had risen to so objectionable a pitch with the old valves. Since this period these valves have come into general use, and their introduction illustrated a principle which was speedily applied by others under different modifications of construction.

FIG. 116.



In Fig. 116 is shown one of these valves,—A closed, B open. It will be observed that this valve has two faces, by which, when open, the water passes, and hence is derived the first advantage of the new valve; for, as the water has two openings by which to pass, each of these openings may be only half the size that would be required if there were only one. The valve, therefore, need not rise and fall through so large a space at each stroke ; and, in proportion as the space it moves through is diminished, the time required and the blow caused by its fall are also lessened. To understand another point in which this valve excels those before it, it is necessary to consider what is the force that causes the valve to open and remain so while the water is passing through. This can be nothing else than the excess of pressure in the water below it, beyond the pressure in the water above it, which excess must be sufficiently great to produce the flow of water through the valve. Now, in a valve made like an ordinary door or lid, this pressure of water tending to open the valve, acts on nearly the whole area of it; but in the Harvey & West valve, a reference to the drawing will show that the upward pressure of the water acts only on the small annular area between the two seats or faces of the valve. The weight of the valve, therefore, is equivalent to a much greater pressure per square inch of this area than in the case of the old valves, and hence, when towards the end of the stroke the current of water through the valve begins to diminish, the valve immediately begins to close, and *before* the stroke is quite completed it is almost closed, and its own weight causes it to close completely and gently before there is any appreciable return current of water. A *gentle* blow is thus effected instead of a severe one, and no water is lost by passing backwards through the valve before it has time to close.

FIG. 117.

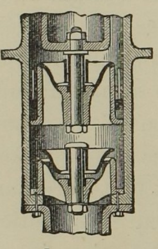
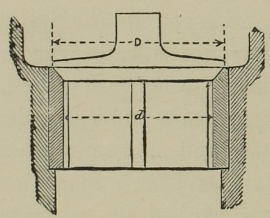


Fig. 117 shows another form of double-beat valve, applied in a bucket-and-plunger pump by the Vulcan Foundry Company.*

If these principles on which the improved action of the Harvey & West valve depends be understood, it will be perceived that the old cylindrical or pot-lid valve shown in Fig. 118 might be made to work equally well if the diameter were made as great as the *combined* diameter of the two faces in the Harvey valve, and also the weight of the valve per square inch of the area of the circle D were equal to the weight per square inch of the Harvey valve on its annular area, as above described. The great size and weight of the valve, however, that would be thus required, would be both expensive and inconvenient, not only as regards the valve itself, but the valve boxes or chambers required in the pump to hold it. If, as an example, the valve be taken of the Cornish engine at the East London Waterworks, and a drawing made of a common valve that would work equally well, the enormous size and weight of the common valve as compared with the Harvey & West will thus be shown very clearly. It generally appears very strange to those who have not studied the subject that a heavy valve such as we have just described should work more smoothly and with a much gentler blow than a similar valve of much smaller weight; but if what we have said above is understood, the reason of this paradox will be readily seen. And the engineer requires but a short experience in pump-work to find what we have said above abundantly confirmed in practice, and that the heavier the valves are made the less noise and concussion has he in the working of his pumps. It might, then, be asked, why not go on increasing the weight of the valves still more if the process is so beneficial? The reply is, that there are in practice other considerations than those we have just noticed that impose limits to this increase of weight. The heavier the valve is, the greater is the effort required to open it, and the greater must be the excess of pressure below to cause it to open sufficiently ; and as, in most cases, the pressure available for forcing the water through the suction-valve of a pump is part of the atmospheric pressure—a power of limited amount,—if the valve is too heavy, it will not open sufficiently to enable the water to follow the piston, and the pump barrel will not be filled before the return stroke is commenced. Then again,

FIG. 118.



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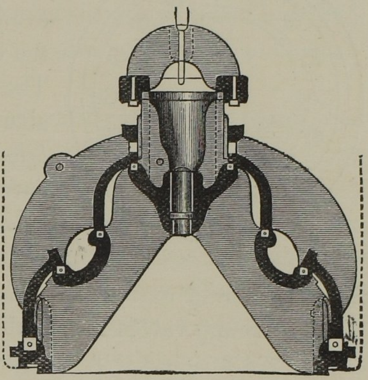
* Valves of this construction were first introduced in the year 1844 by Mr. Archibald Slate, at that time manager of Messrs. Simpson & Company's works at Pimlico.

