H. A. HUMPHREY.

METHOD OF COMPRESSING AIR OR GASES.

APPLICATION FILED FEB. 19, 1910. RENEWED JULY 18, 1917.

1,257,607.

Patented Feb. 26, 1918.

3 SHEETS—SHEET 1.

Fig. 1.

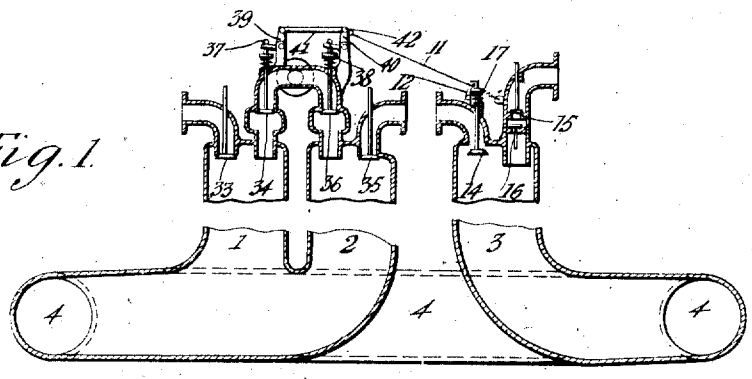


Fig. 2.

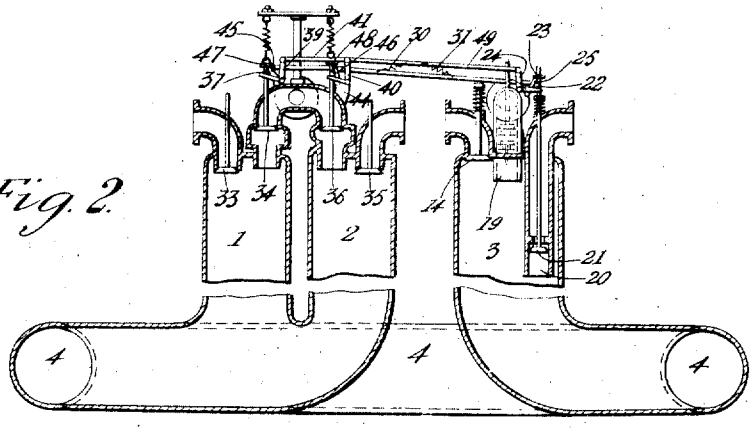
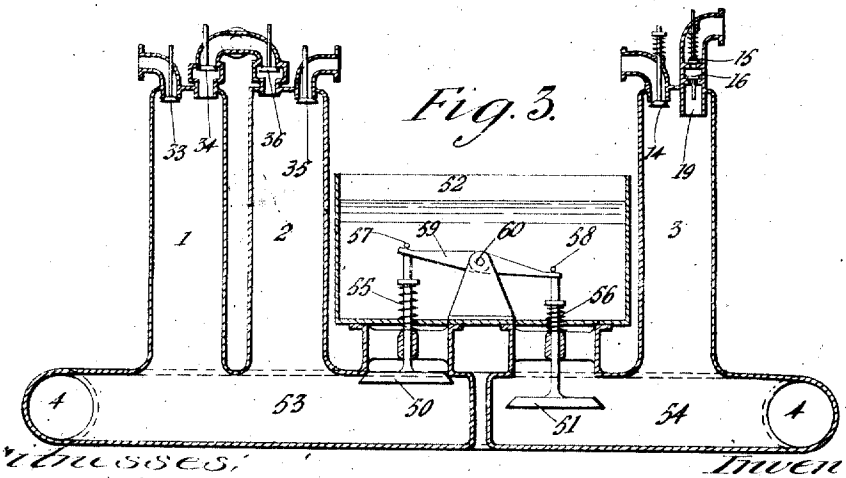


Fig. 3.



Witnesses:

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3 SHEETS—SHEET 2.

Fig. 4.

