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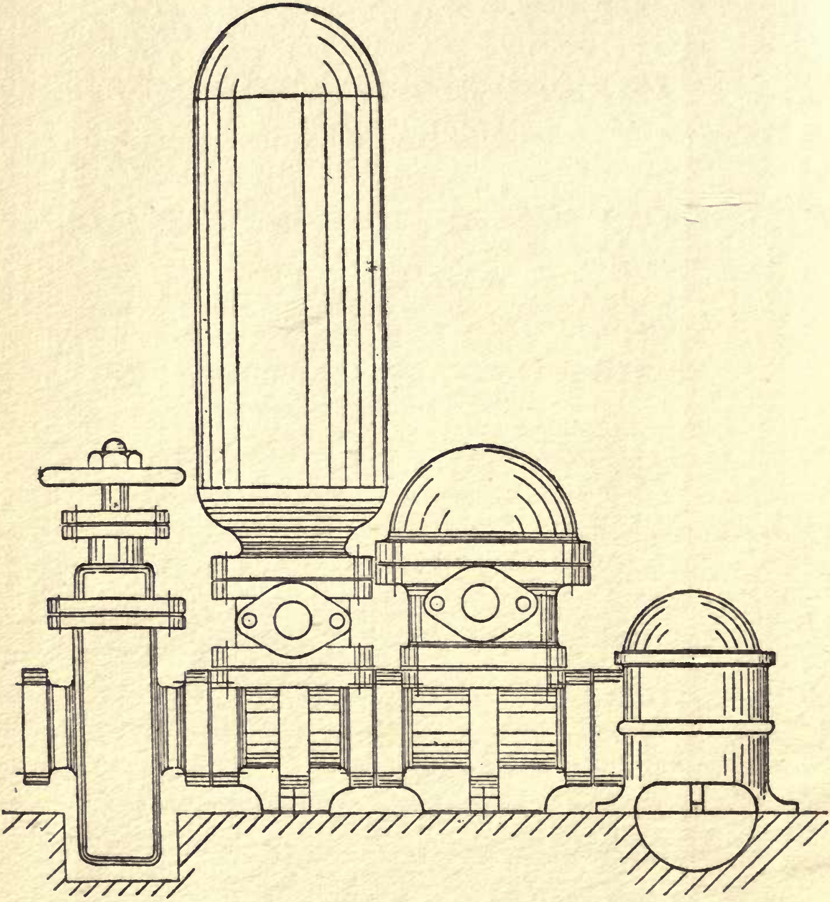

The Hydro-motor.

AUTOMATIC PUMPING
AND
NOTES ON WATER ANALYSIS AND FILTRATION.

BY

W. WALKER FYFE,
AWARDED GOLD MEDAL FOR HYDRAULIC APPARATUS

EDITED BY HIS SON

J. W. FYFE,
M.I.MECH.E., A.M.I.E.E.

With Numerous Illustrations

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1922.

Mechanics Dept

PREFACE.

HYDRAULIC ENGINEERING includes so wide a range of practice and such varied machinery that certain special branches of the subject call for separate consideration. Automatic pumping is one such branch, since the design, construction, and application of apparatus present unusual problems. The urgent need for the utilisation of water power for industrial and domestic purposes has turned the attention of hydraulic engineers to the consideration of all mechanical appliances suited to accomplish this end, and, as there is no modern book on automatic pumping, the author of this manual offers this contribution culled from a lengthy experience and extensive practice. The automatic pump is capable of using large volumes of water now flowing to waste owing to the erroneous idea that the inclination is too slight for practical application, and the author presents herein certain verified results and a simple statement of observed facts. The apparatus has almost unique characteristics worthy of more careful study by mechanical engineers, as, in places where the cost of coal and of transport is prohibitive for the use of other types of machinery, this might be applied with great advantage.

The co-operation of the author's son in the preparation of this little book gives to it the added value of experience abroad and of most recent data.

LONDON, *April* 1922.

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AUTOMATIC PUMPING.

INTRODUCTION.

AUTOMATIC pumping may be said to be confined to one apparatus, commonly named the Hydraulic Ram. For though pumps operated by cranks on the axles of water-wheels perform the same kind of work, yet, in view of all the gear employed, the action cannot be termed automatic.

It is not proposed to trace, except very briefly, the early history and development of this self-acting machine through its various stages; still less that of pumps in general, for though the crude forms, elaborately sketched and described even in modern works on the subject, may interest the mechanical antiquary, little instruction could be gleaned from their introduction, and the reader is assumed to be acquainted with the elementary stages of the subject. Only brief reference will also be made to the crude ideas entertained with regard to the Automatic Pump by many of those engaged in business connected with water supply.

It was believed that this self-acting engine had inherently the power of raising water to a height equal to ten times the fall supplying it. And that, this being a *natural law,* it could be raised no higher, and therefore any attempt to extend its power would prove abortive. Adaptability to conditions beyond this limit was not dreamed of, and any suggestion of the kind was treated with scant respect and the proposer with scorn.

Even in works of great value in hydrodynamics this subject is treated in such fashion as to enforce the conclusion that the statements have been made without any attempt to verify them—mere assumptions, or inductions on insufficient data, often founded on assemblages of mathematical symbols, which sometimes only serve to mask a truth or cloke a fallacy. The hope is entertained that this conclusion will be justified later on.

It is necessary to be intimate with facts before attempting to theorise, and the desire here will be to appreciate the full force of known factors before invoking the aid of hypothetical ones, to ponder well their relative values, and endeavour to find in their inter-relations the true causes of the observed effects, untrammelled by preconceptions, uninfluenced by authorities. It has been well said that to define an error is to demolish it, and a small thing not seldom achieves this object; and, should it be thought that some of the points urged here are insignificant, it may be well to remember that the smallness of a thing is often an inverse measure of its importance; and that precision is only attained by the entertaining of minute differences; that even discrepancy has a value in that its detection leads to enlightenment.

In any effort to dispel obscurity, in any attempt at synthetic concentration, strict care must be taken that assertion shall not outstrip evidence in such building-up; and it is the aim of the writer of this little treatise so to deal with the large collection of facts at his disposal, accumulations of years of investigation and experiment, as to induce the hope of being able to disperse the haze that has surrounded the subject.

Should it seem that in the ardour of his theme he has subjected the contributions of the past to too rigorous a criticism, it may be urged that the strictures apply to the imposition of irrelevant notions; that they are directed as a protest to the treating of the subject with sole regard to the *general* laws of Natural Philosophy, instead of the *particular* laws of the more restricted branches of that science—Experimental Physics or Applied Mechanics. It is to this domain that the matter must be relegated, for the most careful calculation may be upset by the tardy closing of a valve or the friction on a bad casting.

The text has been divided into sections for easy reference, and some forty installations have been selected for study, from scores of others, as being typical; while the essential factors of each, twenty-five in number when complete, have been carefully weighed and considered. So it may be claimed that the structure attempted to be raised has been founded on a fairly broad basis.

PART I.

(DESCRIPTIVE.)

THE PRINCIPLE.

1. THE dynamic principle involved in the action of this water-raising apparatus is the kinetic energy generated by a column of flowing water, in a tube, suddenly brought to rest. It is said to have been first applied by one of the brothers Mon-golfier, who employed the moving liquid shaft abruptly checked to raise a portion of itself to a higher level. To the implement the Frenchmen gave the name of *bélier* (ram), an improper term which literally means *bleater*: it was given no doubt as implying percussive power; but this is shared by bovines, goats, etc., the young, indeed, of the latter developing the bent much earlier than those of any other ruminant. The machine in its simple form is comprised by two valves and an air-vessel placed at the end of a long tube. One valve opens into the air-chamber, the other to the external air.

2. The improper name was applied to the valve case and air-vessel, but pertains more properly to the moving column, and the simple engine might

more correctly be called the Auto-pump, and the compound machine the Hydro-motor, and herein they will be so termed.

3. There are three forms in which they are constructed: the "A" form, to raise a portion of its motive supply; "B," to raise a separate stream by means of the motive current, which may be impure; and "C," by which is raised a portion of both streams.

4. In any description of hydraulic apparatus it is accepted that water is incompressible, for the greatest pressure yet applied only lessened it by one twenty-thousandth of its bulk. When water is let into the auto-pump it finds egress at the external valve and continues to flow with increasing speed until sufficient force is developed to close that valve.

5. In all cases of collision the tendency of the component particles is to disperse, and this result follows unless the cohesion of the opposing bodies be sufficient to prevent it. In the kind of matter we are considering the cohesion is slight and dispersion easy. The fluid column suddenly arrested by the closing of the valve, possessing great mobility, expends its force, like all other forces, at the point of least resistance, this point being the inner valve placed as near as practicable to the air-vessel. The incompressible fluid flows through this valve into

the chamber, taking the place of the highly compressible air therein; the valve on closing retains what has passed through it.

6. The duration of the impulse will be proportional to the force of the impact, but may be unduly prolonged unless the action of the inner valve is such as to receive and secure the dispersed particles in the proper interval; and that must only extend to enable the waste valve to reopen at the instant that the energy of recoil, resulting from the shock, and the static pressure of the water in the driving pipe are in equilibrium; if the blow be too feeble for its reaction to balance the driving head, or the inner valve be tardy in closing, the waste valve will not open again to allow the flow of the water to be resumed. After each stroke the air, expanding in the chamber, forces the water through the ascending pipe to the point of delivery.

The normal position of the external valve—variously called the pulse, beat, waste, escape, or dash valve—is open, whether caused mechanically or by gravity; the inner or ascension valve is normally shut; and on the reciprocal and rhythmic action of these valves depends the regular working of the machine, and its production—the cumulative result of sequent impulses.

THE MOMENTUM.

7. The power operating in the automatic raising of water has been the subject of some controversy, and the point may be dealt with and disposed of as briefly as possible.

The work of the auto-pump is the raising of a portion of the water driving it. All work demands the expenditure of energy. Energy is defined as the power of doing work, and is thus expressed :—

> Energy of motion is proportional to the moving mass and to the square of its velocity $= M . V^2$,

while momentum, the term hitherto improperly used in referring to this machine, is expressed as :—

> The mass of any body multiplied into its velocity in units of distance and time $= M . V$.

8. In order to calculate energy with accuracy, the exact speed at the moment of impact must be known. This, for many reasons, is extremely difficult to find. While momentum only refers to mass without regard to weight, power can be found with little difficulty. The average speed of the water flowing in a pipe when full can be ascertained by simple formulæ, and this multiplied into the weight of water contained in the pipe has proved in practice thoroughly serviceable in computing the

agency representing the energy developed in this apparatus.

9. We shall therefore elude the scientific puzzle presented by the terms "Energy," in which the velocity must be squared, and "Momentum," in which mass must be divided by gravity before being multiplied into velocity, and hereinafter term the co-action of the factors *weight* and *speed* "POWER," and express it in terms of pounds into feet per second; though we may have to refer to energy again when we come to deal with the subject of "piping."

THE POWER.

10. The quality of a force for the work to which it is applied consists in the just proportions of its components; and in the proper adjustment of these factors to the conditions which govern the situation lies at once the function and utility of the machine. A tack hammer driven ever so fast could not perform the work of a heavy sledge, and it would be folly to attempt to fix carpets with the weighty implement.

11. Now, the quality of the column of moving liquid is the matter in question. If the column be too long, it will be too slow and too heavy; if it be too short, it will be too fast and too light. In the latter case it will be inefficient, in the former its impact is likely to be destructive as well as inefficient.

It is by the quality of the power, therefore, that a high efficiency can be attained in the machine, and to determine the margin beyond which it is not safe to go on either side, in view of all the conditions presented by the situation, is the point to be desired.

12. It may be fitting at this juncture to cite and examine several of the statements in some of the authoritative works referred to.

In the article on Hydrodynamics in the *Ency. Brit.*, vol. xii. pp. 532–3, it is stated :—

"The drive pipe should be as long and straight as possible. . . .

"The weight of the escape valve should exceed the static weight bearing on it. . . ."

13. Here is one case, out of many, in refutation of the first statement. The writer was called in to improve a water supply to a mansion, where much worry and trouble was given by a machine giving very little water, and that very uncertainly by reason of frequent stoppages.

After a survey had been made and levels taken, the particulars were found to be :—

Drive pipe, 230 ft. long ; 2½ in. diameter.
Fall, 7 ft. ; speed of column, 3 ft. per sec.
Height of delivery, 46 ft.
Strokes per minute of escape valve, 8 in number.

The main theoretical elements were therefore :—

Weight of driving column, 488 lbs. × 3 ft. per sec.
=Total impact (power), 1464 ft.-lbs. per sec.
Impact per square inch, 298 ft.-lbs. per sec.
Ratio of weight to speed, 163.

14. Having received instructions to make whatever alterations were necessary to secure an adequate supply, a new machine was installed; the driving pipe was cut at a point 63 ft. from it and a tank fixed at that point into which the two ends of the severed pipe were fitted. The changes then were :—

New machine—
Drive pipe, 63 ft. long.
Strokes per minute, 74 in number.
Supply to tank, 164 ft. with 10-in. fall.
Average water supply to tank, 11 gals. per min.
Fall to machine, 7 ft. (average).
Water supply to mansion, 1·14 gals. per min.
,, to waste, 8·25 gals. per min.

The theoretical elements were then changed to :—

Weight of driving column, 133 lbs.
Speed ,, ,, ,, 7·3 ft. per sec.
Total impact, 980 ft.-lbs.
Impact per square inch, 200 ft.-lbs.
Ratio of weight to speed, 18 as against 163.

The percentage of efficiency was therefore :—

$$\frac{\text{Quantity, water raised, } 1{\cdot}14 \text{ gals. per min.}}{\text{,, ,, used, } 9{\cdot}39 \text{ ,, ,,}} \times \frac{46 \text{ ft., height}}{7 \text{ ,, fall}} = 79{\cdot}7\%.$$

The efficiency would have been higher still had it been expedient to replace the old drive pipe.

15. Let us now consider the second statement quoted, and take the case of a fall of, say, 20 ft.—by no means unusual. To exceed the static pressure the valve disc would require to exert a pressure of about 9 lbs. on the square inch, so that even the disc and spindle of a 2½-in. machine would weigh about a hundredweight; for the disc would not contain fewer than 12½ superficial inches and the head pressure would exceed 8½ lbs. But the most astounding thing is that the author must have accepted the dictum of some empiric in the trade and published it without examination.

16. Even in that invaluable compendium "Molesworth" it is remarkable how loosely this subject is treated; efficiency is graduated in a table from 75 per cent. at 4 times the lift to fall, to 10 per cent. at 25 times the height, which may appear very well in a table, but it will be shown later that it is absolutely meaningless.

17. Again, D'Aubuisson's formula for calculating percentages has been repeated—cited again and again with reference to this; by which efficiency is shown

as 86 per cent. at 4 times the height to the fall, to nothing at all at 26 times. It will be shown here that 86 per cent. of duty has been attained not only at 4 times but at over 40 times the fall, and that the force of the driving and the pressure of the ascending columns have balanced at over 130 times the fall.

18. Another fallacy relating to this part of the subject may be referred to here. It has been laid down repeatedly that in driving pipes water flows only one-third of its time.

This is entirely erroneous; if provision were only made by the size of the drive for a flow of three times the waste, high efficiency would be impossible. The effective average flow is very much greater, and will be dealt with further on.

THE DRIVING PIPE.

19. The directions that have been given for determining the length and diameter of the driving pipe have been many and various. Molesworth (23rd edition) gave its length as three-fourths of the height of the delivery, and in a later edition as 2·8 times the fall, which is very different. For its diameter is given 1·45 multiplied by the square root of the supply in cubic feet per second, the product being the diameter of the pipe in feet.

20. Let us test these by actual installations.

One case giving 85 per cent. of duty with a fall of 4 ft. 2 in.; height of delivery, 168 ft.—40·3 times the fall :—

$$\begin{array}{l}\text{Gallons delivered per min.,}\\ \text{,,} \quad \text{used} \qquad\qquad\quad \text{,,}\end{array} \frac{1\cdot07}{50\cdot81} \times \frac{168}{4\cdot16} \begin{array}{l}\text{ft., height}\\ \text{,, fall}\end{array} = 85\cdot04\ \%.$$

The waste was 49·7 plus 1·07=quantity used. Length of drive was 100 ft.

By the first rule it should be 126 ft. (168×·75); by the second, 4·16×2·8=11·64 ft. (*sic*).

Now, as to diameter: "Diameter of supply pipe $=1\cdot45\sqrt{Q}$. Q=quantity of supply in cubic feet per second." (*Vide* page 545, 23rd edition.)

Supply, 50·81 gals. per min.÷6·23=8·1÷60
$$=\cdot135\sqrt{\cdot135}=\cdot36\times1\cdot45=\cdot522\text{ ft.}\times12=6\cdot26\text{ in.}$$
The drive is not 6¼ in., but 5 in. in diameter.

21. Let us take another case :—

$$\begin{array}{l}\text{Quantity raised, gals. per min.}\\ \text{,,} \quad \text{used} \qquad \text{,,} \qquad \text{,,}\end{array} \frac{1\cdot25}{16\cdot7} \times \frac{141\cdot28}{11\cdot75} \begin{array}{l}\text{ft., height}\\ \text{,, fall}\end{array} = 90\%.$$

The length in this case by the first rule is right :—

141·28×·75=105·96 (the actual is 106 ft.);

by the second, hopelessly wrong :—

11·75×2·8=32·9 ft.

As to diameter (pipe installed 3-in. diameter) :—

$$16\cdot7\div6\cdot23=2\cdot68\div60=\cdot0446\sqrt{\cdot0446}=\cdot22\times1\cdot45$$
$$=\cdot319\times12=3\cdot828=1\cdot63\text{ times the area.}$$

22. Another case :—

$$\frac{\text{Gallons delivered per min.,}}{\text{,,}\quad\text{used}\quad\text{,,}}\ \frac{1\cdot636}{13\cdot636} \times \frac{42}{6\cdot04}\ \frac{\text{ft., height}}{\text{,,}\ \text{fall}} = 83\cdot5\ \%.$$

Here the diameter is pretty nearly correct :—

$$13\cdot636 \div 6\cdot23 = 2\cdot188 \div 60 = \cdot0364 \sqrt{\cdot0364} = \cdot19 \times 1\cdot45$$
$$= \cdot2755 \times 12 = 3\cdot3 \text{ in.}$$

The pipe was 3-in. diameter, but the length was altogether wrong; by the first rule, $42 \times \cdot75 = 31\cdot5$; and by the second still worse, $6\cdot04 \times 2\cdot8 = 16\cdot91$. This drive was 53 ft. long—and too short; but the space was restricted, or else the efficiency would have been higher still.

23. In the 28th edition the rule is changed to :—

"Length of drive in feet $= H + 1\cdot2\ (H \div h)$.
$H =$ head delivery in feet. $h =$ head of supply in feet."

Taking our first instance,

$H = 168$ ft. plus $1\cdot2 \times (168 \div 4\cdot16) = 6818\cdot76$ ft. (?) ! !

What reliance can be placed on such rules ?