the difference of pressure above and below the valve, which causes it to open, can only be produced by an expenditure of part of the motive power, and therefore every increase of the weight of the valve causes an increased loss of power. This loss of power is measured by the capacity of the pump multiplied by the difference of pressure above and below the valve when open; and if the pump is working to a high lift, this difference is but a trifling proportion of the whole power of the engine; but in very low lifts it may form a very important element of loss. In practice, if the horizontal area on which the water acts be divided by the weight of the valve in pounds, it will be found that the weight of valves in good examples of pump-work is from $\frac{3}{4}$ to $1\frac{1}{2}$ lb. per square inch of area. As in any form of pump two valves have to be opened in order that water may be passed through the pump, it follows that the power expended in working the pump-valves is equal to that required to pump the water under a pressure per square inch equal to twice that required to raise the valves. If the valves weigh 1 lb. per square inch of area, this is equal to $2\frac{1}{3}$ feet head of water, and therefore the power required to open the valves is equal to that required to increase the head by double this, or $4\frac{2}{3}$ feet. If the whole lift is 100 or 200 feet, this does not constitute a very material percentage of the whole; but if the lift is small, say 8 or 10 feet, it is a very material and indeed inadmissible addition to the load on the engine. For this reason the Harvey & West valve, or others working on the same principle, are seldom used for very small lifts. Shortly after their introduction, a good example occurred of the necessity of conforming to the principles hereinbefore explained. An eminent engineer adopted these valves in large pumps constructed to pump water from one of the London docks, where the lift was not more than 10 or 12 feet, and it was soon found that the resistance caused by the valves was so great that the engine was scarcely equal to the work, and the valves had to be changed for others better adapted to the situation.

We have thus endeavoured to explain the principle on which Harvey & West's valves effected so great an improvement on the valves previously in use. These valves are now usually called Cornish valves, from having been introduced by a Cornish firm, in conjunction with Cornish engines; but they are now in general use in good pump-work, and the same principle is made available in many different forms. Messrs. Harvey & Co. have also introduced a four-beat valve, which is illustrated in Fig. 119.

Fig. 119.



We have already observed that this class of valves is not suitable for very low lifts, and for this purpose the valves that are now most used are those made of vulcanised india-rubber, working on a grating, an example of which is given in Fig. 120. India-rubber, being a soft material, makes less noise in closing than metallic valves, and it has the great advantage of readily making a water-tight joint even when there are solid impurities in the water; and if the sheet of rubber is made sufficiently thick, and the grating small enough in the openings, it will stand very high pressures. But it is found in practice that if *large* rubber valves are applied to large pumps, the concussion caused by them, though not so *sharp*, is yet quite as great as with any other valves. This arises from the large valves opening to a proportionate extent, and from the fact that, the rubber being about the same weight as water, these valves have little force applied to close them, until the water, by setting up a backward current, closes them suddenly, acting as in a hydraulic ram. For this reason, if india-rubber valves are used in large pumps, they should be subdivided into a number of small ones, as shown in Fig. 121, or in any other convenient manner. Where the lifts are small, and heavy metallic valves are not suitable, india-rubber valves as thus constructed are found to give the best practical results, and are now almost universally used in the air-pumps of steam-engines, for which they are peculiarly suitable, as well as for circulating-pumps where surface condensers are used. Like metallic valves, they have been used in a great variety of forms.

Fig. 120.

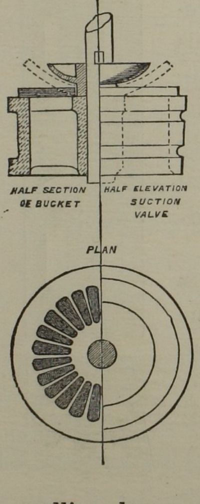


Fig. 121.

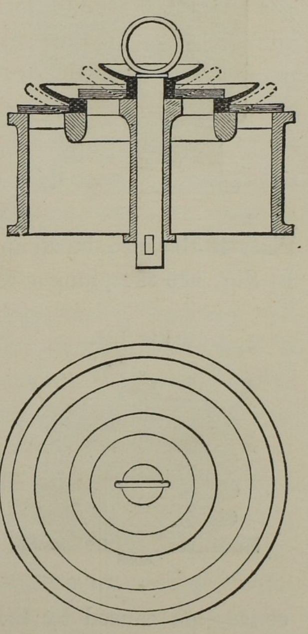


Fig. 122 illustrates a form of india-rubber valve, recently patented by Mr. David Thomson.* It was

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* Thomson and Porter's patent. These are now extensively used in the sewage pumping stations of the Metropolitan Board of Works, and in many waterworks.

designed specially for pumping town sewage; but of course it may be used with advantage in many cases for pumping water also. Sewage water, being full of impurities, the india-rubber valves are in some respects very suitable; but in the usual way of applying them they require a metal grating to be placed under the valve, and this quite prohibits their use for sewage purposes, seeing that the grating, by stopping the chips and various solid matters of larger size in the sewage, would very speedily choke the valves

To secure the great advantages of india-rubber for such purposes, while obviating this fatal objection to its use, the valve in question was designed.