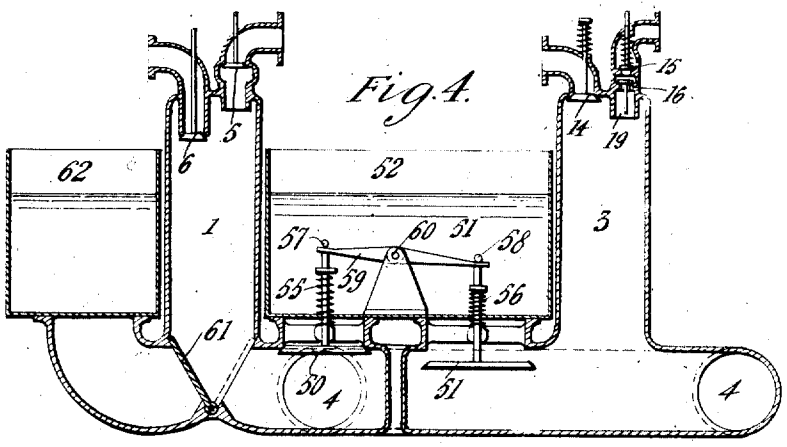


Fig. 5.

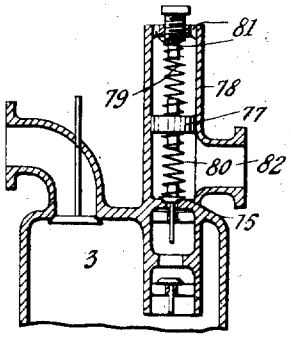


Fig. 6.

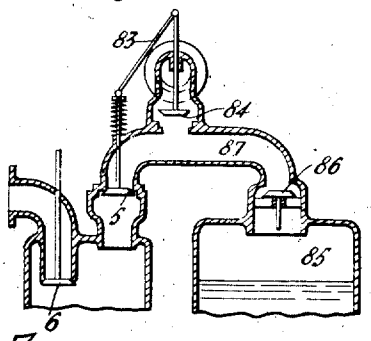
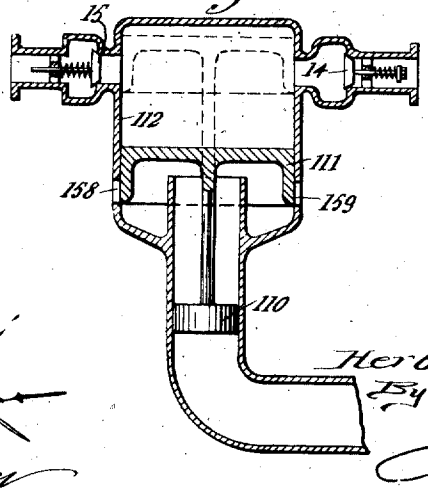


Fig. 7.



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3 SHEETS—SHEET 3.

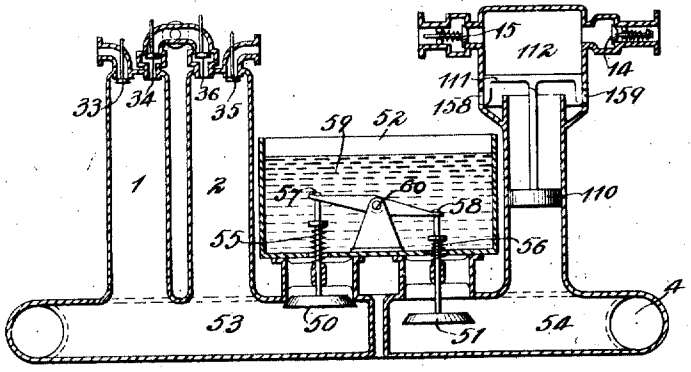


Fig. 8.

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UNITED STATES PATENT OFFICE.

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METHOD OF COMPRESSING AIR OR GASES.