24. Eytelwien's rule for the diameter on the same page is also very erroneous. D in inches $= \sqrt{2+9}$ gals.

$$\left.\begin{matrix} Q \text{ waste} \\ q \text{ raised} \end{matrix}\right\} \begin{matrix} = \sqrt{50\cdot81} = 7 \text{ in. : if in cub. ft.} = \sqrt{8\cdot1} = 2\cdot8 \times 2\cdot5. \\ \text{gives the same result, 7 in. against 5 in. (§ 20).} \end{matrix}$$

25. It has been affirmed with some authority that the proper type of driving pipe should be tapered, in order that the flow might be uniform through its entire length; and such examples are

given as the following: "A one and a half-inch pipe with 10 ft. of fall will pass 134 gals. per minute, and it will require a pipe two and three-quarters diameter, one yard long, with six inches of head to pass the same quantity." The identity of this mode of supply with that of town's mains is here suggested, and will have occasion to be discussed later on.

26. In a recent work connected with this subject will be found the following misleading statement: "The following example will give some idea of the power exerted at the end of a long pipe when the flow is suddenly stopped; a pipe flowing full bore with a velocity of 25 ft. per second is equal to a head of 10 ft. If the pipe is 2 in. diameter, and 150 ft. long, the contents will be 204·5 lbs., which multiplied by 10=2045 ft.-lbs. of energy." The intention here is to treat the case in accordance with the law of falling bodies: If a velocity of 25 ft. per second were impressed on a body weighing 204 lbs., the problem would be expressed :—

$$\frac{\text{W}\,.\,\text{V}^2}{2\,.\,\text{G.}}=\frac{204\,.\,25^2}{2\,.\,32{\cdot}2}=\frac{127{,}500}{64{\cdot}4}=1979\text{ lbs.}$$

But this does not quite meet the case. A column of water flowing through a 2-in. pipe 150 ft. long under a head of 10 ft. could not attain a speed of 25 ft. per second, but only about one-fifth of that velocity, and might reasonably be expected to develop power when suddenly stopped equal to 1030 ft.-lbs. or thereabout. Hence such statements —absolutely true in their proper aspect—are untrue in the aspect presented, and misleading.

Before closing this part it must be stated, in case § 23 should be thought exceptional, that many nearly as absurd could be quoted: two will suffice.

(1) Duty over 90 per cent., $\frac{\text{Height } 66 \text{ ft.}}{\text{Fall } \;\; 8 \;\; ,,} = 8\frac{1}{4}$, drive 80 ft.; by rule should be 554·4 ft.

(2) Duty over 80 per cent., $\frac{\text{Height } 96 \text{ ft.}}{\text{Fall } \;\; 4 \;\; ,,} = 24$, drive 132 ft.; by rule should be 2332·8 ft.

THE SLUICE VALVE.

27. It is expedient that means of stopping the flow of the driving water should be at hand; but if this be furnished by the ordinary sluice valve a high efficiency cannot be attained. As a free flow is essential from source of supply to point of impact, it will be clear at a glance at an internal drawing on any maker's catalogue that the space shown when the gate is raised must inevitably prevent this, by causing eddies in the current; and these valves have been ascertained in practice to reduce the power of the motive column to an extent scarcely to be credited.

The stoppage of supply has often been arranged for by a flap valve on the end of the pipe at its source; but such an adjunct cannot be anything like tight (though absolute tightness is not necessary), but its use tends to create air spaces and reduce the solidarity of the column, by admitting air into it which, when the fall is low, takes a long time to work out.

THE ESCAPE OR DASH VALVE.

28. The usual form of this valve is the inverted spindle pattern. Adjustment, of which this form of valve admits, was in the old machines effected very crudely by cotter pin and iron washers; and the first improvement on this method was observed on the "Douglass" machines imported from America, on which the spindle sleeve was fitted with a screwed cap and jam-nut.

Of recent years a noted English maker, in the desire to prevent shock and noise, has adopted a form of rubber band valve said to have been designed originally for, and fitted on, a Cornish pumping engine years ago as an ascension valve with very good results. In years gone by the ball valve with a grated domed cap was largely used, but this form offered no means of adjustment and soon got out of true; still, where driving water was abundant, machines so fitted went on working for years without giving much trouble.

29. The greatest defect shown by the inverted spindle was rupture to the neck, where it is joined to the disc, when the speed was high and the stroke heavy. And a point to be noticed was one of great importance—that, though the total impact was the same or even much greater, if the velocity was low the fracture did not occur. The metal also presented an aspect at the fracture very different from an ordinary break; but we may have to discuss this point at greater length further on.

THE INNER OR ASCENSION VALVE.

30. Of all the forms of valves which have been adopted for use in this machine perhaps the most common has been the disc and spindle for retaining the water raised. Susceptible of a measure of adjustment, when its area was large and its life small it doubtless answered the purpose fairly well. But with every valve adapted to this end some *slip* is inevitable, and it is important that the aim of reducing it to the lowest point possible should be borne in mind. In no machine whatever is a sensitive valve more to be desired than in this, but in order to attain it strength has been often sacrificed.

The *trip* of the spindle is well known, but *slip* is even greater with valves of the ball type which were also frequently used. In the "Douglass" machine the ordinary leather clack is employed, as in the ordinary force pump. The fish-mouth "Perreaux" valve has been tried and gave good results for a time, but its life was short. A double-cone valve has also been used with good effect, and had great endurance, but in some cases had to be discarded for noise. Best of all as regards results was the sensitive grid valve, especially in cases of low falls; but under a high delivery it was not lasting. In all situations where water is scarce, fall low, and delivery high, the valve to be desired must be both sensitive and strong; but under all conditions the point of prime importance is the closing of it immediately after the full effect of the stroke shall have passed through, thereby also assisting to reduce the interval between the strokes to the minimum period.

THE AIR-VESSEL.

31. A large air-vessel is of great service, but of course, like everything else, it may be overdone.

It has been set forth repeatedly that the capacity should equal the cubic contents of the delivery pipe. There appears no reasonable basis for this rule.

32. Let us take three installations where the average efficiency equalled 85 per cent.

$$\begin{array}{lr} & \text{Cub. in.} \\ \text{(1) Delivery pipe, } \tfrac{3}{4} \text{ in., 750 ft. long} & \left.\begin{array}{r} =3975 \\ =\ 600 \end{array}\right\} =6{\cdot}62 \\ \qquad \text{Contents of air-vessel} & \end{array}$$

Cub. in.

$$\left.\begin{array}{ll}\text{(2) Delivery pipe, } 1\tfrac{1}{4}\text{ in., 510 ft. long} & =7589\\ \qquad\text{Contents of air-vessel} & =1100\end{array}\right\}=6{\cdot}89$$

$$\left.\begin{array}{ll}\text{(3) Delivery pipe, 1 in., 1800 ft. long} & =16{,}960\\ \qquad\text{Contents of air-vessel} & =\ \ 2{,}160\end{array}\right\}=7{\cdot}8$$

The average of these is seven times larger than what is required; and in case (3), to be in accord with a rule to be presently noticed, the air-chamber would have presented the imposing structure (suggestive of Stonehenge) of a pillar 2 ft. in diameter 13 ft. high.

33. But if this rule is far in excess, the one given in the 25th edition of Molesworth errs greatly on the other side:—

"Contents of air-vessel in cub. ft. $= \cdot 0055 d^2 . \text{H}$."
H = delivery head in ft., d = diameter in inches.

By case (1), H = 66 ft., $d. = \frac{3}{4}$ in.

$\therefore\ \cdot75^2 = \cdot5625 \times 66 \times \cdot0055 = \cdot204 \times 1728 = 352{\cdot}5$ cub. in.,

which is little more than half what is needed.

By case (2), H = 71·3 ft., $d. = 1\frac{1}{4}$ in.

$\therefore\ 1{\cdot}25^2 = 71{\cdot}3 \times \cdot0055 = \cdot57 \times 1728 = 1080$ cub. in.,

which is much nearer, but—

By case (3), H = 69 ft., $d. = 1$ in.

$\therefore\ 1 \text{ in.} \times 69 \times \cdot0055 = \cdot379 \times 1728 = 655$ cub. in.,

less than one-third of the required capacity.

We hope to show that the space in the delivery pipe is less important in relation to the capacity of the air-vessel than the adaptation of the chamber space to the power, nature, and frequency of the discharge.

THE DELIVERY PIPE.

34. It had been laid down as an established proposition, years ago, that the area of the delivery pipe should be sufficiently large to preclude a higher pressure in the air-vessel than that due to 3 ft. over the normal static pressure, and has been repeated again and again. It has reappeared in a work of recent date, but still remains an assumption, for it is unsupported by the slightest proof or explanation.

35. So the question naturally arises why this engine should be restricted in the output of the power peculiar to its construction? Turning again to "Molesworth," we find in the 23rd edition this rule :—

"Diameter of rising pipe in ft. $= \cdot 75\sqrt{Q}$.
$Q =$ quantity of supply in cubic ft. per sec."

In the 28th edition it is altered to :—

"Diameter of delivery $= \frac{1}{2}$ diameter of drive in in."

Taking a case with over 90 per cent. of duty, by the first rule we have :—

$Q = 5\cdot94$ gals. per min. $= \cdot95$ cub. ft. $\div 60 = \cdot0158$.
$\sqrt{\cdot0158} = \cdot125 \times \cdot75 \times 12 = 1\cdot125$ in. diameter, equal

to ·994 superficial area. The delivery installed is $\frac{3}{4}$ n. = ·4417 area, and is therefore less than one-half. By the second rule, half diameter of drive, which is 2 in. diameter, it is somewhat nearer. It must be stated that the extra pressure in the air-vessel did not amount to 3 ft., being only 1 lb. above the static value, showing the friction in the delivery to be insignificant.

36. When, however, we consider larger supplies, the discrepancy is much greater. Let us take a case already noticed (§ 20) in connection with the diameter of the driving pipe.

$$Q = 50{\cdot}81 \div 6{\cdot}23 = 8 \div 60 = {\cdot}13\sqrt{{\cdot}13} = {\cdot}36 \times {\cdot}75 \times 12$$
$$= 3{\cdot}24 \text{ inches delivery diameter.}$$

By the second rule, $2\frac{1}{2}$ in., the drive being, as was stated, 5 in. diameter; but the sectional area even here is more than six times that of the installed delivery, viz. 1 in., giving 85 per cent. of duty with only 4 lbs. additional pressure in the air-vessel, which, if added to the height, 168 ft.+9=177 ft., would increase the duty to close on 90 per cent. at a height of over 42 times the fall.

PART II.

(CONSTRUCTIVE.)

THE DRIVING PIPE.

37. IN arranging a scheme of water supply the first necessity is a thorough survey of the vicinity more or less adjacent to the point of delivery and storage, the position of which is generally selected beforehand by the employer with the view of facility of distribution.

After inspection and gauging of the supply stream, and all other conditions of the situation have been carefully considered, the site for the machinery is determined on; and, as the supply may, and very often does, vary with the seasons, where the supply is not abundant, it is usual and expedient that the employer should guarantee a minimum on which the engineer can base his scheme and in turn guarantee the supply to be raised.

38. In the study of the facts disclosed by his survey, the engineer must consider the fall at his disposal first, in relation to the driving supply guaranteed to him; ascertaining carefully, especially if these two elements have rigidly defined limits, the

total force at his command, and then the quantity to be raised and the height of the delivery. And here it may be fitting to affirm the supremacy of this motor above all others, in utilising low falls; in obtaining a sensible product with the aid of an all but insensible factor—due to the attraction of gravitation. And in this its importance can hardly be exaggerated, as the following example may serve to show.

39. In the case to be cited the driving supply was unlimited, being drawn from a river, but the fall was hardly perceptible. The client's need for a domestic supply was, however, urgent, and cost was not a serious consideration. After two carefully taken lines of level the attempt was resolved on and a machine was installed. It was soon found out that the levels of the surface varied frequently by reason of the rainfall in the hilly country nearer the river's source. But a permanent supply was obtained, gladly acknowledged, and suitably remunerated. The falls varied from 14 in. in the normal state to 9 in. during the rains, giving respectively 720 to 216 gallons per day of 24 hours. The percentage of duty could not be ascertained, as the waste could not be measured, the lip of the dash valve being submerged; but in all such cases economy in the driving has not to be studied. The elements of this installation will be dealt with in § 63.

40. We will now consider a case of definite limits :—

Drive, 53 ft. long ; 3 in. in diameter.

Fall, 5·83 ft. Weight of driving column = 22·94 lbs. per square inch.

Velocity, 8·38 ft. per second.

Power ∴ 22·94 × 8·38 = 192 ft.-lbs. impact per square inch, which is the theoretical maximum.

To test this, the discharge was confined in the air-vessel, and 186 lbs. pressure was indicated by an hydraulic pressure gauge, so that 6 lbs. were lost in friction in the drive, or the maximum working speed was not gained. The "balance of power" would, therefore, have been reached at a height of 427·8 ft. above the lip of the dash valve—between the power of the drive and the static head of delivery —over 73 times the fall.

41. Let us take a case of a lower fall with the same restricted length of drive and diameter.

Fall, $14\frac{3}{4}$ in. = 1·23 ft.

Column as before, 22·94 lbs.

Velocity, 3·7 ft. per second.

Power ∴ 84·73 ft.-lbs. impact per square inch.

Under this test the pressure gauge indicated 70 lbs. on the square inch = 161 ft. ÷ 1·23 ft. = 130·9 times the fall.

42. Another case, in which the limits were very rigid, especially the driving supply, which was only

0·666 of a gallon. By careful adjustment a fall of 5·62 ft. was obtained, and a long drive was adopted :—

Drive, 160 ft. ; $\frac{3}{4}$ in. diameter.
Fall, 5·62. Weight of column, 69·28 lbs. per sq. in.
Velocity, 2·26 ft. per second.
Power ∴ =156 ft.-lbs., theoretical maximum.

The pressure gauge indicated 73 lbs.=167·9 feet. The static pressure was 20 lbs.=46 ft., and the quantity raised was: 0·066 gal. per min.—waste, 0·60. We had then :—

$$\frac{\text{Quantity delivered, } 0{\cdot}066}{\text{,, used, } 0{\cdot}666} \times \frac{46 \text{ ft., height}}{5{\cdot}62 \text{ ,, fall}} = 82\%.$$

Delivered into tank at house, 95 gallons per day.

43. In a case where water was abundant and a possible fall of 25 feet assured, the quantity required to be raised was 100,000 gallons per day to a height of 138 feet. As the computation of the waste water would have involved considerable expense, however desirable, and not being really necessary, it was not entertained, and the situation and requirement were considered without reference to it.

Notice was drawn in § 18 to the empiric dictum regarding the capacity of the driving pipe ; and it must be stated that the average flow over the waste was *not three times but seven and a half times* that quantity, extending over a numerous series of installations, and ranged from 3·7 to 19 times the required driving supply; and, in consequence of the low rate first cited, the efficiency was low, but the conditions were such that could not be amended.

44. Now, with these elements before us :—

Required quantity to be raised, 100,000 gals. per day;
Height to be raised, 138 ft.;
Fall fixed at 24½ ft., *i.e.* difference of level between surface of driving water and lip of dash valve;

we now require to calculate the dimensions of our driving pipe. In § 26 it was pointed out how misleading statements in molar physics may be made if due regard be not paid to the mode of their presentation; and we have now to consider the determination of two of the most important factors in the problem of auto-pumping, and the two most difficult to determine adequately.

45. There are many formulæ for calculating the flow of water through pipes. The following method, adapted from "De Prony's," the writer elected to use through years of practice as being both simple and safe :—

$$V = 40\sqrt{D \,.\, H}.$$

V = Velocity in feet per minute.
D = Diameter of pipe in feet.
H = Fall in feet per mile.

$V \div 60 =$ Speed in feet per second $= V'$.
$V \div 3 = Y =$ Yards per minute.
$d =$ Diameter of pipe in inches.
$Y \times d^2 \div 10 =$ Gallons discharged per minute.

To find the quantity necessary for driving :—

Multiply the quantity to be raised by the height to which it has to be raised, divide by the fall, and reduce to the efficiency expected.

Now, here may be the most fitting place to notice at some length this matter of efficiency.

46. In the 28th edition of "Molesworth," on the page already cited (§§ 16–17), D'Aubuisson gives efficiency under the Greek initial η :—

$$\eta = 1{\cdot}42 - {\cdot}28\sqrt{H \div h},$$

and higher on the page we have :—

$$\eta = 1{\cdot}12 - 0{\cdot}2\sqrt{H \div h}. \qquad (H = \text{lift};\ h = \text{fall.})$$

Now let us clearly have in view that the square root of height divided by the fall is to be multiplied by 1·42 minus the insignificant fraction ·28 in the one case, and in the other by 1·12 minus ·2.

In the case cited (§ 17),

$$\frac{H}{h} = \sqrt{40{\cdot}3} = 6{\cdot}34 \times 1{\cdot}42 - {\cdot}28 = 1{\cdot}14 = 7{\cdot}2 \text{ per cent.},$$

instead of 85 per cent. (§§ 17–20).

47. If we take an installation where the duty was

90 per cent., the discrepancy is still more remarkable. In this case :—

$$\frac{\mathrm{H}}{h}=12\,.\,\sqrt{12}=3{\cdot}46\times1{\cdot}12-{\cdot}2={\cdot}92=3{\cdot}18\text{ per cent.}$$

The principal factors of this installation were :—

$$\begin{array}{l}\text{Gallons delivered per min.,}\\ \text{,,}\quad\text{used}\quad\quad\quad\text{,,}\end{array}\ \frac{1{\cdot}25}{16{\cdot}7}\times\frac{141{\cdot}28\text{ ft., height}}{11{\cdot}75\text{ ,, fall}}=90\%.$$

48. Let us now revert to § 44. Our factor there required is the quantity necessary for driving, and we want 100,000 gallons per day, say 70 gallons per minute. We have therefore :—

$$\frac{70\times138}{24{\cdot}5\times\mathrm{E}}.$$

Taking E as 70 per cent., which has been always found very safe, we find the required quantity to be 563 gallons per minute. Now, this into our average 7½ (§ 43) would give us 4300 gallons roughly as the required carrying capacity of our drive per minute, and 117 ft. was tentatively taken as length being found convenient for the situation.

49. We will try what De Prony's formula will do for us (§ 45). $\mathrm{V}=40\sqrt{\mathrm{D}\,.\,\mathrm{H}}$; then, by Rule of Three :—

$$117 : 24{\cdot}5 :: 5280 : \mathrm{H}=1105{\cdot}6\text{ fall in ft. per mile.}$$

For D, trying 10 in.=ft.=·83, then

$$1105\times0{\cdot}83=917\sqrt{917}=30{\cdot}28\times40=\mathrm{V}$$
$$=1211\text{ ft. per min.};$$

then $1211 \div 3 = 403{\cdot}6 \times d^2 \div 10 = 4036$ gallons per min., which is nearly 300 gallons short.

Then by 12-in. pipe (unity feet),

$$\sqrt{1105} = 33 \times 40 = 1320 \div 3 \times 12 \text{ ft.}^2 \div 10$$
$$= 6336 \text{ gallons per minute.}$$

The 12-in. pipe was installed, and the machine delivered 80·3 gallons per minute at the point required=115,632 gallons per day.

50. The formulæ might be stated in simple proportion sums, and perhaps the adept in figures will excuse the elementary process in the interest of those to whom computation is not so familiar.