In this valve the movable valve or lid which closes the opening does not, as in other valves, rest on the valve face when closed, but has separate supports at A A A; and it is also made smaller than the opening to be closed. It is provided with an india-rubber flap, secured to the valve by a wrought-iron ring and bolts; and this flap, projecting beyond the valve all round, closes the opening completely, which otherwise the valve is too small to accomplish. By this means the advantages of india-rubber in making a valve water-tight, when even large substances are carried with the water, are retained, while the evil of the grating in stopping these floating bodies is avoided. The movable valve is made, as in purely metallic valves, of considerable weight, and this causes it to fall noiselessly on its supports *before* the completion of the stroke of the pump or the reversal of the current of the water; and when the stroke is quite completed there is nothing to close but the narrow projecting lip of india-rubber which causes little or no noise or concussion. These valves are found to answer extremely well in practice for pumping sewage.

FIG. 122.

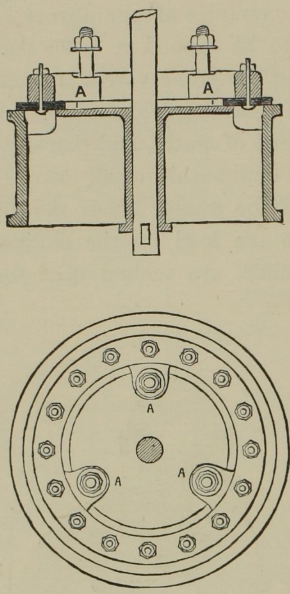
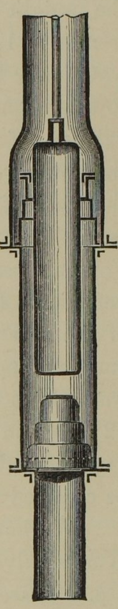


FIG. 125.



For pump-valves india-rubber is frequently used in the form of rings or bands, the circumferential tension of which serves to close the valve unaided by the back pressure of the water. Fig. 123 illustrates one of such valves, of the kind much used by the late Mr. W. R. Morris, of the Kent Waterworks. The passage of the water is through a number of small holes perforated in the casting which forms the valve-seat. Fig. 124 represents a form of valve patented by Mr. Holman, in which rings of india-rubber are arranged to close into grooves formed in the valve-seating. At the bottom of each of these grooves is a continuous opening through which the water passes when the valve is open. The valves, shown in Fig. 123 and Fig. 124, are supposed to be open; Morris's valves are shown in Fig. 125 applied in a very neatly designed single-acting plunger pump at work at Crayford; and on Plate 48 they are shown applied in two bucket-and-plunger pumps at the Canterbury Waterworks. In Fig. 125 the plunger works through the seat of the delivery valve.

FIG. 123.

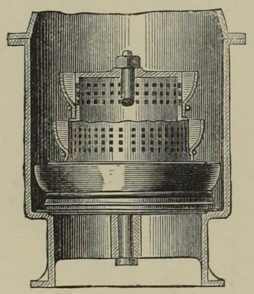


FIG. 126.

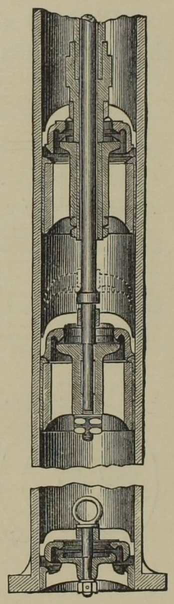
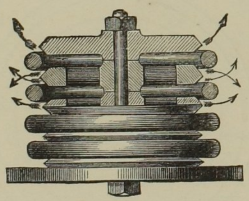


Fig. 126 shows a double bucket pump used by Messrs. Mather & Platt for putting down bore holes. There are two buckets and one common suction valve. The upper bucket is worked by a hollow rod, through which the rod of the lower bucket passes. The gearing by which these two rods are worked is so arranged (Plate 8, Fig. 20) that the buckets make alternate strokes, and thus the delivery of water is rendered uniform.

FIG. 124.



But before leaving the subject of valves, there is one curious phenomenon of their working that should be noticed. In ordinary pump-work the noise and concussion caused by the valves take place on the closing of the valves; but when pumping under very high pressures, such as are dealt with in the hydraulic machinery now so generally used for working cranes, &c., and for working hydraulic presses, the valves are sometimes found to cause severe concussions when *opening*.