1,257,607. Specification of Letters Patent. **Patented Feb. 26, 1918.**

Original application filed July 17, 1908, Serial No. 444,061. Divided and this application filed February 19, 1910, Serial No. 544,882. Renewed July 18, 1917. Serial No. 181,451.

To all whom it may concern:

Be it known that I, HERBERT ALFRED HUMPHREY, a subject of the King of Great Britain, residing at 38 Victoria street, Westminster, in the county of London, England, consulting engineer, have invented certain new and useful Methods of Compressing Air or Gases, of which the following is a specification.

In a pending application, Serial No. 444061, of which the present application is a division, there is described a process of compressing air or gases, which consists in propelling a mass of liquid outwardly from a combustion chamber by the energy of expansion of an ignited combustible charge, thereby delivering air under pressure and compressing elastic fluid in a compression chamber, allowing some of the energy of this compression to cause the mass of liquid to return to the combustion chamber and in so doing to cause an inflow of air or gas into the compression chamber and the expulsion of the products of combustion and the compression of an elastic cushion in the combustion chamber, expending the energy stored in this elastic cushion to propel outwardly, for the second time, the mass of liquid and thereby to entrain a fresh combustion charge in the combustion chamber and compress the air or gas in the compression chamber, and finally allowing the compressed air to reverse the flow of the mass of liquid causing it to rise in the combustion chamber and compress the fresh combustion charge therein. Such a method involves a four stroke cycle, but according to this invention the cycle is changed to a two-stroke one, so that air under pressure may be delivered each alternate stroke.

The cycle of operation is in many respects similar or analogous to that described and claimed in my copending application Serial No. 438,425, filed June 13, 1908, which application contains claims which may be read upon the disclosure of the present application.

In carrying out my present invention I use a pump of the kind referred to in my copending applications Serial Nos. 438425 and 438427 as well as in the copending application Serial No. 388902 of A. Cerasoli and myself and Serial No. 438426 of W. J. Rusdell and myself, wherein a mass of liquid is propelled outwardly from a combustion chamber by the energy of expansion of an ignited combustible charge, which mass returns toward a combustion chamber to compress a fresh combustible charge; and I use such a pump in combination with an air or gas vessel having suitable valves, as an air or gas compressor or as a blowing engine and obtain considerable advantage as compared with blowing engines which have been previously employed wherein the air is alternately drawn into and expelled from a vessel by oscillation of water therein.

In my combination the continually changing *vis viva* of the mass of liquid which moves between the pump and the compressor practically controls the functions so as to bring about a unified machine.

For the purpose of my present invention it is not necessary that the pump of the kind in question should take in any fresh liquid, as the energy generated by the combustion instead of raising or forcing fresh quantities of liquid has to be mostly expended in compressing the air or other elastic fluid and delivering such fluid under pressure. In some cases, however, there will be both an intake and discharge of liquid at each cycle.

It is a feature of my invention that at each cycle a portion of the energy stored in the air or elastic fluid compressed should be reconverted into the energy of motion of a mass of liquid so as to cause the latter to return toward the combustion chamber as aforesaid to compress the combustible charge or a portion thereof. Thus, that portion of the apparatus in which the elastic fluid is compressed may serve the double purpose of delivering such elastic fluid under pressure and storing energy for compressing the fresh combustible charge.

Liquid oscillates through one or more pipes between the pump portion of the apparatus and the compressor portion, and by allowing fresh liquid to enter and leave the apparatus at each cycle, the liquid which is heated in working may be cooled outside the apparatus and returned thereto. The places at which liquid is taken into and rejected may be arranged so that the amount of cooling at the pump portion and the compressor portion may be advantageously varied to suit different circumstances.

When there is an intake of fresh liquid a

portion of the energy of combustion may be used in raising liquid thus admitted.

If a relatively large volume of compressed air at a lower pressure than would otherwise be the case, is required, the apparatus may be allowed to take in relatively large volumes of fresh liquid so that the volume of moving liquid is increased and can displace more air in the compressor, but this additional liquid can be discharged again at each cycle.