Let H, F, G, R, and E represent height, fall, gallons for driving, gallons required, and efficiency respectively. Then:—

$$F : H :: R : \div E = G = \text{Gallons driving.}$$

(1) $24{\cdot}5 : 138 :: 70 : \div (E = {\cdot}7) = 563$; or:—

$$\frac{138}{24{\cdot}5} \times \frac{\overset{100}{\cancel{70}}}{\cancel{{\cdot}7}} = \frac{13,800}{24{\cdot}5} = 563.$$

(2) $H : F :: G : R \times E = \text{Gallons required.}$

$$\frac{24{\cdot}5 \times 563 \times {\cdot}7}{138} = 69{\cdot}9.$$

(3) $G : R :: H : F \div E = \text{Fall required.}$

$$563 : 70 :: 138 : 17{\cdot}15 \div {\cdot}7 = 24{\cdot}5.$$

It is essential that the drive should be straight on plan, uniform in gradient, and ample in area; but of course the latter may be overdone, like everything else. Care must be taken in this connection, and the caution expressed with reference to the quality of the power (§ 11) obtains here. If too large, the speed will be so excessive that the valve will "chatter" and an effective stroke will not be obtained. It must not be too small either; and if economy is to be studied, it should not be effected at this end of the system. With ample power behind the machine a small delivery pipe can be allowed for and discounted; but by no possible arrangement can the force of a small drive be augmented, except by additional head, and it is assumed that of that particular all advantage has been taken.

51. Reference was made in § 25 to a tapered drive having been recommended to induce a uniform velocity from end to end. In arranging lines of gravitation supplies uniform velocity is of great importance and must be carefully studied, with due regard to the effect of contour in relation to the hydraulic mean gradient and the avoidance of shock; but in driving pipes shock has to be arranged for, and the reaction (recoil) beyond the range of the machine to be as far as possible prevented. Now, a tapered drive, in any but a toy apparatus, would involve needless expense, diminish the friction which checks the recoil, and increase the interval between the

strokes. A syphon drive with a foot valve has been installed with good effect where a rocky bank would have caused great expense in cutting, but is only recommended in extreme cases.

52. Now as to length; several examples have been given showing how unreliable the rules cited are, and if the writer were asked to state a definite rule for finding the *exact* length of the driving pipe, the frank reply would be, "I am unable to do so, nor do I know anyone who can." But with more learning and wider experience such a rule may perhaps be found; and if so, those most interested will be laid under deep obligation to the finder—especially the practical man, if it be not rendered useless to him by the number and complexity of the factors. But though exactness cannot be assured, a fairly serviceable approximation can, and may be stated in the following terms:—

Let H be the height of the ascending column in ft.
,, S be the static pressure of the ascending column in lbs. per square in. $=H\times{\cdot}433$.
,, F be the fall of the driving column in ft.
,, L ,, ,, length ,, ,, ,, ,,
,, V' ,, ,, velocity ,, ,, ,, ,, p.s.
,, P ,, ,, power of the driving column in ft.-lbs. per square in. $=L\times{\cdot}433\times V'$.

Then $P=S\times 8$; that is, the drive must have a dynamic force (in weight×V′)=8 times the static force of the ascending column. That is the average: it need rarely exceed 12, but never be below 4. A few examples:—

	L.	F.	H.	V′.	P.	÷	S.	Ratio.	Weight.	Ratio to V′.	E.
	ft.	ft.	ft.		ft.-lbs. per sec.		lbs.		lbs.		%
(1) A 4-in. pipe	100	4	180	5·45	236	,,	78	3	544	100	50
(2) ,, 5-in. ,,	100	4	168	6·37	276	,,	73	3·8	850	133	85
(3) ,, 2-in. ,,	80	8	66	7·0	243	,,	28	8·57	108	15	927
(4) ,, 1-in. ,,	36	1·5	11	2·8	43·6	,,	4·7	9·0	12·2	4·3	916
(5) ,, 2½-in. ,,	63	7	46	7·3	200	,,	20	10	133	18	90
(6) ,, 3-in. ,,	106	11·75	141	7·8	357	,,	55	6·5	323	41·4	90
(7) ,, 3-in. ,,	39	12·5	69	13·7	231	,,	30	7·7	118	8·6	53

In explanation:—(1) Low duty due to drive being too short for the height and work—"B" Machine requiring longer drive, which could not be got. (2) Just on the margin. (4) Drive so small as to discount the low weight ratio. But the low duty of (7) was entirely due to the disproportion of the components of P, by reason of the short drive, which could not be lengthened except with complicating bends. The weight over V′ should not be less than 12 times. Generally, it may be stated that the force of the impact should be so determined as to exceed that of the static pressure and the frictional resistance in the delivery pipe, in an ample degree, by arranging the area, extent, and inclination of the drive with special regard to the required quantity of discharge (§ 75).

THE SLUICE VALVE.

53. The necessity for an efficient stop valve on the driving pipe was noticed in § 27, and exception was taken to the rough-and-ready flap in the driving tank. On the necessity arising for a stoppage of the water, recourse must be had to the tank, and on the flap being lowered by the chain supporting it the waste valve at once opens and the drive begins to empty itself, aided by the untight flap. The quantity flowing being more than can be admitted by the leaking flap, air will enter through the waste valve and collect in the drive, taking sometimes hours to work out. The ear easily detects its presence by the peculiar softness of the stroke, and until it is expelled no good work can be done. The exclusion of air from the drive is absolutely imperative—indeed, water holding much occluded oxygen is sometimes troublesome, the incidental shocks perhaps assisting segregation.

54. It is essential therefore that the drive be laid straight on plan, and the slope, however slight, uniform. The mischief caused by even small portions of air may be well illustrated by the following incident. The writer was called in to report on a case in which

the delivered quantity was only about half that guaranteed. The supply was from a spring, and was allowed to plunge into the tank from some inches above the surface. The cause of the shortage was at once seen—small globules of air were being by this means drawn into the tank and thence carried into the drive. On the water being let into the tank gently the evil was cured, and in an hour the harder stroke indicated that the guaranteed quantity was being raised. The defect of the ordinary sluice valve as an adjunct to this apparatus has been alluded to in § 27, and in an installation where it was replaced by the one designed by the writer, and now to be described, the efficiency was raised from 65·4 per cent. to 87 per cent.

55. The reduction of speed caused by the opposition offered by the gate-recess is very material It matters not though the drive be of ample area and adequate length, unless the path of the moving column be free from such obstructions there can be no high percentage of duty. In point of fact the interior of the drive cannot be too smooth; for speed, such an important component of the power, is not only augmented, but the frequency of the stroke is enhanced by the low skin resistance within the pipe, and any effort to shorten the period of recoil must be made as near the point of dispersion as possible, on which more anon.

Fig. 1 shows the frictionless sluice valve on plan; fig. 2, section on A B (longitudinal); and fig. 3, cross-section on C D, showing the valve open, and fig. 2, showing it shut.

The fairway of the valve body and the gate are bored together after the gun-metal rings, which are cast in, are faced, and the gate block made an easy fit between them.

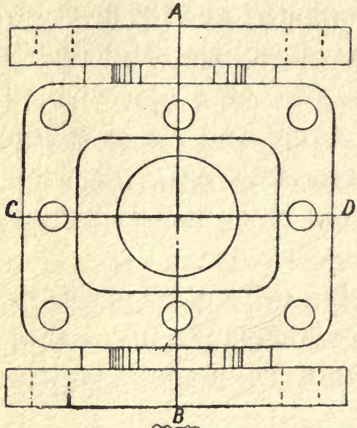
It will be seen that the valve will not be perfectly tight when the gate is down, which is not necessary; but when up, and open, presents the smallest possible obstruction to the current.

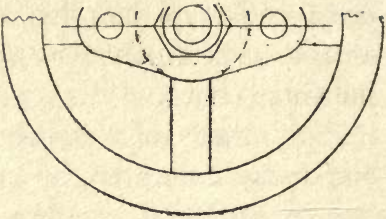
THE DASH VALVE.

56. The first essential in regard to this valve is strength, and the second lightness. The former need is obvious in view of the shocks to which it is necessarily subjected, and the latter has been recognised by some makers and provided for by attaching chain and balance to the top of the spindle. So far from being as heavy as to overcome the static pressure of the driving column, which has been shown (§ 15) to be erroneous, it could scarcely be too light consistent with tenacity. It is to be observed that this absurd rule has been repeated in a work devoted to this subject lately published.

57. The next requisite is facility of adjustment.

FIG. 1.





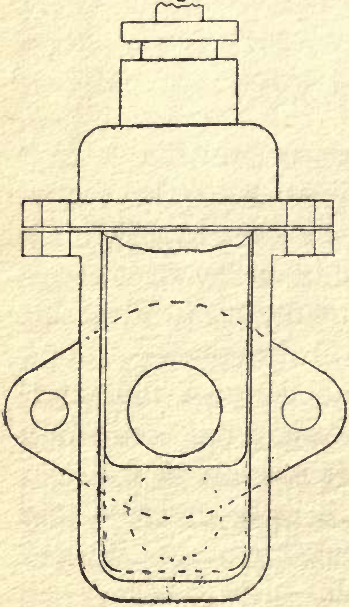


FIG. 3.—Section on C D.

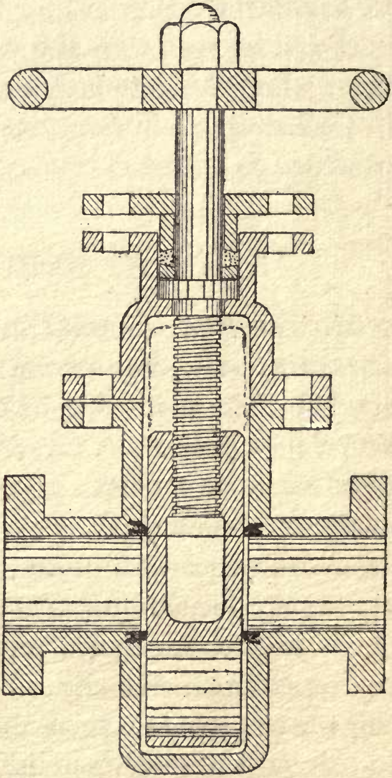


FIG. 2.—Section on A B.

The area of passages should be equal to that of the drive and the fairway of the body of the machine, and the alteration and adjustment of the stroke have for their object the earliest possible attainment of

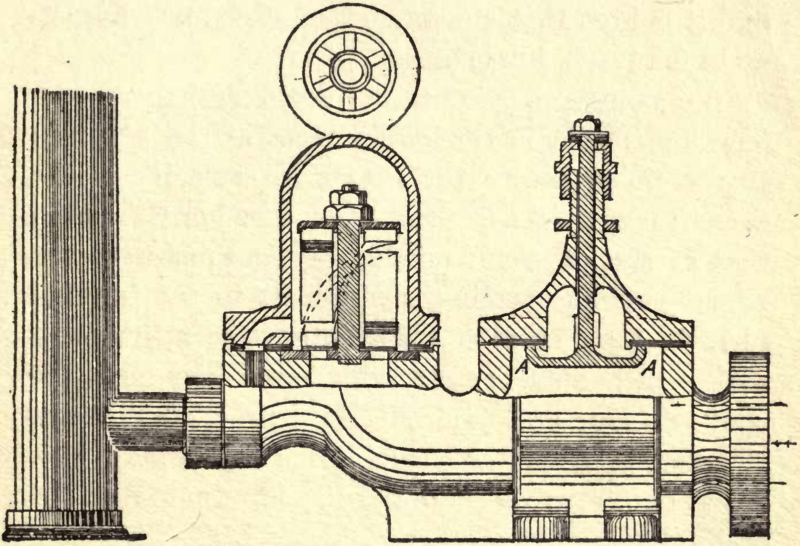


FIG. 4.

something nearly, but not quite, approaching the full speed of the column. The nearer this is reached with the certainty of its not being exceeded, the higher—other things being equal—will be the effective duty of the apparatus.

58. The area of the annular space A (fig. 4) being equal to that of the inlet to the machine, it is clear

that opposition to free flow is presented by the disc of the valve; but if the disc be allowed to drop sufficiently far to admit of force getting above it ample enough to exceed the power of the moving column to raise it, then no stroke will be obtained, and it is here that the advantage of definite adjustment is of such importance.

In a general way it has been said that the proper length of stroke is that which just arrests the flow at the point before the maximum velocity of the current is arrived at. And it must be borne in mind that as such a small portion of the apparatus can be subjected to tooling, inequalities in the internal surfaces may involve modifications in adjustment with which rules could not cope. The arrangement of cap and jam-nut, as before stated, was a great improvement, and in cases where this form of valve is adopted is all that may be desirable.

59. But where the power is great, more especially when the speed component is high, rupture of the spindle is apt to occur near the point marked on fig. 4, even when strengthened, as shown, to an extent of making the valve unduly heavy. So, to entirely avoid such risks, it was found advisable to reverse the valve, as shown on fig. 5—by which device, be the stroke ever so heavy, rupture is prevented, and the tendency of the repeated impacts is rather

to compress than separate the particles of the metal.

60. Adjustment is of such moment that the importance of it can hardly be magnified, and easy access to means of alteration of all sizes of machines —particularly the larger sizes when handling is necessarily more difficult—has been found of immense advantage in an experience extending over many years, in which it has also been found that out of no apparatus of the three types can the best work be got without having recourse to heedful stroke adjustment.

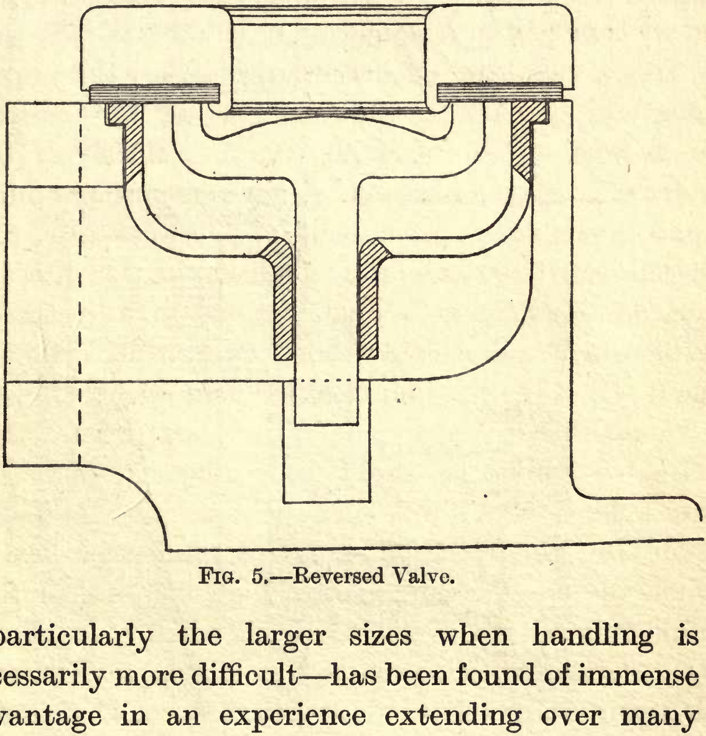


Fig. 5.—Reversed Valve.

61. By the double wedge—rack and pinion—device

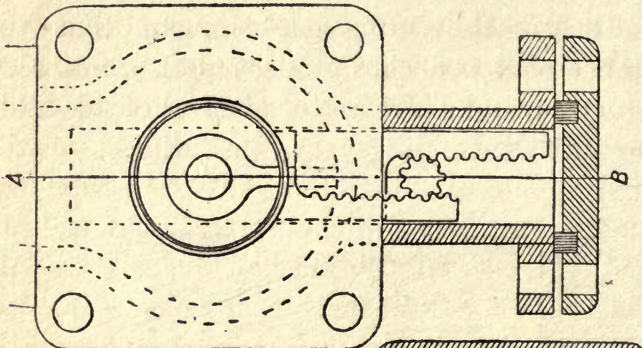


Fig. 7.—Reversed Valve Adjustment Device.

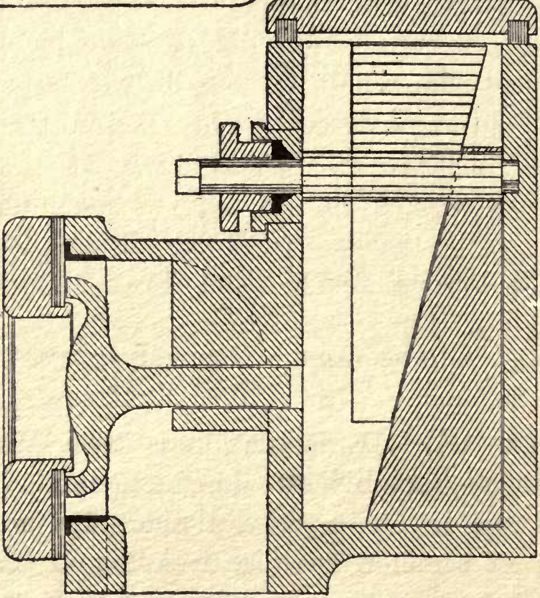


Fig. 6.—Section on A B.

(figs. 6 and 7) the requirement has been met. The most minute alteration of stroke on any machine, from the smallest to the largest, can be effected with facility, and the pinion shaft can be secured by jam-nut and fixed by lock and key to prevent being tampered with.

62. Where a few inches of fall only is obtainable, the stroke fairly heavy, and a large quantity to be delivered at a medium height, the form fig. 5, with disc and spindle of aluminium, may be used with great advantage. The difference in weight makes a material difference in utilising low falls. If we take the valve of a 2½-in. machine, which is a very handy testing size, change is soon apparent. Of the same dimensions as gun-metal and sufficiently strong, it is less than one-third of the weight, and where 7¼ in. of water is required to support the bronze valve 2¼ will support the aluminium one. The cube of the moving part (fig. 5) in a 2½-in. machine would be about 7 in., and would weigh, in bronze (neglecting displacement): 2·16 lbs.÷area 3¼ in. diameter =8·29=·26 lb. per sq. in.÷·036=7·25 vertical in. of water; in aluminium =·077 lb. per sq. in.÷·036 =2·14 in.