Pumps for such purposes are generally small, compared with those used for raising water, and of course the valves also are proportionately small. Suppose that the clear opening through one of these valves should be 2 inches diameter, and that the breadth of the valve-face should be $\frac{3}{4}$ inch all round, then, when the valve is closed, the water-pressure under it acts on a circle 2 inches diameter, and above it on a circle 3½ inches diameter. The areas of these are about as 1 to 3, and therefore, before the valve can open at all, the pressure under it must be three times as great as that above it ; but the instant the valve moves at all, the water rushes between the valve and its seat, and acts with the full pressure on an area of valve three times as large as before. This action of a very high pressure on a suddenly enlarged area causes the valve to fly up like a bullet from a gun, and thus causes a very objectionable concussion. The cure for this is to reduce the width of the valve-faces, which it is found in practice may be done to a very great extent without injuring their durability, and thus the evil we have been describing is cured. The first to notice and clearly explain the causes of this curious action of pump-valves was Sir W. Armstrong, who read a paper on the subject, which will be found in the 'Transactions of the Institution of Civil Engineers' for 1853.

The water-passages in pumps should be as direct as possible, of ample size, and with either no elbows or as few as possible. This is a point in which many double-acting pumps are rather defective, and in which the plunger-and-bucket double-acting pump is superior to others, and can therefore generally be worked faster than any other double-acting pump under the same circumstances. In constructing pumps, care should be taken that in those parts where there is alternately the maximum pressure, and the minimum pressure or partial vacuum of the suction-pipe, there should be no air-traps or spaces where air can be collected and cannot get out. If any such exist, this air expands when the pump is drawing in water, and so diminishes the quantity taken in : during delivery it is compressed, and so much water occupies its place and is not expelled. The efficiency of the pump is thus diminished, and the air-space may be so great as almost to stop the delivery entirely. This, in fact, sometimes happens with small pumps badly designed.

All pump-work requires to be made very strong and substantial; for, however much improved valves and good general arrangements may diminish the shocks to which it is exposed, yet the motion of the working parts being reciprocating, and water being an inelastic fluid, the pump-work is still exposed to considerable shocks and vibratory strains, which in time tell injuriously on it, if it is not both amply strong and fixed securely on firm foundations.

It is of course important, both for the sake of equalising the strains on the pump-work and on the pipes through which the water is pumped, that the delivery of water should be as nearly constant as possible; or, where it cannot be constant, that provision should be made to mitigate as far as possible the evil effects of inconstant flow of water. One of the most important and generally used pieces of apparatus for this purpose is the air-vessel. This is simply a vessel generally cylindrical, with a dome-top and an inlet for the water from the pump at the bottom: the air in the upper part of the vessel is of course compressed to a pressure equal to that of the water being pumped. At those parts of the stroke at which the motion of the pump-piston exceeds the average speed, the surplus water compresses the air to a small extent, and is thereby received into the air-vessel. Again, at those parts of the stroke where the speed of the pump-piston is below the average, the water thus stored in the air-vessel passes out by the expansion of the air, and supplies the deficiency. This apparatus is nearly as simple and efficient a regulator of the flow of the water as the fly-wheel is to the steam-engine, and the only trouble connected with it in practice is that of keeping it charged with air. Compressed air in contact with water is absorbed with more or less rapidity, and hence in ordinary cases air-vessels have a tendency to get empty of air and filled with water. When this happens the vessel is no longer an air-vessel at all, and cannot perform the functions of one. Provision should therefore be made for charging air-vessels with air ; and the simplest way of doing this is to put an air-cock on the suction-pipe of the pump, by which it can be allowed to draw air occasionally, which, being pumped along with the water, passes into the air-vessel, and is caught there. But if the pump-barrel is considerably below water, this plan cannot be applied, as in these circumstances the pump will not draw air at the suction-pipe ; and even when air can thus be passed through the pump, the air-vessel is sometimes so placed that it cannot arrest the air, which therefore passes on into the pipes with the water. Under any circumstances, too, pumping air through the pump diminishes the delivery of water, seeing that whatever space is occupied by the air in the pump-barrel cannot be filled with water.

The most general way of charging the air-vessel with air is by having a small pump for the purpose worked by the engine. In working such pumps it is essential that they should be made to pump water along with the air, as the water fills up the clearance spaces in the pumps, and thereby compels the air to be discharged. Without this the air in the pump-barrel would, in many cases, be merely alternately expanded and compressed by the working of the pump, and would scarcely be pumped into the air-vessel at all. Also, the valves and pistons of these pumps require constant attention to keep them sufficiently tight, as a very small crevice, which with water would allow the escape of only an insignificant quantity, would with air allow the escape of all contained in the pump-barrel at each stroke.

To obviate these practical difficulties, a method of charging air-vessels is sometimes adopted, which is free from all the inconveniences we have just pointed out.