The foregoing general statements will be further elucidated by reference to the accompanying diagrammatic drawings showing sections of pumps and accessories thereto, operated according to the invention, it being premised that the invention may be applied in any suitable apparatus, that shown being merely by way of illustration.

In the drawings Figure 1 is a diagrammatic vertical section of an apparatus, with parts omitted, operated according to the method of this invention, in which there are two combustion chambers and one compression chamber; Figs. 2, 3, and 4 are similar sections of modified forms of the apparatus; Fig. 5 a vertical section of a device for controlling the opening of the air delivery valve; Fig. 6 is a vertical section of a measuring device; Fig. 7 is a section of a device whereby the elastic fluid compressed may be separated from the compressing mass of liquid, and Fig. 8 is a vertical section of a device embodying the features of Figs. 5 and 7.

A form of apparatus, which may be regarded as one of the simplest examples inasmuch as it does not require that there shall be either an intake or discharge of fresh liquid at each cycle, is shown in Fig. 1, in which 1 and 2 are the combustion chambers of the pump and 3 is the air vessel or compressor chamber, the construction of the latter being the same as in Fig. 1, of the copending application Serial No. 444061. The combustion chambers are connected to the compressor chamber by a duct 4 for liquid. It is unnecessary to set forth in detail the cycle of operations occurring in the pump or to describe the functions of the valve gear, as they are fully dealt with in my pending application Serial No. 438427, but the action of the combined apparatus may in general terms be described.

Fitted to the top of chamber 1 is an exhaust valve 33 for burnt products, which opens under the action of its own weight and closes by impact of liquid upon it, an admission valve 34 which is opened by suction against the action of a light spring which closes the valve again when the pressure on the two sides of the valve are sufficiently equalized. An exhaust valve 35 and an admission valve 36 are corresponding parts fitted to chamber 2. Pins 37 and 38 on the stems of valves 34 and 36 are adapted to engage with one end of bell cranks 39 and 40 respectively and the other ends of these bell cranks are connected together by link 41. A pin 42 is attached to one end of link 41 and engages in the slotted end of rod 11 which is attached to pawl 12 and serves a purpose similar to that of the rod bearing the same number in Fig. 1 of my pending application Serial No. 444061 above referred to. The position of the valves shown in Fig. 1 of the drawing accompanying the present application is correct when ignition is about to occur in either of the chambers. Assuming that ignition occurs in chamber 1, there will be a cushion of burnt products in the top of chamber 2 (or a cushion containing a portion of the combustible charge if a modification of this type of pump is being used) otherwise the chamber is full of liquid. In chamber 3 there will be a charge of air which is at atmospheric pressure. The pressure due to combustion in chamber 1 drives the liquid downward and outward from that chamber and through pipe 4 into chamber 3, driving out air past valve 14 which is at present locked open. When expansion has been carried to or about atmospheric pressure in chamber 1, exhaust valve 33 opens and in chamber 2 liquid falls, causing admission valves 36 to open and drawing in a fresh combustible charge into this chamber. This charge may be determined in quantity by a measuring device, such as that described below, and after the charge is drawn in the admission valve shuts under the action of its spring. Up to this stage the energy of expansion had been mostly utilized in imparting kinetic energy to the liquid, but when admission valve 36 opened, its movement caused pin 38 to operate bell crank 40, rod 11, and pawl 12, thus withdrawing this pawl and permitting valve 14 to shut.