63. In § 39 an installation is described where a varying fall of only a few inches was obtainable, of which 9 in. were made available as a minimum,—raising 216 gallons per day over 45·33 times its head. An attempt to utilise 6 in. failed, for, though the current had force to close the valve, no effective result could be obtained from the slight shock. Had

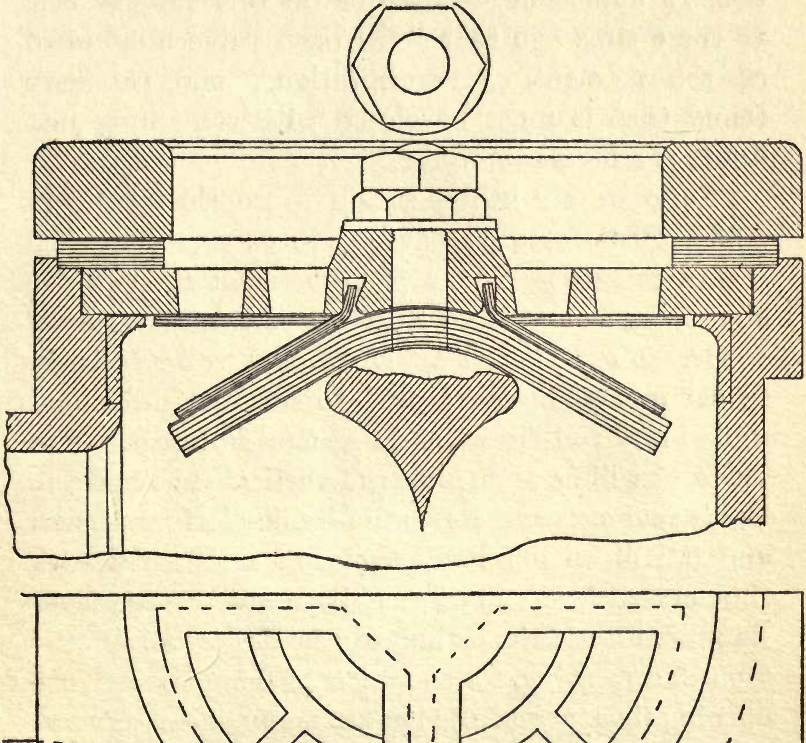
aluminium been used (but it was not so procurable then as now), the result would have been different, as there would have been nearly 4 inches more of clear current force, on which more anon. The main elements were :—

	L.	F.	H′.	V′.	P.	Total Impact.
A 4-in. pipe	117 ft.	9 in.	34 ft.	2·22	112 per sq. in.	1420 ft.-lbs.
,, ,,	,,	14 ,,	,,	2·76	140 ,, ,,	1758 ,, ,,

64. The form of valve fig. 5 is recommended for high falls, but for low falls it will prove of great service, so little head is required for its support; particularly if the moving part is made of aluminium; while figs. 8 and 9 might prove of advantage where the fall was low, the volume of the current large, the escape submerged, and where silent working was imperative. The slight spring on the plates is only necessary to open the valve on the reaction, along with the form of the rubber disc cover.

65. Now, at the stage at which we have just arrived the question emerges, Is it necessary to have to *lift* the valve under any conditions of fall, low or high? Accepting as fact for the moment that the disc-spindle form is the most suitable for heavy work, the progress in the development of the aluminium industry enables the question to be answered in the negative. The price of this metal, until lately prohibitive, is now cheaper than gun-metal of equal dimensions; it is more than two-

Fig. 8.



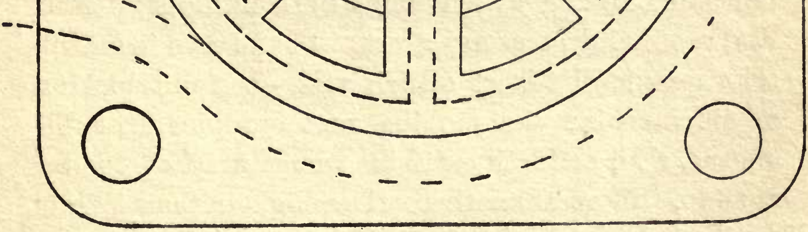


Fig. 9.—Silent Horizontal Dash Valve.

thirds lighter, and for our purpose in other respects equally applicable. A writer on this subject told us some time ago that "the dash valve must open at the moment of regurgitation," and we have found that it must be closed with something just under the maximum force.

66. So we are in a position to consider cases in which great force is required, in cases where even inches of fall is of the utmost importance in the advantageous use and disposal of large bodies of water. Fig. 10 shows a form of dash valve designed to act under any impact up to 100,000 ft.-lbs. and under any fall from a few inches upwards. The valve, as will be seen, is placed vertically, as in fig. 5, but is reversed, and forms the terminal of the drive; and it will be observed also that, contrasted with the vertical forms 5 and 6, additional fall is acquired. But more is obtained than can be deduced from the view of a drawing, for the water rushing through the opening (figs. 5 and 6) rises in many cases to some considerable height, absorbing both time and power, and producing no useful effect. Let us turn to fig. 10. The spindle-disc is of aluminium. In full size for a 2½-in. machine the moving part contains 13 cubic inches, and, deducting displacement, weighs in water 0·48 lb. More than three times lighter than bronze in air, it is nearly five times lighter in water.

This valve can be adapted to any situation or any requirement. As before stated, falls are measured from the level of the driving supply to the lip of the discharge; but strictly with the vertical form in action

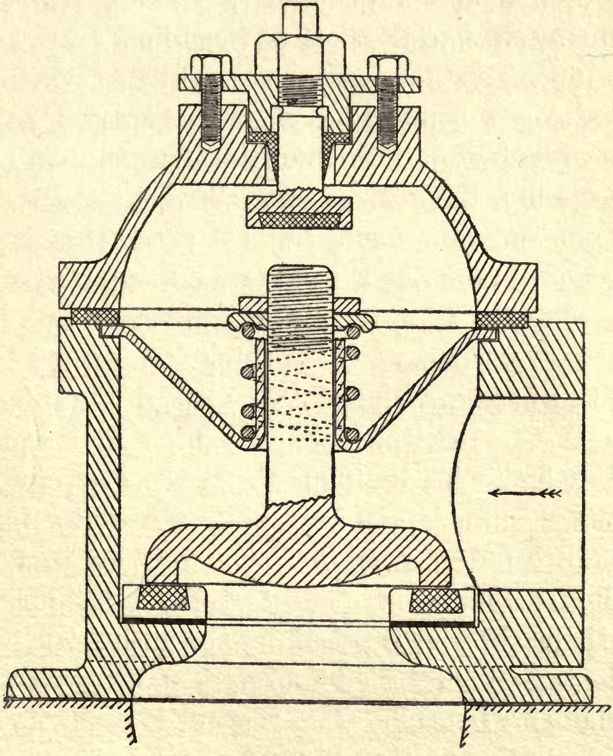


FIG. 10.—Final Form of Escape Valve.

this is rarely, if ever, maintained, and the effective range of power exerted ought to be measured from the driving surface to the top level of the discharge. With this form the effective fall will be from that surface of supply to the line of the discharge orifice, an inch or two above base. It may now be considered as clearly shown that that portion of the force uselessly producing a high apex of outflow should be usefully applied to the desired purpose.

The opening of an escape valve in this position is affected by a spring, as shown, adjusted to the tension required to raise the disc from the discharge opening only, the orifice being closed by the current as in the ordinary form, but the force that had to be expended in lifting the valve is now exerted on the spring with the advantage of the increased fall.

The spring method of opening the escape being substituted for gravitation, the utmost advantage is taken of the existing fall. The vertical form is adopted, but with the flow above the disc, and the advantage gained may be readily shown by taking as instance a 4-in. machine. The moving part is of aluminium and about 30-in. cube, weighing less than three lbs.; it is raised by the spring with such slight tension as just to overcome its weight, on the instant of recoil. The seating is separate and held in position so that it can be easily removed for renewal or repair. The mouth of discharge is but 2 in. above the base, and the top adjustment is always accessible for alteration of stroke (§§ 60–61).

But a more important advantage is gained by the adoption of this form of dash valve. It has been pointed out in §§ 58–66 that to take full advantage of the speed factor of the power the flow should be checked just before full speed is reached. By the adjustment here furnished this can be effected with great facility and precision. The valve being removed from the egress opening by the spring, on which tension need be only sufficient to raise its weight—about one pound in aluminium on a 2½-in. machine,—free course is made for the full current at its maximum velocity. Then the valve can be depressed until the point is reached when the current will close it.

THE ASCENSION VALVE.

67. What has been urged with regard to adjustment respecting the dash valve is of no less importance where the inner valve is concerned. Let us first consider the case for spindle form. Its position being necessarily internal, it is not easy of access, and adjustment has hitherto only been effected by the occasional removal from its seat. In order to prevent *trip* as far as was possible, the space between the spindle and sleeve in which it works was as narrow as could be allowed for free play, but in opening the entire disc must be raised, however short the lift may be. It will be at once perceived that for a given discharge the shorter the lift the greater the area of

the disc must be. Now, an impact that would be strong enough to overcome one square inch of opposing force, indicated in pressure, might fail if opposed by several; and it is thus that valves of the order of the grid, Perreau, etc., have advantage through their mobility over those presenting a rigid surface to the opposing force. Another point of importance to be noticed is the right-angled change of direction impressed upon the flowing body—which change, however, is shared by the grid, but not by the Perreau valve.

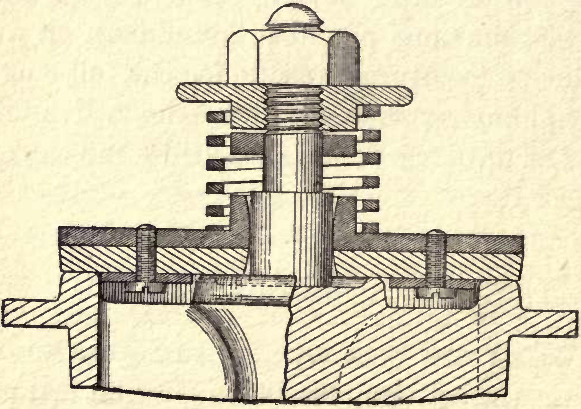


Fig. 11.—Ascension Valve.

68. The form shown in fig. 11 has given very good results, and stands enormous pressure well, but it is open to the objection of the spindle valve as to abrupt change of direction; though, unlike it, the whole disc need not be raised, as it admits of tilting;

yet, like it, in requiring to be removed to be adjusted. The ordinary grid valve is well known and, owing to its mobility, is enabled to pass quantities of water under pressures to which the rigid disc could not respond, and close again so quickly that slip was almost entirely prevented; but the rubber disc, though sensitive, is not lasting.

69. Fig. 12 is a form of valve which has given very great satisfaction under low falls and high deliveries. A great improvement was effected over the ordinary grid valve by sinking the disc, forming a flat centre, and rising straight on on section to the outer edge at an angle of about 10°. A disc of the same sectional form of sheet brass interposed between one of hydraulic leather and the ordinary rubber disc gave fairly great stability, and proved very serviceable for all heights from 50 to 200 feet, at which it is practically self-adjusting, while the substitution of a strong rubber guard for the brass one retained much of the sensitiveness of the grid.

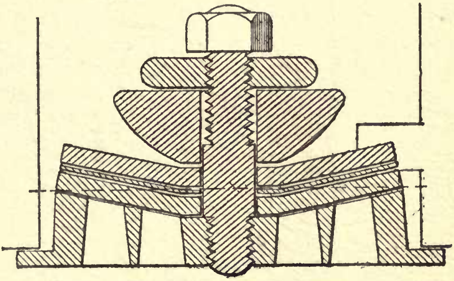


FIG. 12.—Grid Valve (*a*) protected.

70. Fig. 13 is an improved form of fig. 12, in that it is more sensitive in receiving quantities for dis-

charge at great heights, the strengthening plate being re-arranged and inserted in four sections, each of which is free to move independently. To equal its full discharge a rigid disc would have to be raised

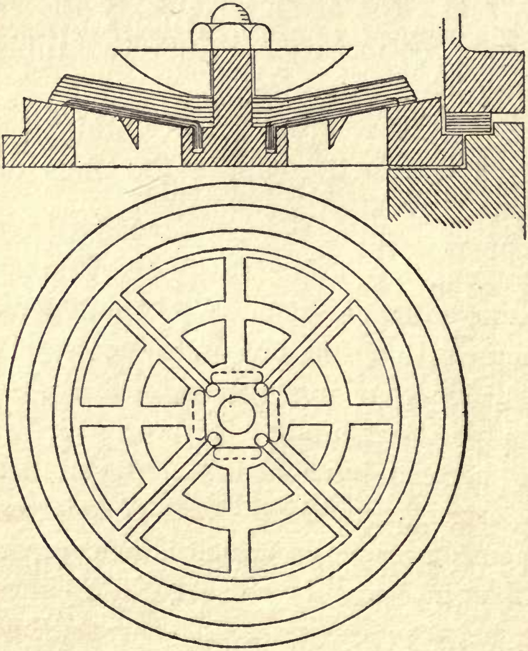


Fig. 13.—Grid Valve (*b*) improved.

nearly half an inch; but whatever its discharge, the rigid disc must be raised as a whole against a pressure on a surface of 16 square inches. Now, the dispersion (§ 5) may be secured by the yielding of any of the sections of fig. 13 and the period of rest shortened thereby.

71. But for deliveries at medium heights when large quantities are required, none of the foregoing designs are particularly well suited. In such cases it is essential that the ascension valve should be capable of passing suddenly a large quantity of water and instantly closing to retain it with least possible slip; and in order that this be achieved and the full value of the stroke obtained, the path of the fluid must be practically straight, and the lift of the valve accurately adjusted to the force of the impact.

Fig. 14 shows the valve designed to meet these requirements, in position as adjusted, and figs. 15 and 16 the mode of adjustment. A, spindle and disc of aluminium with spring not under stress. B, annular spindle guide engaging by screw easily in C, which is operated horizontally by worm on spindle F causing vertical movement on B compressing the spring to the required tension. C revolves by easy movement on bridge D, which is held in position by dents E let into coved recesses in G, the intermediate casting between the air-vessel and the body of the machine. Into G are fitted the air-charging and water discharge valves. H, special composition pressed into coved dovetail recess in the body while in a semi-viscous state. This valve is suitable for deliveries at any elevation, and by adjustment will pass and retain whatever quantity is required. Fig. 17 shows the same valve on cross section, with

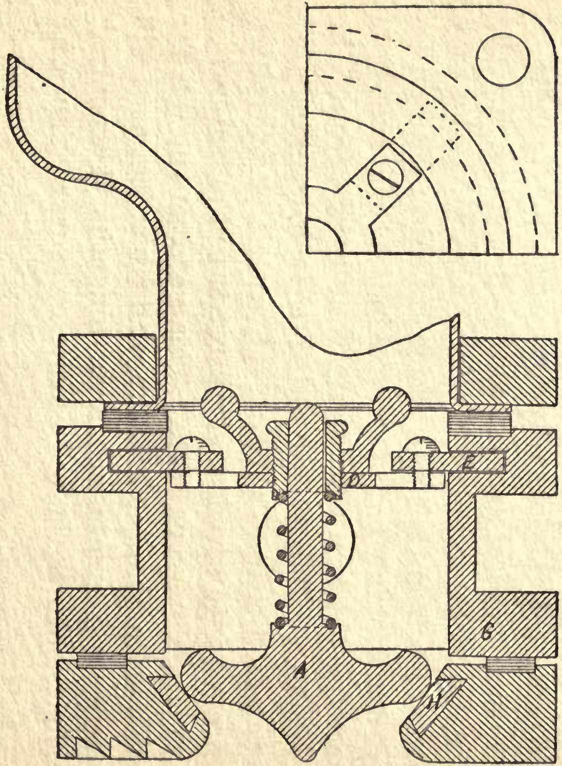
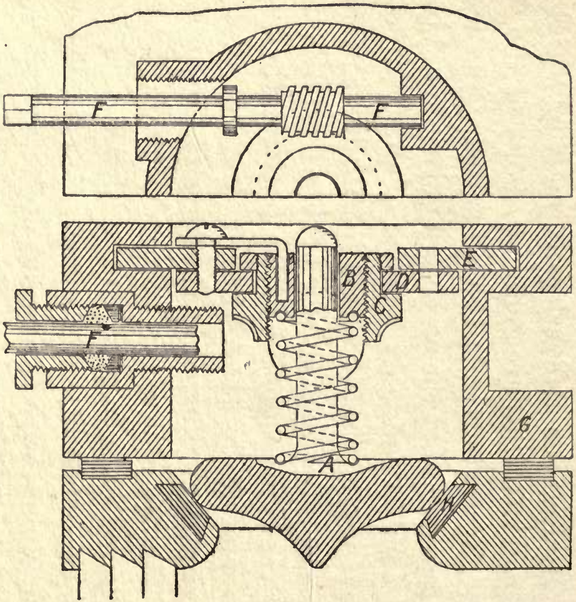


FIG. 14.—Ascension Valve.



FIGS. 15 and 16.—Ascension Valve with Adjustable Device.

the composition pressed into the disc instead of the body, which will offer more facility in cases of renewal.

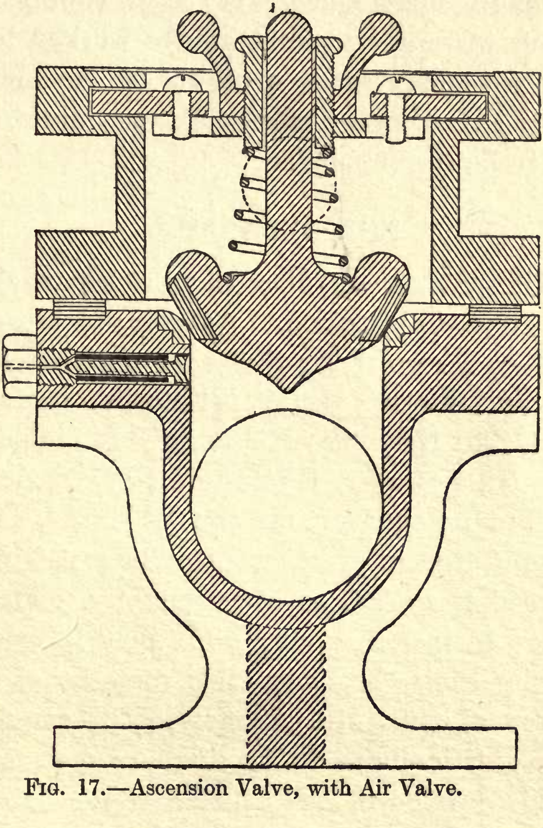


FIG. 17.—Ascension Valve, with Air Valve.

A word may be said here with regard to an automatic air-valve for supplying the absorption in the air-vessel, commonly called the snifting valve. It should be placed as close under the ascension valve as possible, shown on fig. 17. It is often dispensed with, not being considered essential; but it can do no harm, unless too much reliance is attached to it, the necessarily small inlet being very apt to choke. In numerous instances machines have worked for long periods without recharges of air or any attention whatever; but occasional visits to machines are always to be recommended.

THE AIR-VESSEL.

72. The material and dimensions of the air-chamber are of great importance. As regards dimensions, it has been shown (§ 32) that they may be exceeded unduly by following certain rules, while by following others (§ 33) they may be unduly diminished. It is essential, however, that the air space should be ample, but no general rule can be stated, as it has been found that in practice the cubic space in inches has varied from 250 to 500 times the diameter of the drive in inches, giving high duty in each case. In special cases, however, this may be exceeded: in drives above 4 in. diameter; in cases where large quantities have to be discharged at comparatively low levels—in such cases extreme elasticity of "cushion" above the valve is of supreme service; and also when compound machines are installed, whether raising a separate stream or both; but the subject will be referred to at greater length when we come to deal with that type of apparatus.

73. Regarding material, copper has been extensively used, but has been found unreliable, as well as costly, being apt to scale under great stresses—unless made of very thick plate—and the inevitable shocks. Cast iron held the field almost exclusively until the perfection to which electric welding arrived enabled steel to command the first place, where strength and lightness combined were desirable. Air-

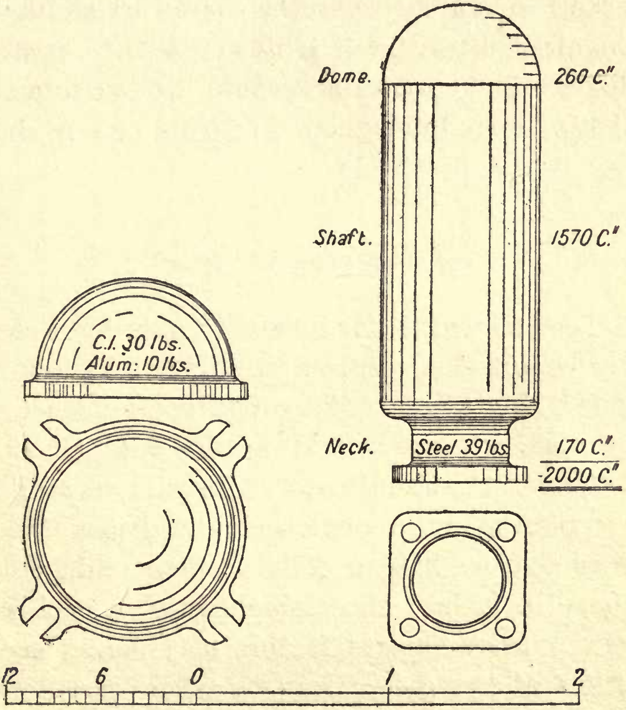


Fig. 19. Fig. 18.

Air-Vessel for 4-in. machines with dome cover for diaphragm or plunger.

vessels of welded steel plate are by far the most preferable for these apparatus, and figs. 18 and 19 show the suitable forms. It is of the greatest moment that the form of the chamber should be adapted to the required work, for it is not enough to confine a portion of air to act as a cushion if the effect of its elasticity be diminished by throttling or any similar cause. See Appendix II.

THE DELIVERY PIPE.

74. In §§ 35 and 36 has been shown the needlessness of incurring useless expense in laying an excessively large delivery pipe. Like every other part of the installation, its size should be determined by the conditions of the situation. If there is ample power at his disposal, the engineer should not increase expense by installing a delivery pipe unduly large, on the plea of not increasing pressure in the air-vessel. With adequate factors of fall and supply, or either of them, his duty is, where the delivery point is distant, to satisfy himself that the air-vessel is ample in capacity and strength to sustain without strain the stress put upon it. It is one of the special functions of the machine of which full advantage may be taken, as the following cases will show—three cases, out of many similarly treated, taken as typical :—

THE DELIVERY PIPE.

	Pressure per sq. in. in lbs.			Distance.	Diameter of Delivery.	Quantity Raised.		Friction.
	Static.	Working.	Excess.			Per Min.	Per Day.	
				ft.	in.	gals.	gals.	per cent.
(1)	30·5	75	44·5	1800	1	6·14	8,000 to 10,000	7·4
(2)	43	72	29	2100	$\frac{3}{8}$	·26	374	4·14
(3)	32·5	59·5	27	1800	$\frac{1}{2}$	1·17	1685	4·5

75. In determining the diameter of the delivery pipe, after the height of discharge has been allowed for, the distance has to be considered, and a profitable suitable diameter tentatively resolved on. The question then arises, What power can be spared over that required for the raising of the supply fixed upon? Perhaps it may be well to illustrate the process by reference to one of the cases cited above.

In case (1) it is shown that 44·5 lbs. additional pressure overcame the resistance of a 1-in. pipe 600 yards long, giving, in accordance with a varying fall, from 8000 to 10,000 gallons per day. This extra pressure is equal to an extra height of 102·35 ft.

Now, by De Prony's rule we have :—

$$1800 : 102{\cdot}35 :: 5280 : 300{\cdot}22 \text{ fall in ft. per mile} \times 1 \text{ in. in ft.}$$
$$= {\cdot}083 = 24{\cdot}9\sqrt{24{\cdot}9} \times 40 = 199{\cdot}6 \text{ ft. V per min.} \div 3$$
$$= 66{\cdot}5 \text{ yd.} \times \frac{1 \text{ in.}^2}{10} = 6{\cdot}65 \text{ gallons per min.}$$

The minimum delivery was 6·14 gallons =8840 per day. It will be seen that, letting the extra pressure stand for height, the required diameter can be found. The main elements in the case were :—

$$\frac{\text{Height, 75 lbs.} \times 2{\cdot}3 = 172{\cdot}5}{\text{Fall} \qquad = \qquad 20{\cdot}0} \times \frac{6{\cdot}14,\ \text{quantity raised}}{70{\cdot}14 \qquad ,, \qquad \text{used}} = 747\,\%.$$

It is not to be inferred that, although through allowance being made for probable frictional resistance of discharge a closely approximate delivery pipe may be determined on, a very high duty can be attained; but where the driving supply is abundant it is well to consider this point, and observe how the necessary water expenditure varies with the required quantity in relation to the area of the delivery.

In case (1) we have 7·4 lbs. extra pressure for each hundred yards of distance, when as much as 6 gallons per minute is required with a 1-in. pipe; while

In case (2) there are $4\frac{1}{7}$ lbs. more force per 100 yards to be expended when even the small quantity of something over a quarter of a gallon per minute only is required, the distance being 700 yards, with a $\frac{3}{8}$-inch pipe; and,

In case (3) $4\frac{1}{2}$ lbs. extra pressure per 100 yards is involved to deliver 1·17 gallons per minute at a point 600 yards distant through a $\frac{1}{2}$-inch pipe.

Cases could be multiplied, but enough has been advanced to show the scope of the apparatus and the range of its operation.

At the same time it must be clearly borne in mind that where the driving supply is limited, care must be taken, in determining the area of the delivery pipe, that incident friction shall not exceed the water expenditure that can be afforded.

PIPING AND JOINTS.

76. The friction within pipes and at the joints is an important subject connected with water supply.

When considering the cases of public works the engineer must have before him the regular transmission of large quantities for distribution at the points required for present needs and also with probable future needs clearly in view. Among mechanical details smoothness of internal surfaces and flush joints are prime desiderata, and are provided for by him as far as economic considerations will admit. But, important in all cases as they undoubtedly are, they are to be regarded as of still greater moment with respect to the supplies the nature of which we are engaged in considering.

In most cases pipes of cast iron with leaded spigot and faucet joints have been used as being more suitable than flanged ones, having cost prominently in view; but even on the score of flushness, flanged joints (except when made with extreme care) offer little more advantage in the matter of friction. So, the finding of a driving conduit more suited for our purpose than the cast iron commonly used, or the tapered copper pipe referred to (§ 25), has been the subject of some considerable cogitation.

77. Rusting, which has given much trouble in the past, having been in great measure prevented by galvanising, the point of attack left to be assailed was the joint. In several sections the need of abolishing friction as far as was possible in the driving pipe has been pointed out, and the occasional giving-way of leaded joints, even when made with the greatest care, has directed still more serious attention to the point and led to the adoption of the method shown on figs. 20 and 21. The figures show with sufficient clearness, it is hoped, the aim of the design, but it may be well to add, to what has been set forth and urged elsewhere (§ 54), something further regarding the advantage secured by a smooth drive. We must glance again for a moment at the matter of energy. Though it has been considered expedient to dispense with the epithet and content ourselves with the "substitute" POWER, yet a brief reference will perhaps help to elucidate what is to follow.

We have found it sufficiently serviceable to multiply directly the speed per second (found by the simple formula explained above) into the weight of the liquid column; but the trend of evidence—of which the following case is a noteworthy example—seems to lead to the conclusion that the actual speed generally attained, by reason of the frequent stoppages, is really only something near to the square root of what the mathematical computation of energy demands, and it is only referred to here to show, and if need be to enforce, the importance of a smooth drive.

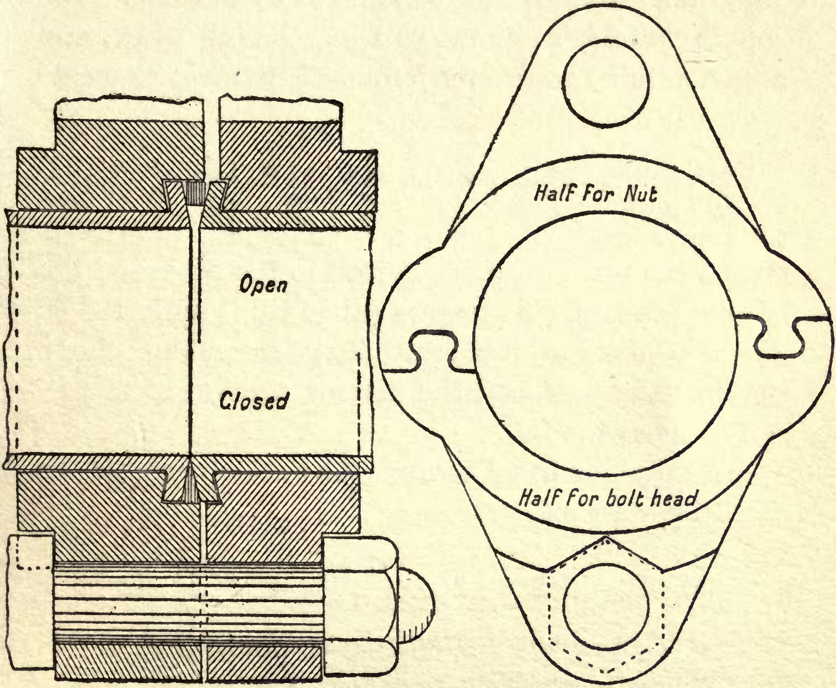


Fig. 21. Fig. 20.

Frictionless Pipe Joint.

78. In a small installation, which offered a favourable opportunity for experiment, referred to, § 52, and (4) in the list of examples, a drive of strong lead pipe was used and laid as straight as possible. The length was 36 ft., diameter 1 in., the fall 18 in., and there were of course no joints. The main elements were :—

$$\begin{array}{l} \text{Water delivered, gals. per min.} \\ \text{,,} \quad \text{used,} \qquad \text{,,} \qquad \text{,,} \end{array} \frac{0{\cdot}15}{1{\cdot}2} \times \frac{11}{1{\cdot}5} \begin{array}{l} \text{ft., height} \\ \text{,, fall} \end{array} = 916\,\%.$$

When the pressure was confined in the air-vessel the stroke beat up the pressure gauge till it indicated 90 lbs. on the square inch, so that the ascending column would have balanced the driving column at 207 ft. =138 times the fall.

Now, by our usual formula, our velocity should be 2·8 ft. per second.

$$36 : 1{\cdot}5 :: 5280 : 220 \times \left(\frac{1 \text{ in.}}{12} = {\cdot}083 \text{ ft.}\right) = 18{\cdot}26$$

$$\sqrt{18{\cdot}26} = 4{\cdot}27 \times 40 \div 60 = 2{\cdot}8 \text{ ft. per second.}$$

$$\therefore\ L = 36 \times {\cdot}433 = 15{\cdot}5 \times 2{\cdot}8 = 43{\cdot}6 \text{ ft.-lbs.} = P.$$

But this is far below 90 lbs. We are forced to conclude that our ordinary average speed has been far exceeded by means of the smoothness of the driving pipe. As a matter of fact, the speed required to produce a pressure of 90 lbs., with weight 15·5, is 5·8 ft. per second, which would be about 74 per cent. of $2{\cdot}8^2$.

But further search into this would serve no practical end; enough, if our purpose is attained.

To ensure smoothness, then, and close joints, galvanised steel tubing is recommended, and connected as shown, the flanging wrought before galvanising and the jointing of moulded rings of the special composition before mentioned.

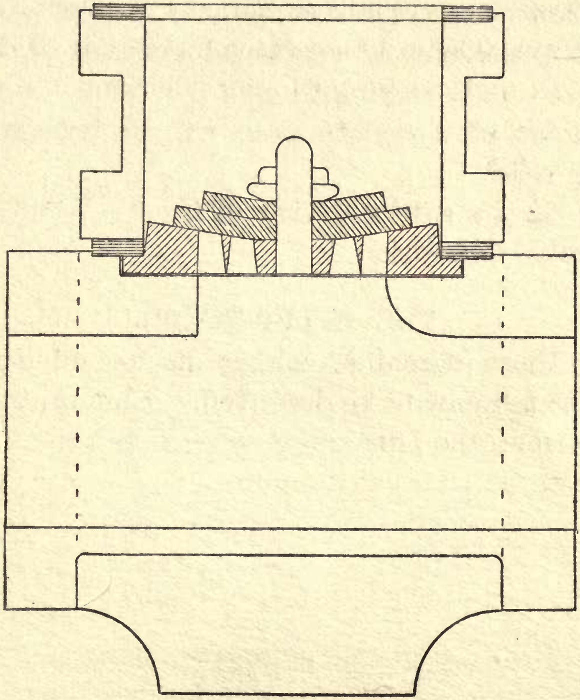


Fig. 22.—"A" Body.

Finally, let the Power be conceived as a solid moving cylinder with a portion chopped off at the end, bringing it for an instant to rest, but in the intervals between the strokes having a continuously increasing rate of waste at one end, and a correspondingly continuous rate of supply at the other—but the cylinder remaining a " constant " suffering no change, the waste only serving to give it motion,—then the advantage of a smooth path will be brought into strong relief.

Fig. 22 is a sectional view of the "A" body, with grid valve in position.

THE HYDRO-MOTOR.

79. Those machines which dispose of separate streams fall now to be described. They are made in two forms: the Diaphragm pattern and the Plunger pattern.

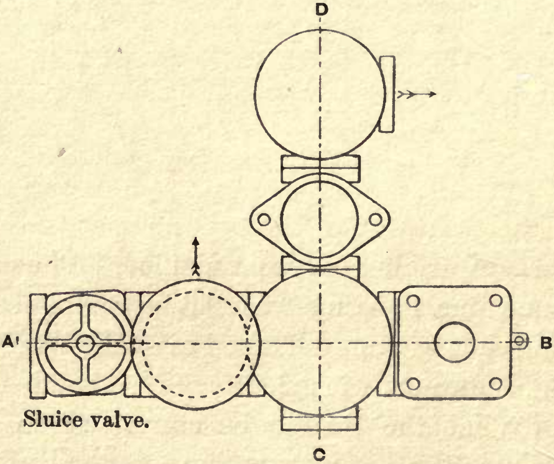
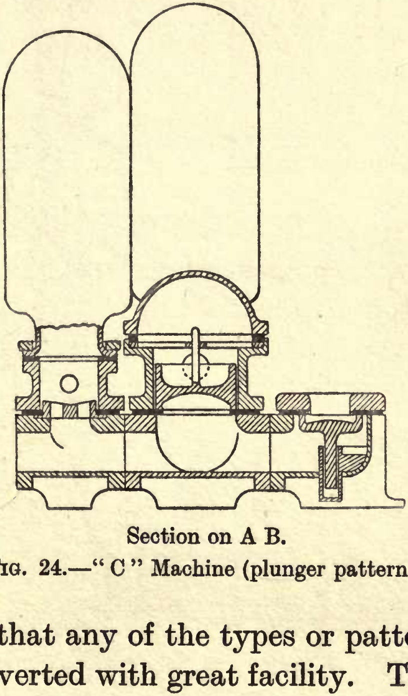


FIG. 23.—"C" Machine. Plan.

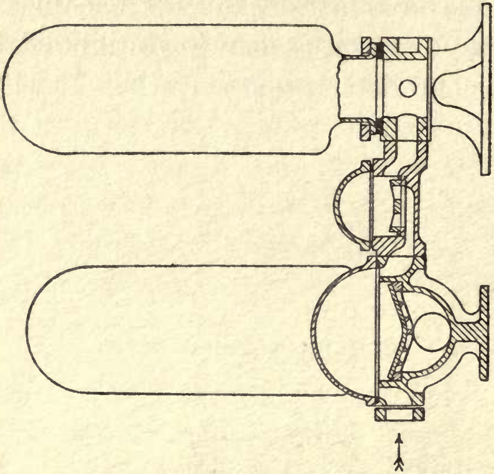
Fig. 23 is a plan of the "C" motor; and fig. 24 the longitudinal section A B, plunger pattern. Figs. 25 and 26 are cross sections of "C" machines, plunger and diaphragm patterns, showing intermediate ascension valves and detached air-vessels. It will be seen at a glance that any of the types or patterns may be fixed or converted with great facility. The complete "C" machine is formed as shown on plan, fig. 23, with sluice valve and detached air-vessels; the "B" machine is formed with the "A" form removed; and the "A" machine—the auto-pump—with the centre part removed.



Section on A B.

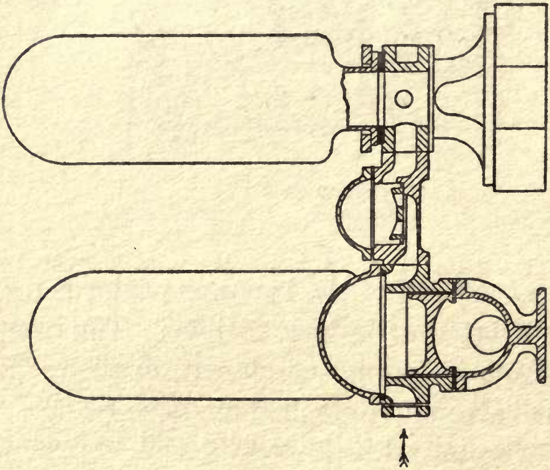
FIG. 24.—"C" Machine (plunger pattern).

It is to be noticed that the action of the hydromotor more nearly resembles that of the ordinary force pump than does the auto-pump: there being no dispersion as in the "A" machine, the reaction of



Section on C D.

FIG. 26.—"C" Machine (diaphragm pattern).



Section on C D.

FIG. 25.—"C" Machine (plunger pattern).

the stroke is utilised either to deflect a diaphragm or to impel a plunger.

Figs. 27 and 28 represent half cross sections and plan of the body of the "B" machine (diaphragm pattern), and fig. 29 the longitudinal section. The full deflection of the diaphragm equals a displacement of 6 cubic inches. But before proceeding further it will be necessary to discuss the question of the cushioning effect of the air confined in the chamber.

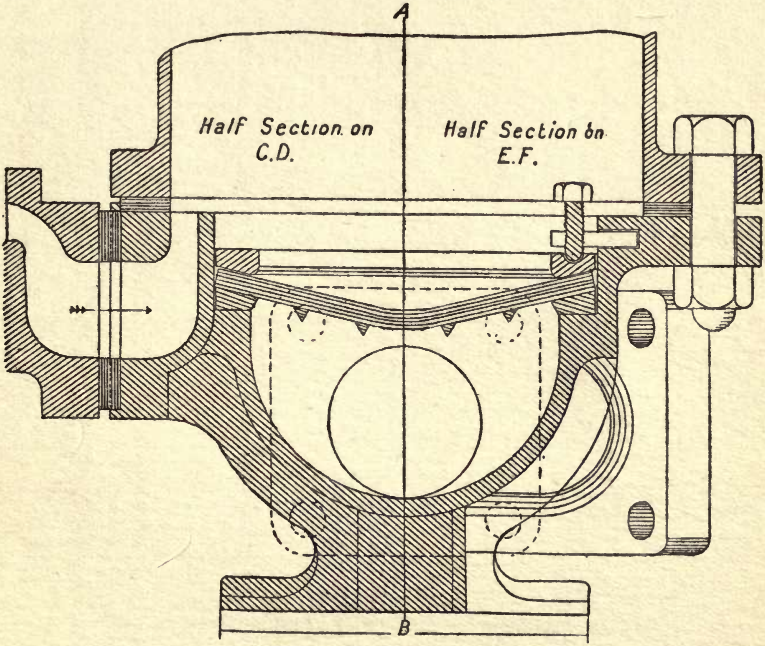


Fig. 27.—Cross Section, "B" (diaphragm pattern).

80. The requirements in regard to space for air

compression in the auto-pump and hydro-motor are different. In the former the narrowing above the flange over the ascension valve is not detrimental, as the surface space is sufficient to receive the dispersion without friction. But the case is different with the latter, for, as the whole surface of the under side of the diaphragm or plunger is exposed to the full force of the reaction, so in like manner the whole upper surface affects the opposing force by the displacement in bulk which ensues, rendering it necessary

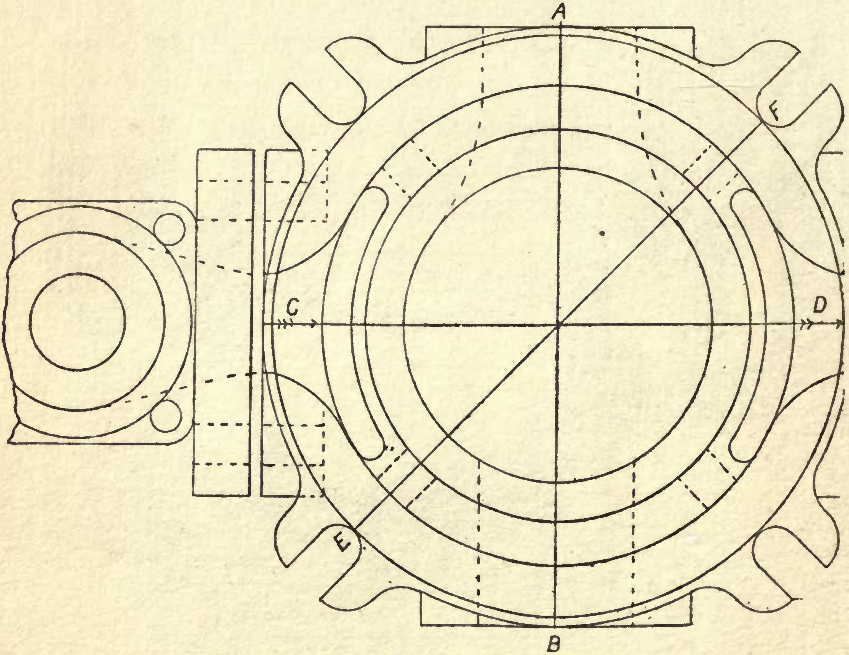


FIG. 28.—Plan, "B" (diaphragm pattern).

that a surface space equal to the disturbed area should be provided, and that that area be not contracted. And it is more important than volume in

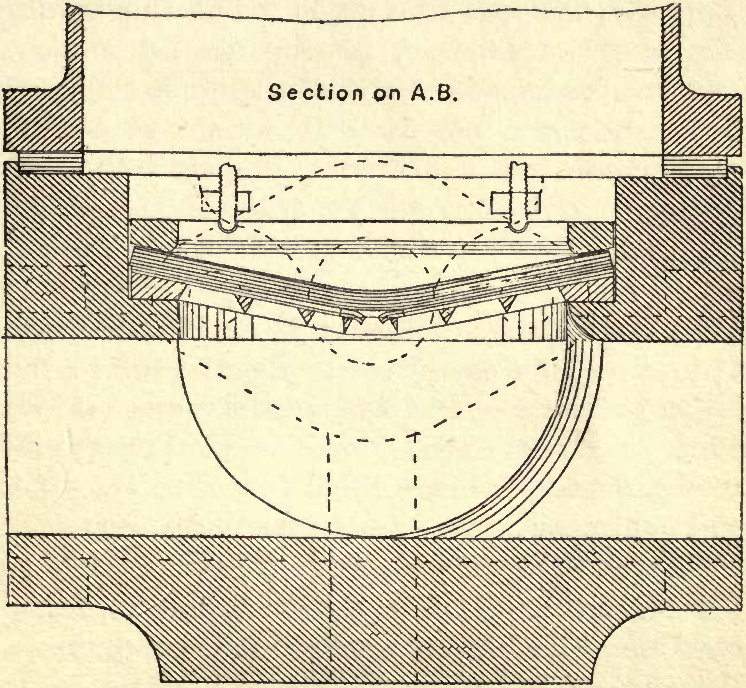


FIG. 29.—Longitudinal Section, "B" (diaphragm pattern).

this particular case, though the storage value of volume must not be lost sight of either.

81. The value of the form of the air-space being in accordance with the displacement, and the disposal of the air-volume being in the direct line of compression, was well illustrated some time ago in a case with

which the writer was indirectly concerned. An order was given for an ordinary force pump to be fixed in a very deep well on the condition, insisted on by the employer, that one man should be able to work it. The operative engineer, who in time past was for years associated with the writer, apprehensive, from past experience, that the ordinary air-vessel would not conform to the conditions upon which the order was given, devised one which answered the purpose perfectly. A piece of M.I. pipe, 4 in. diameter and about 3 ft. long, was fixed on the upper flange of the pump, just over the ascension valve, into which the 1¼-in. head pipe was fitted to dip to within a few inches of the valve, leaving an annular space of only 10 in. of sectional area around it. But though the total air-space was only about 300 cubic in., yet it was so disposed in the line of compression that a lad could work the pump with ease. It may be argued that the same volume of air, however disposed, should have the same elasticity under the same pressure. Perhaps so; but cushion efficiency has been found different in practice.

82. It has been found then that volume is not so important immediately over the diaphragm as lateral space, and that the capacity of the hemispherical cover is sufficient at that point for the hydro-motor, in which in all cases the principal air-vessel is detached, and also when placed over the ascension valve

of the auto-pump when it is detached as shown on fig. 4 in cases where the drive exceeds 3 in. diameter (see Appendix).

83. Sections, figs. 27 and 29, show the manner in which the diaphragms are fixed. They are by preference made of the best india-rubber as giving the best results whether as to work or endurance. Diaphragms of carefully prepared hydraulic leather have been extensively used and with very good results; but, like all such articles of animal tissue, they were apt to become hard and inflexible, whilst the life of the manufactured article was more prolonged and its resiliency was decidedly advantageous. Under average conditions they have lasted for considerable periods, and when strain is shown it is always on the under side; but, protected by guard and radial plates as shown on fig. 29, rupture can only occur after long periods. The diaphragm undoubtedly affords obvious assurance of the non-admixture of the streams, and when rupture does take place the action at once ceases. Still, in cases where the stroke is very heavy and the delivery exceedingly high, the plunger pattern is to be recommended, and, though the separation of the streams is not obvious, it is still assured and will be discussed presently.

84. In no case in the experience of the writer has the diaphragm been deflected to its full extent, and beyond this only could rupture occur on the upper

side. The extent of the deflection naturally varies with the conditions; a slight movement on a large surface will produce by frequent strokes a very large cumulative result. An 8-in. disc, with a movement of a quarter of an inch at its centre thirteen times a minute under a low fall, raised nearly 500 gallons per day to a height of 180 ft., 45 times the fall. A deflection of 0·128 of an inch with 170 strokes per minute raised 720 gallons in twenty-four hours to a tank 173 ft. above its suction valve. Three thousand two hundred gallons per day were delivered at a height of 118 ft. by a deflection of 0·74 in. by a 3½-in. machine

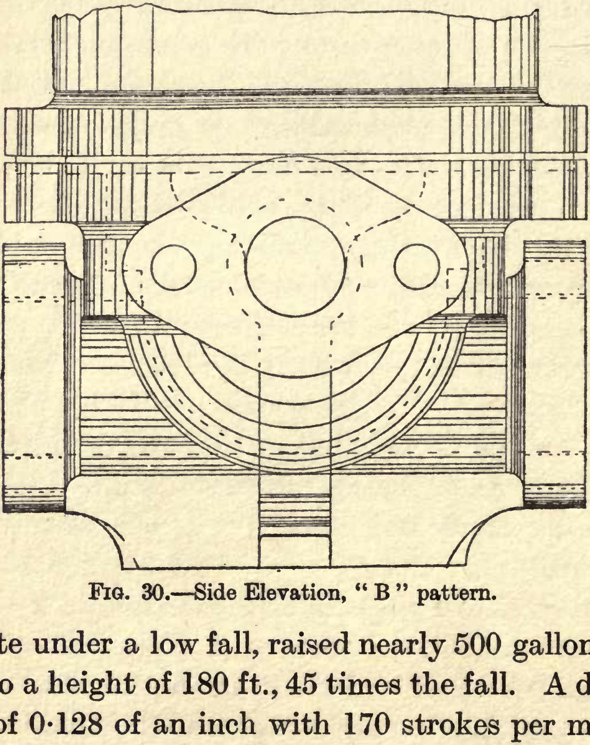


FIG. 30.—Side Elevation, "B" pattern.

giving 80 per cent. of duty; while 90 per cent. efficiency was obtained by a deflection of 0·41 in. on another " B " machine at a height of 12 times the fall.

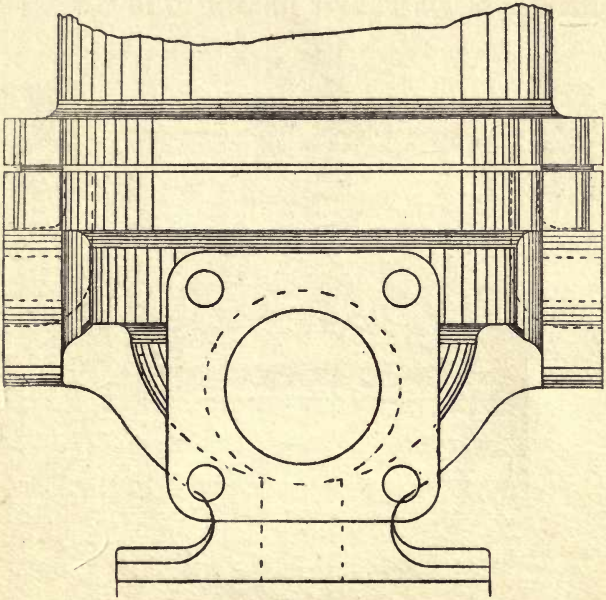


FIG. 31.—End Elevation of " B " pattern.

85. The angle of deflection varies slightly in practice, from 12° in the 1-in. machine to 15° in the 4-in., and no advantage can be obtained by increasing the angle. (Figs. 30 and 31, elevations.)

86. We will now discuss the plunger pattern of the hydro-motor. Referring to figs. 32 and 33, which are cross section and half plans of the 2-in. " B,"

it will be seen that a cylinder is introduced, by an intermediate casting placed between the body and the hemispherical cover, in which the plunger works. Now, the serious objections hitherto entertained with regard to this description of pump were: (1) the large amount of friction required to be overcome

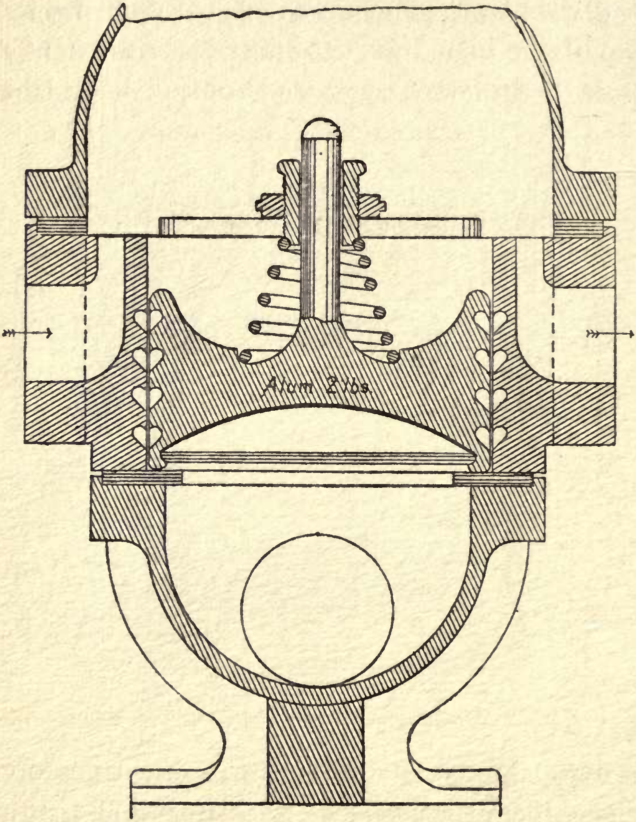


FIG. 32.—Cross Section, " B " (plunger pattern).

incidental to the effective separation of the two liquids, and (2) the weight necessary to ensure the immediate return of the impeller. The finest form or quality of packing was incapable of affording a sufficiently quick return even with the burden of such a weight as to diminish the effective force to an insignificant fraction. To reserve the greatest possible portion of power, then, it was essential that the friction should be reduced to the minimum, and one of the first requirements was a light plunger.

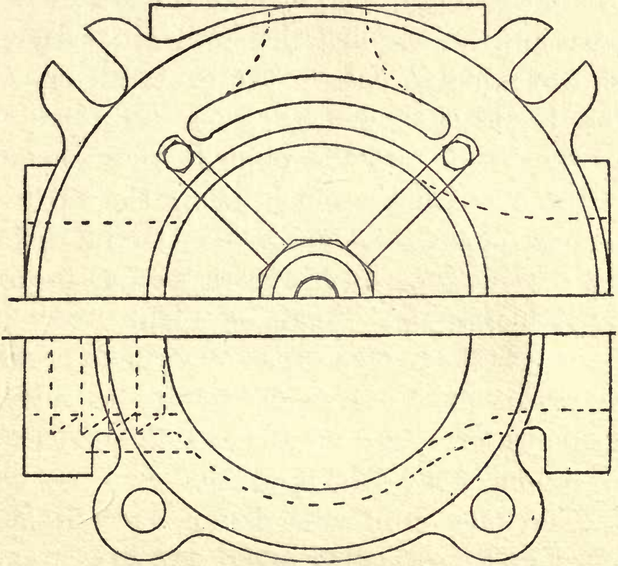


Fig. 33.—Half Plans, Upper and Lower Flanges, "B" (plunger pattern).

Aluminium again recommended itself as being less than one-third the weight of bronze, unoxidisable, and, bulk for bulk, cheaper. The section shows the most suitable form of plunger and spring of the lightest tension, adjusted as only sufficient to form the valve at the base as shown, and to assist the atmospheric pressure in return.

87. The corrugations on the perimeter of the plunger and in the cylinder wall are designed to check any upward flow in the event of any of the driving liquid passing the valve at the base—which is hardly possible, as the plunger would require to be raised about half an inch before the valve could be uncovered, and this would exceed the full deflection of the diaphragm, which experience has shown has never been reached. Again, a slight study of the figure will indicate that when the stroke occurs the tendency of the pure liquid would be, under the pressure, to force its way downwards and check any upward flow of the driving water.

88. The pure supply is drawn at one side and expelled at the other, as in fig. 32; but either port may be used as may be most convenient, the valves (figs. 34, 35, and 36) attached to correspond. It may be here pointed out that a longer drive is necessary for the "B" or "C" machines in order to obtain the best work. But this is not always easy of attainment, for the source of the driving supply is generally common to both, and they usually occupy the same chamber when installed together. On more than

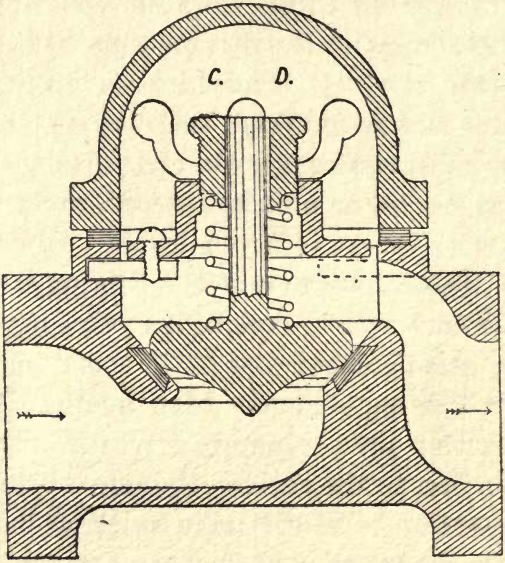
one occasion a low duty had to be accepted on the hydro-motor for this reason, when fixed alongside an auto-pump giving a high percentage of efficiency. This was the cause of (1) (§ 52) being low—though the height was 45 times the fall. P should have been 300 ft.-lbs. with the driving pipe 50 ft. longer.

89. When the "C" machine is installed, the disparity is not so marked, the stop valves on the ascending pipes can be adjusted to pass equal quantities, or otherwise, as may be desired, and frequently the deliveries are at different levels. In such cases a proportionate quantity of the driving water only is charged to power in computing efficiency. As an economic arrangement the "C" combination can hardly be beaten, and has been adapted on occasion to deliver three separate streams: the driving supply portion to the stables, the pure spring supply to the mansion, and soft rain water collected and pumped to the laundry as or when required.

90. It is to be noted that the reaction of the stroke of a "B" machine is generally more prolonged than on an "A," and, to assist in checking this, corrugations may be made in the inlet of the "B" body, as shown on fig. 33, and also on the elevation of the 2½-in. "B" body (fig. 37), and may be always made on the "A" body, but never on the "B" body when forming part of a "C" machine.

Figs. 34, 35, and 36, show the intermediate valve placed on either side of the "C" body.

The function of this development of the automatic pump has been described as the exerting of the power of one falling stream of water to the raising of another. But the machine in its simplest form has been employed in the disintegration of the gravel rock for the recovery of alluvial gold, and can be applied economically to the transmission of motive power by utilising the force latent in slow-moving streams at present in many localities going to waste.

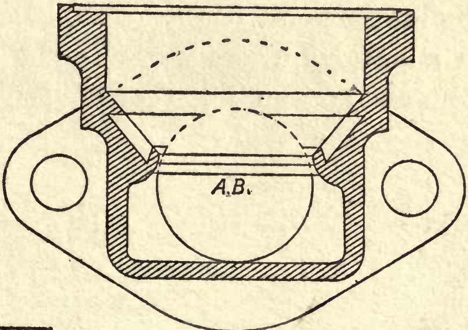


Section.

Fig. 34.—Intermediate Valve.

To the Pelton water-wheel, pump pressure lines have been used, but the essential function of this impulse motor is the utilising of small quantities under great heads, which is the reverse of that of the hydro-motor, in this instance, of which the design is to use large quantities under small heads.

Fig. 35.—Section.



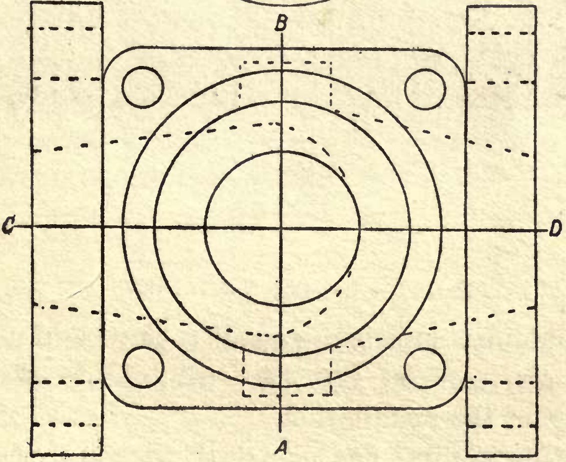


Fig. 36.—Plan.

The method of operation is the discharge of the actuating stream in the form of one or more jets on peculiarly shaped buckets on the periphery of the wheel at its lowest point.

Now, in situations where water is abundant and incline slight, and accumulation can be easily obtained by damming, sufficient pressure can be developed in the air-vessel of the "A" machine to effect the purpose of the installation.

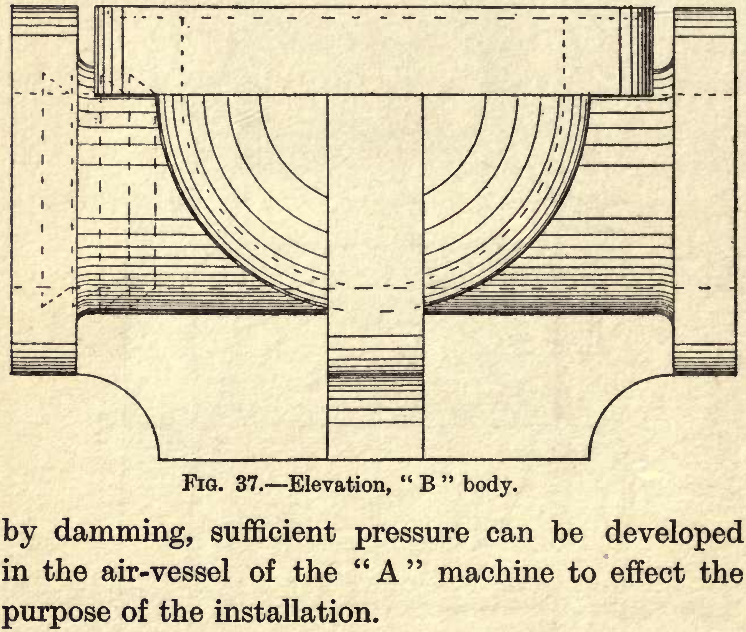


FIG. 37.—Elevation, "B" body.

Friction in pipes has been dealt with in several sections, and it may be pointed out here that loss of head from this cause, in long pipe lines, is entirely eliminated from "power-cost," and in cases where it may be of moment to save the operating quantity, *i.e.* that discharged on the wheel buckets, it can be returned to the source by placing the wheel at any convenient level. Thus, power can be produced by accumulated pressure, and form a cheap substitute—where water is plentiful and fall low—for high gravitational head.

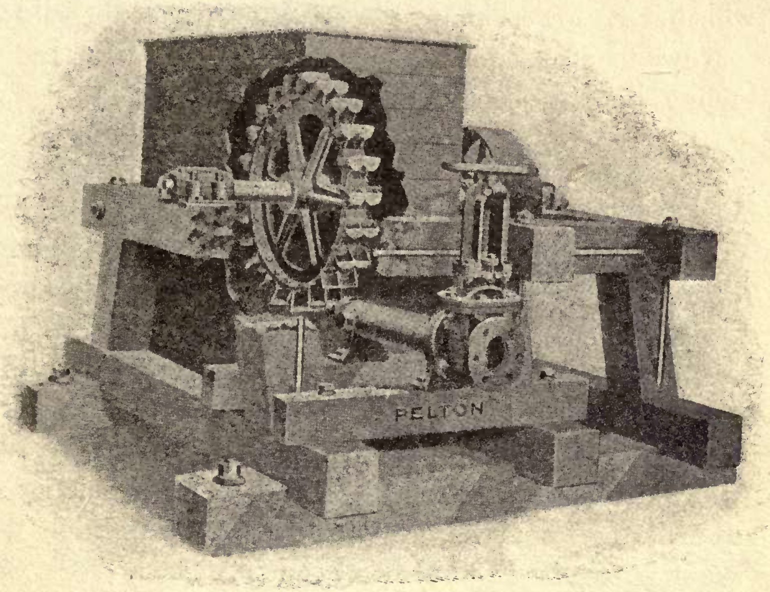


Fig. 37a.—Pelton Wheel mounted on wooden frame.

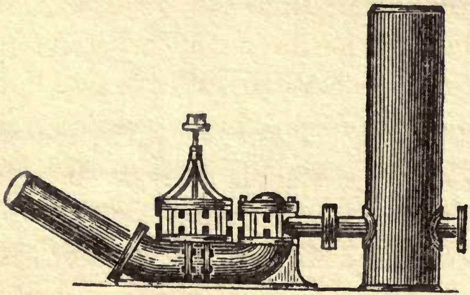


Fig. 37b.

SUMMARY.

DRIVING PIPE.

We have cited cases showing the evils resulting from drives being too long (§§ 13 and 14) and from those being too short (§§ 22 and 52 (1), (7)), and have also set forth those evils consequent on diameters of which the areas are unsuitable, and the danger of following rules giving diameters many times larger than what was needed, and lengths (§ 23, nearly 70 times) longer than those giving high efficiency; and a rule for arriving at a close approximation to what is required (§ 52) has been furnished. It now only remains to add—what may be gathered from the foregoing—that when the delivery is low, speed is the paramount factor; and when high, weight is the most essential factor of the power.

SLUICE VALVE.

Reason has been shown why the sluice valve of commerce is an unsuitable adjunct to apparatus for the automatic raising of water, and drawings given showing the design (figs. 1, 2, and 3) of the valve by which efficiency was raised over 22 per cent. (§ 54). And it has also been pointed out that the old-fashioned flap valve is altogether unsuited as a means of stopping off the water from the machine.

DASH VALVE.

Figures have been furnished showing designs best suited for different conditions, situations, and requirements: where the greatest power is needed, the reversed spindle valve is most essential (figs. 5, 6, and 10); where inches of fall only is attainable, figs. 8 and 9 are recommended as specially applicable; and the importance of facility for adjustment has been urged.

ASCENSION VALVE.

The prime necessities of easy opening and quick closing have been strongly enforced and illustrated. And in situations where deliveries are low and large quantities are required, the advantage of an inner valve of large area can scarcely be over-stated. Indeed, in special cases the "B" part of the apparatus might be substituted for the "A," and the diaphragm, guard, etc., replaced by a large grid (figs. 12 and 13), and both ports in combination used for delivery. But for high deliveries and all ordinary cases, fig. 17 is to be recommended.

AIR-VESSEL.

The subject of air arrangement is discussed in §§ 31–33, 72, and 73, and more fully in §§ 80 and 81, and illustrated by figs. 23 and 24. For particulars of capacities and dimensions, see Appendix.

DELIVERY PIPE.

The elimination of friction in all pipes, as far as practicable, is doubtless very desirable. But this desire does not justify the incurring of needless expense in laying down long stretches of pipes of excessive sectional area. Careful heed must be given in all cases to jointing and the avoidance of all acute or needless bends—beyond this each case must be considered and determined in accordance with the principles set forth in §§ 76–78, on:—

PIPING AND JOINTS.

The method of jointing explained and illustrated under this heading, though strongly recommended for driving pipes, is not of such moment in regard to delivery pipes; although in cases where large quantities are required for delivery at considerable distances a fractional unit or two in diameter might well be saved by its adoption, and with decided advantage.

THE HYDRO-MOTOR.

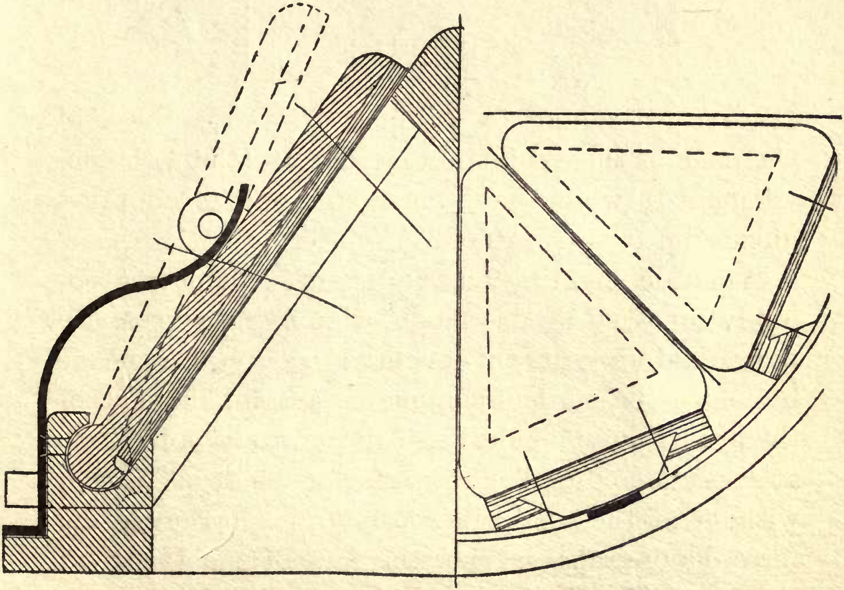
The raising of water by the securing of the dispersion resulting from impact, and of separate streams by the induced movement of diaphragm or plunger, has been fully dealt with in the text, and nothing further need be added here. The particulars in regard to diaphragms will be found in the Appendix.

ADDITIVE.

Having attempted to establish the advantages of the form of the external valve, fig. 10 (§ 66), the developments which have emerged from its adoption now claim to be recorded.

When deliberating on the inevitable shocks absolutely involved in this mode of applying power, the writer had for years endeavoured to arrive at a means by which the most objectionable accompaniment of them, viz. noise, could be, if not entirely prevented, at least so reduced as to cease to be troublesome, without at the same time losing any portion of the force, having also in view the fact of the thrust of the impact becoming more formidable as the size increases. Whilst accepting the suitability of the spindle-disc form of dash valve for heavy work, reservation had to be made in respect of these two defects.

Reference has been made to the fish-mouth (Perreaux) valve and its defect—weakness, by reason of the yielding nature of the material, india-rubber; but the principle on which it was constructed cannot fail to be acknowledged. Direct flow is a most important property in a valve, but in most of them the fluid changes its direction four times in passing through. In figs. 19 and 22 the passage is very nearly direct, yet when large sizes come to be arranged for, the areas of the unpierced discs, increasing as the squares, engage serious attention. In order, then, to obtain the advantages and avoid the defects of the foregoing, recourse was had to the pyramid form, by which the surface can be conveniently increased and direct flow assured. By the adoption of this form,



Side view. Plan.

Fig. 39. Fig. 38.

Details, Pyramid Valve.

then, the strength of the old "clack" can be utilised; but with its form so modified and with such slight opening movement as to produce at once a strong

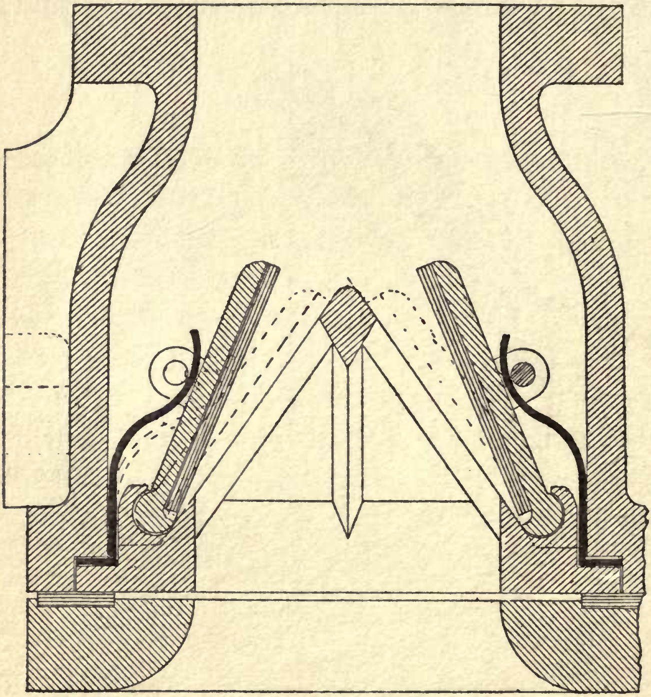


FIG. 40.—Hexagonal Pyramid Escape Valve.
Longitudinal section, terminal.

and sensitive valve of large area in comparatively small space.

Figs. 38 and 39 show an octagon pyramid by which the full area of the diameter is obtained with valve covers opening little over an inch, arranged for an ascension valve 8 in. diameter suitable for a 12-in. machine.

The suitability of this design as an ascension valve may be considered obvious, but the advantage of its extension to use as an escape valve may not be so apparent. Figs. 40 and 41 show the hexagon form adapted for a 4-in. drive. It will at once be seen

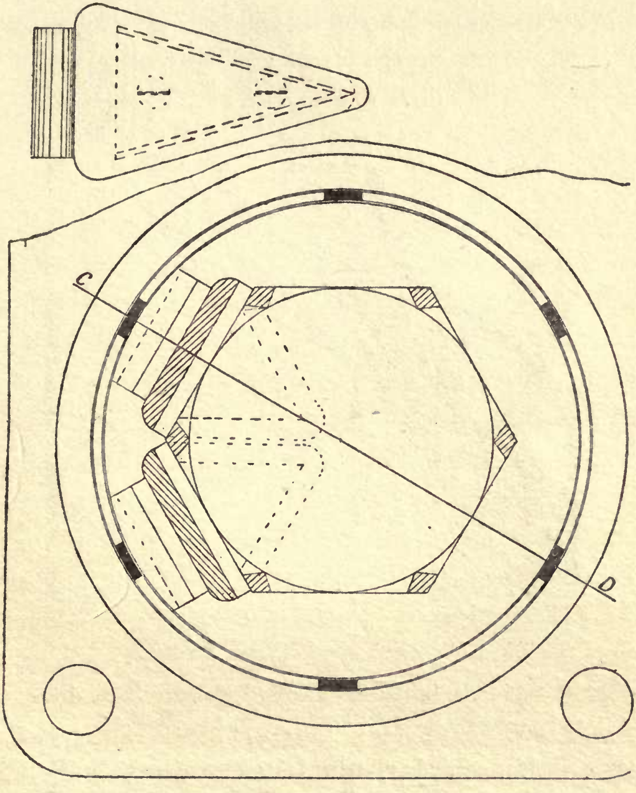


FIG. 41.—Hexagonal Escape Valve. Cross section.

that when fully open to equal the area of the drive the port-covers offer little opposition to the effluent stream; while in closing, their combined effect, as regards noise and jar, must be comparatively slight, the action being nearly transverse to the current instead of in line, and no percussive agents being impelled: so that the terminal, which this valve, like fig. 10, shall form, will only have to sustain the force of the arrested fluid column, which is really all

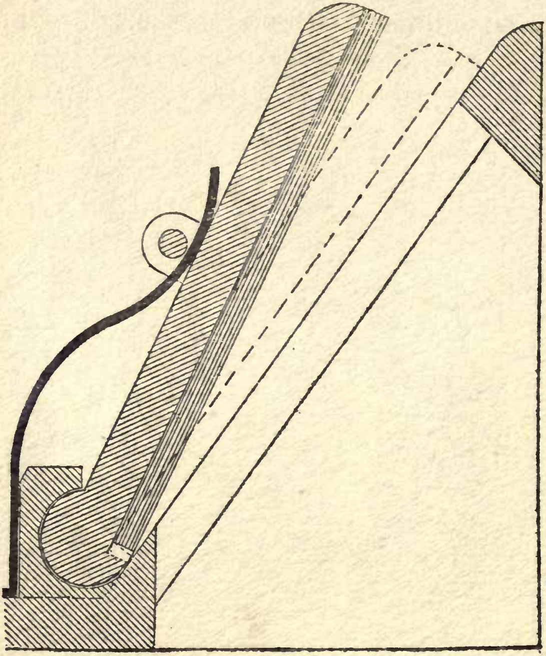


FIG. 42.—Details, Octagonal Escape Valve for 12-in. drive, or Ascension Valve for 18-in. drive. Section.

that is effective, and be relieved of the forward heavy blow.

This form of valve will suit for both ascension and escape, and will enable the largest-sized apparatus to be employed with facility, comparative silence, and safety. A glance at figs. 42 and 43 will show the arrangement for a 12-in. escape valve, and ascension for an 18-in. machine with full area, the port-covers opening only 1½ in. Figs. 44 and 45 show an 18-in. escape valve arranged with ports in two tiers, the under forming a duodecagon, and the

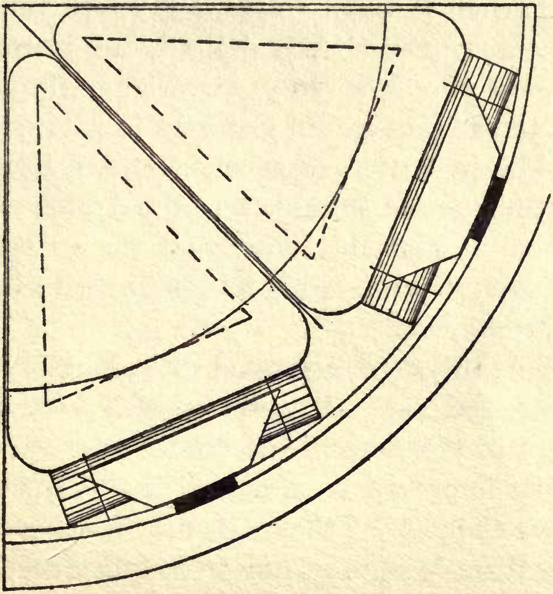


Fig. 43.—¼ Plan, Octagonal Escape Valve for 12-in. drive, or Ascension Valve for 18-in. drive.

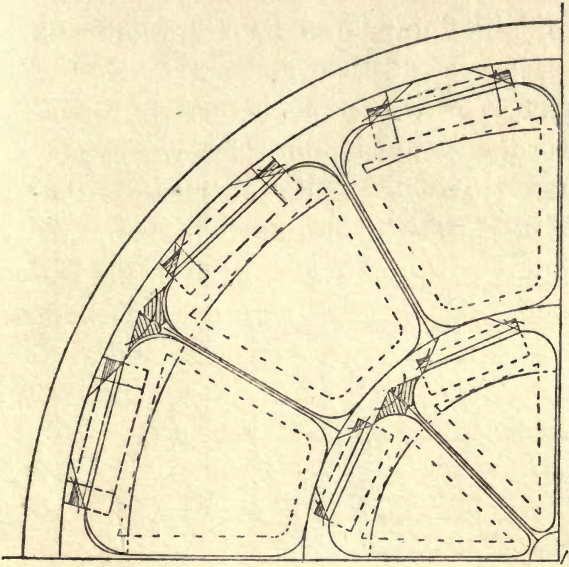
upper arranged as in figs. 43 and 44, and here again the properties of aluminium and its adoption will prove of great service.

Attention has been drawn to the changes of direction of current through valves, and check valves not seldom check more than is desired, and increase the friction on the flow very materially, discounting greatly the advantage they extend in preventing return. The pyramid arrangement shown by figs. 46 to 49 will be found suitable for all purposes and any situation. It must be noted that the strip springs on all these pyramid valves are to be set to the very lightest tension.

The suitability of this form of valve for large pumps may be urged here. The reader will no doubt be cognisant of the form of the double-beat valve, and also of its improved form named the "Crown," and what was claimed for them: it may be of service to refer to them briefly. They were introduced to replace in large pumping engines the flat valves in which the "slip" was very large and the concussion on closing very great. The new design effected a marked improvement, but it was not achieved, as some have alleged, by the area of the valve covers being reduced—indeed, in the Crown form the area is rather increased,—but in the increased facility of escape at the upper seating.

The weight to be raised, however, by reason of its

Fig. 45.—¼ Plan.



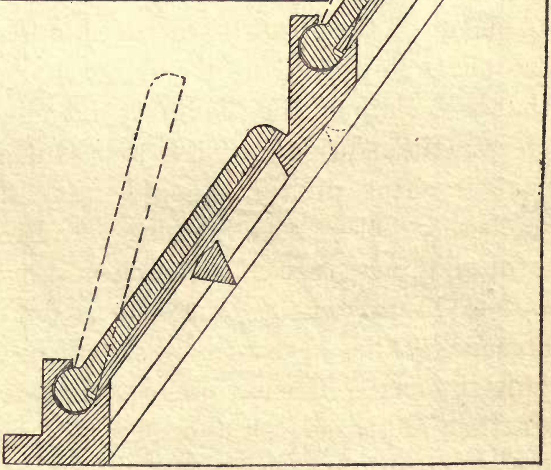


Fig. 44.—Pyramid Valve, side view, 18-in. diameter.

FIG. 48.

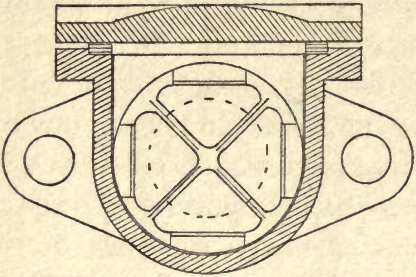


FIG. 49.

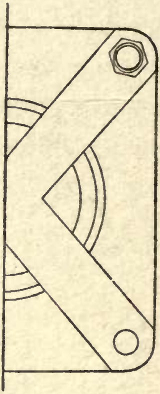


FIG. 47.

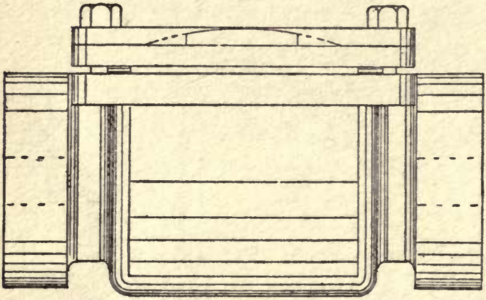
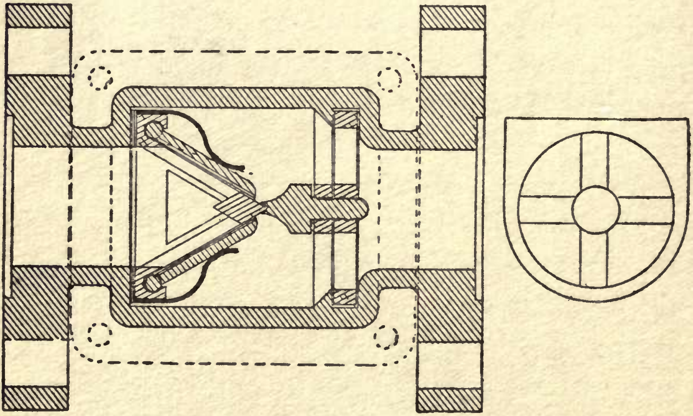


FIG. 46.



Check, Discharge, and Section Valves.

bulk was still inevitably heavy, in some pumps approaching three-quarters of a ton in metal alone, which, added to a resisting surface averaging 1300 square in. and say even 100 ft. in height, involved a very heavy expenditure of fuel. The facility offered by the pyramid design for adaptation to large areas may therefore be entertained with some degree of consideration.

NOTES.

NOTES ON WATER ANALYSIS.

(Being Extracts on Water Analysis from various Sources.)

It is highly necessary that a water that is to be used for drinking and culinary purposes should be analysed and a report on its qualities obtained.

An analysis on potable water should comprise determinations of solids, chlorine, free ammonia, albuminoid ammonia, whether the water contains less than one-tenth of a grain of lead or copper, and whether there is more than the least trace of iron in it ; with these data at hand a decision may be arrived at as to whether it shall be used for domestic purposes or not.

Drinking water falls into three classes according to the degree of organic purity, as follows :—

Class I. Water yielding not more than 0·0035 grain of albuminoid ammonia per gallon. This class comprises the most highly filtered waters, both natural (*i.e.* deep spring waters) and artificial, *i.e.* such water as has passed through a series of certified thoroughly purifying media. Water of this class cannot be objected to organically.

Class II. comprehends the general drinking waters of this country, and gives 0·0035 to 0·007 grain of albuminoid ammonia per gallon, and it is generally believed that water falling into this class is organically safe.

Class III. comprises the dirty waters, and is characterised by yielding more than 0·007 grain of albuminoid ammonia per gallon.

Unless the water contains more than 40 grains of solids per gallon, no exception need be taken to the solids.

Five or ten grains of chlorine per gallon are not a bar to the use of a water, but only a reason for suspicion and rigorous investigation.

If no trace of albuminoid ammonia be found, a water may be passed as organically pure, despite much free ammonia and chlorides. When, however, the albuminoid ammonia amounts to 0·0035, then the free ammonia becomes an element in the calculation, and a water yielding a considerable quantity of free ammonia along with 0·0035 grain of albuminoid ammonia per gallon demands careful examination.

The absence of chlorine or of more than one grain of chlorine in a water yielding more than 0·007 grain of albuminoid ammonia is a sign that the impurity is of vegetable origin, and it would be a mistake to allow water highly contaminated with vegetable matter to be taken for domestic use.

A high degree of freedom from poisonous metals is demanded of drinking water ; and a special testing for lead, copper, and even iron, forms an essential part of the usual analysis of such a water.

Good drinking water ought not to contain more than $\frac{1}{10}$ or $\frac{2}{10}$ grain of iron per gallon, and should contain less than $\frac{1}{10}$ grain of lead or copper. In fact, the presence of either to any appreciable extent would condemn a water.

It occasionally happens that it is requisite to test a drinking water for arsenic. The water in mountainous districts, especially where metals abound, should be very carefully searched for metals. In deciding upon the water supply for either mansion or district, the question of the possible presence of poisonous metals is of great importance, since it is by no means certain that filtration is capable of removing such impurities.

NOTES ON FILTRATION.

Waters contaminated with animal and vegetable matters are purified in nature by the decomposition and oxidation of their organic matter, by subsidence, and by filtration through porous strata.

There are several modes of purifying water artificially, the most common of which is filtration, which need only interest us here, and will be briefly discussed.

If a water contains solid particles of a given magnitude and we pass that water through wire gauze the meshes of which are smaller than the particles, we shall, of course, separate the particles, and, unless the gauze or the particles are elastic, the rate at which the water passes through will not affect the result. This is the first process, and is simply straining. But the second process—filtration,—if properly conducted, involves the removal of the foreign particles by adhesion to the media through which it passes; and the third is the subsidence or precipitation of other particles which have not the viscous quality of clinging to the interstices in their passage. In the last case the element of speed is of great moment, and defines the rate at which the water must travel. The filtering media generally in use are sand and one or other description of carbon. The sand performs the straining and adhesive function, while that of the carbon is to effect the destruction of the organic matter by causing the oxygen dissolved to combine with it, which results in the decomposition of complex nitrogenous matters and the liberation of free ammonia.

Careful investigation of recent years has disclosed the fact that there is formed a filmy skin on the interstitial surfaces by the water in its passage through the media, which has decided power in the trapping of bacteria. So that it now becomes a question of considerable import how far the operation of sand-cleaning is to be carried.

The following is a description of the "Empire" filter designed by the writer, which has proved very effective:—

THE EMPIRE FILTER.

CLAIMS.

What is claimed for this filter is that water is more thoroughly purified than by other at present on the market, in respect of (1) the liquid is made to traverse a greater depth of filtering medium; (2) it is again and again broken up and redisposed over the sectional area of its track, so that alleys of easy passage, if existent, are thus neutralised; (3) the chemical energy and all-reaching action of the filtering material; and (4) the thorough efficiency obtained in the least possible space. Figs. 50, 51, and 52.

FILTERING MATERIALS.

The filtering materials are gravel, sand, kieselguhr, and highly "magnetic" porous carbon, disposed in the channels in consecutive order. The carbon is prepared from the natural rock, containing no phos-

FIG. 50.

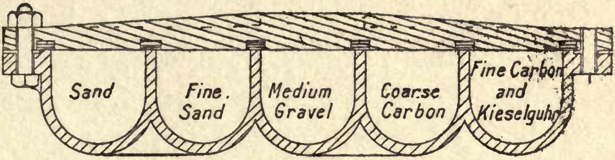


FIG. 51.

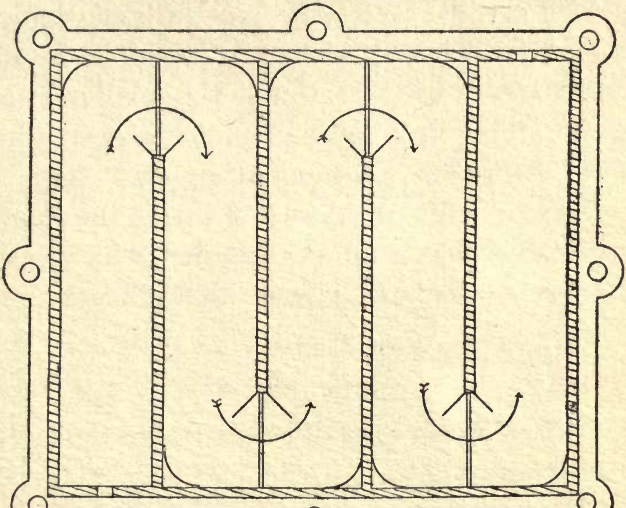
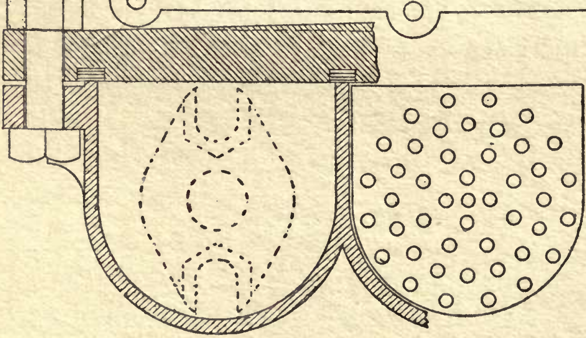


FIG. 52.



"Empire" Filter.

phates, which under certain circumstances are so troublesome with animal charcoal. It possesses deodorising and purifying properties of a high order, and also that of occluding oxygen, giving it off to the liquid in its passage, which in process of combustion with organic matter evolves carbonic acid, much improving drinking water. Presenting by its porosity the largest area of action in the smallest cubical space, containing nothing soluble, it is also free from animal or vegetable contamination and from poisonous metals: while the diffusion within the channels of the diatomaceous earth (kieselguhr), which has a peculiar effect on bacteria, is very advantageous.

ACCESS.

The filter is easy of access; chokage or fouling can be readily detected, and cleansing at once effected. The arrangement enables the water to be kept long in contact, by reason of its length of traverse through the purifying medium, and undue velocity of discharge is prevented.

CONSTRUCTION.

The filter is made in cast iron and galvanised: but the smaller sizes are by preference japanned on the outside and the interior coated with porcelain enamel.

The body consists of a single casting, so also does the cover, both being as light as possible consistent with suitable strength; and the cover is furnished with radial ribs to the points where the stress is greatest. The channels, five in number, in the smaller sizes, are charged as shown on section; in the divisions between the media are inserted dispersion plates of aluminium, proportionally perforated, the combined areas slightly exceeding the area of the inlet pipe, sufficient only to exclude any friction at these points, but causing redistribution at every stage.

DISTRIBUTION.

The area of the channel is twenty-five times that of the inlet pipe, but, unlike similar apparatus, this space is thoroughly exposed to the passing current, while the "depth" through which it flows is enormously increased. Let the filtering medium be ever so carefully disposed, some "easy alleys" will almost invariably exist: if so, the dispersing plates neutralise their effects, and the draw-off, being equal to the supply, can receive its complement only by draining the whole sectional surface.

A glance at the filters usually advertised will show that the draw-off may supply itself from any single alley or tiny space of its proportionally immense, but mostly unused, area.

APPENDICES.

APPENDIX I.

DIAPHRAGMS.

Size. Hydro.	Diam. of Diaph.	Thick.	Angle.	Full Deflection.				In Action. Formulæ.
				Depth.	Area.	Cub. in. ÷2.	Gals. per Stroke.	
in.	in.	in.	°	in. in.	cub.in.			
1	3	$\frac{3}{16}$	11	·6 × 2¼	3·976	1·192	·0043	A = Area.
1½	4	$\frac{3}{16}$ or ¼	12	·7 × 3	7·06	2·47	·0089	B = Strokes per min.
2	5¼	¼	12	·9 × 4	12·56	5·65	·02	C = Delivery, gals. per min.
2½	6½	$\frac{5}{16}$	13	1·4 × 5	19·63	13·74	·049	D = Deflection in inches.
3	7½	⅜	14	1·6 × 6	28·27	22·61	·081	E = Deflection in cub. in. per stroke.
3½	8½	$\frac{7}{16}$	15	1·8 × 7	38·48	34·63	·1213	F = Deflection in gals. per stroke.
4	9½	½	15	2·15 × 8	50·26	54·3	·1958	$D = \frac{E}{A} \times 2.$
5	12	⅝	15	2·5 × 10	78·5	98·1	·43	$E = \frac{C}{B \times \cdot 0036}$
6	15	¾	15	3 × 12	113	169·0	·74	$F = \frac{C}{B}$
8	19	1	15	4·4 × 16	201	442	1·59	

APPENDIX II.

AIR-VESSELS.

Size "A."	Shaft.				Dome, Cube.	Neck, Cube.	Total Capacity.	"B" Dome.			Total Weight in Steel.	
	Diam.	Height.	Area.	Cube.				Diam.	Area.	Cube.	"A."	"B."
in.	in.	in.	in.	in.	in.	in.	in.	in.	cub.in.	in.	lbs.	lbs.
1	5	10	19·64	197	33	20	250	3	7·06	7		
1½	6	13	28·27	367	56	27	450	4½	15·9	24		
2	7	15	38·48	577	89	34	700	6	28·2	56·5		
2½	8	16	50·26	800	134	66	1,000	7·5	44·1	110	24	
3	9	18	63·61	1,145	190	135	1,470	9	63·6	190	31	
3½	9½	19	70·88	1,346	224	150	1,720	10·5	86·5	302		
4	10	20	78·54	1,570	260	170	2,000	12·0	113	452	39	
5	11	21	95·03	1,995	348	197	2,540	15·0	176	884		
6	12	22	113	2,486	452	262	3,200	18·0	254	1527		
8	14	24	153	3,672	718	400	4,780	24·0	452	3620		
10	16	26	201	5,426	1070	504	7,000					
12	18	28	254	7,122	1518	760	9,400					
15	20	30	314	9,420	2080	1000	12,500					
18	22	34	380	12,920	2780	1300	17,000					

APPEN

ELEMENTS OF CERTAIN TYPICAL INSTALLATIONS,

Description.		Drive Pipe.			Water: Gals. per min.			Delivery Pipe.			Waste Valve.		Pressure.	
Size.	Type.	Diam.	Length.	Fall.	Used.	Raised.	Waste.	Diam.	Height.	Length.	Stroke.	Long.	(S) Stat.	Dyn.
in.		in.	ft.	ft.				in.	ft.	ft.	per min.	in.	lbs.	lbs.
2	A	2	80	8·0	5·94	·669	5·28	¾	66	750	54	¾	28	29
2½	B	2½	63	7·0	8·25	1·14	8·25	¾	46	..	74	..	20	23
2½	A	2½	63	7·0	9·39	1·14	8·25	¾	46	..	74	..	20	23
3	A	4	90	2·3	22·7	1·33	20·37	1	32	201	..	..	13·8	..
3	A	3	100	14·5	34·12	6·0	28·12	1¼	71·3	510	40	1½	31	38
5	A	5	100	4·2	50·81	1·07	49·74	1	168	..	20	½	73	77
3	B	3	106	11·75	16·7	1·25	16·7	1	141·2	..	61	⅜	55	60
3½	B	3½	72	7·3	44	2·21	44	1¼	117·3	..	43	1	51	53
4	B	4	100	3·10	28·25	0·3	28·25	1	180	..	13	½	78	80
3	B	3	90	7·3	24	1·43	24	1	80·3	2070	34	¾	35	..
3	B	3	90	7·3	21·7	1·73	21·7	1	80·3	2070	36	¾	35	..
3	A	3	53	6·04	13·63	1·63	12·0	¾	42	..	..	..	18·2	..
3	B	3	53	6·04	13·85	1·37	13·85	¾	42	..	..	..	18·2	..
3	C	3	53	6·04	14·69	1·714	13·85	¾	42	..	..	..	18·2	..
4	A	5	27	7	73·66	14·02	59·64	2½	23·2	300	89	1¼	10	..
¾	A	¾	160	5·62	·666	·066	·60	½	46	1386	45	3/16	20	21

DIX III.

SEVERAL OF WHICH ARE REFERRED TO IN THE TEXT.

Power.					Efficiency Ratio.			Details.
Weight.	Speed.	Theo.-Impact.		Weight over Speed.	Per cent.	$\frac{P}{S}$	Height to Fall.	
		Total.	(P) Per. sq. in.					
lbs.	per sec. ft.	ft.-lbs.	ft.-lbs.	times.				
108	7	756	243	15	·927	8·67	8·25	
133	7·3	980	200	18	·90	10·0	6·57	
133	7·3	980	200	18	·797	10·0	6·57	
486	4·4	2140	170	110	·834	12·3	14·2	
302	9·22	2788	398	32·7	·865	12·8	4·9	
850	6·37	5420	276	133	·851	3·8	40·3	
323	7·8	2500	357	41·4	·90	6·5	12	
298	8·26	2466	257	36	·807	5	16	
544	5·45	2970	236	100	·50	3	47	Restricted drive—too short.
272	6·9	1877	268	39	·654	7·6	11	Fitted with ordinary sluice valve.
272	7·1	1931	273	34	·87	7·8	11	Changed to frictionless sluice valve.
160	8·5	1360	194·7	19	·834	10·7	6·95	Restricted space-drive—too short.
160	8·5	1360	194·7	19	·688	..	6·95	Restricted space-drive—much too short.
160	8·5	1360	194·7	19	·811	..	6·95	Half water raised added to waste.
230	16	1728	188	14	·629	..	..	Drive too large and too short for economy.
30·48	2·26	69·2	156·5	13	·81	7·8	8·3	95 gals. per day.

APPENDIX IV.

DIMENSIONS AND PROPORTIONS OF PYRAMID VALVES ADAPTED TO AUTO-PUMPS.

Diam. of Drive.	Diameters and Areas of Valves.				Per cent.
	Ascension.	Escape.	Ascension ÷ Escape.		
in.	in.	in.			
1½	1¼	1½	1·22	1·76	·69
2	1½	2	1·76	3·14	·56
2½	2	2½	3·14	4·90	·64
3	2½	3	4·90	7·06	·70
3½	3	3½	7·06	9·62	·73
4	3½	4	9·62	12·56	·76
5	4	5	12·56	19·63	·64
6	5	6	19·63	28·27	·69
8	6	8	28·27	50·26	·56
10	8	10	50·26	78·54	·64
12	10	12	78·54	113·0	·69

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