The kinetic energy then stored in the moving liquid is used to compress the charge of air at this time inclosed in chamber 3 and to deliver a portion of such charge under pressure past valve 15. There remains, however, sufficient air in the chamber to form the necessary elastic cushion to store the energy required to give the compression stroke. This stored energy is utilized to produce a reverse flow of the liquid so that liquid now begins to fall in chamber 3 and to flow back toward the pump portion of the apparatus rising in chamber 1 to expel burnt products through exhaust valve 33 and then into chamber 2 to compress the fresh combustible charge ready for the commencement of a fresh cycle by the ignition of this charge. After atmospheric pressure has been reached in chamber 3 the further movement of the liquid, due to its kinetic energy, draws a charge of air into this chamber

through valve 14 which is sucked open to admit this charge and locked in its open position by pawl 12 engaging above collar 17. Thus everything is in readiness for commencing the next cycle by the ignition of the compressed combustible charge in chamber 2. The arrangement described insures that the burnt gases in either chamber 1 or 2, according to which is giving the working stroke, shall be expanded to atmospheric pressure.

If bell cranks 39 and 40, rod 11 and pawl 12 are removed, the apparatus will still work but care must be exercised in designing the proportion of the parts to insure that the burnt gases are allowed to expand to atmospheric pressure.

The main difference in this case is that valve 14 is shut at the beginning of the working stroke and that air is compressed from the time that liquid begins to rise in chamber 3 instead of from the time when the burnt gases have expanded to atmospheric pressure. In either case the most advantageous working occurs when the pressure at which the air or gas is delivered does not exceed a certain limit depending on the mean effective pressure of the ignited expanding gases. Consequently a modified arrangement is advisable when other ranges of pressure for the compressed air are desired.

Fig. 2 shows such a modified arrangement in which chamber 3 has an additional pipe 20 communicating with the atmosphere and projecting for a considerable distance into the chamber and this pipe contains a valve 21 for air, on the stem of which is a pin 22 and a collar 23. There are also counterparts of the gear shown in Fig. 1, thus, bell crank 39 has one of its arms adapted to engage with pin 37 on the stem of valve 34, and the other arm of this bell crank is connected by link 41 with bell crank 40. Pawl 25 is fitted to engage under collar 23 and is also connected by rod 43 and link 44 with pawls 45 and 46 adapted to engage under the collars 47 and 48 of admission valves 34 and 36 respectively, pin 22 fitted to stem of valve 21 is adapted to engage with one arm of bell crank 24. Springs 30 and 31 are connected as shown between the two rods 49 and 43 so that the movement of rod 43 tends to follow the movement of rod 49. It will be seen that while link 44 is of such a length that pawls 45 and 46 can both be in engagement under their respective collars, pawl 25 cannot at the same time be in engagement under collar 23.

The operation of this arrangement is as follows:—

Assuming that there is a compressed combustible charge in chamber 1, that liquid fills chamber 2 with the exception of an elastic cushion in the top thereof, and that the valves are in the position shown. Liquid is at a relatively low level in chamber 3 and the chamber contains a charge of air. The charge in chamber 1 is now ignited and liquid is driven downward and outward from this chamber through pipe 4 into chamber 3. Air is discharged past valve 21 into the atmosphere until the level of the liquid reaches the bottom of pipe 20 when liquid rising in this pipe shuts valve 21 by impact and the valve is immediately locked by pawl 25 which is brought beneath collar 23 by the tension on spring 30.

Further motion of the liquid compresses the air now inclosed in the chamber. A portion of the compressed air is discharged under pressure, but there remains sufficient to form the necessary elastic cushion to store the energy for compressing the combustible charge.

As before described, when the ignited gases in chamber 1 have expanded to atmospheric pressure, exhaust valve 33 opens, and liquid falls in chamber 2 opening valve 36 so soon as the pawl 46 is released from under collar 48 by the movement of pawl 25 and rod 43 to the right; a fresh combustible charge, preferably measured, is thus drawn in. The opening of admision valve 36 operates through pin 38 bell crank 40 and moves rod 49 to the left thus putting tension on spring 31 so that when admission valve 36 shuts again, rod 43 is urged to the left and pawl 46 engages under collar 48 and withdraws pawl 25 from under collar 23.

The liquid having come to rest a reverse flow occurs, the elastic cushion in chamber 3 expands, and liquid flows toward chambers 1 and 2 giving the usual exhaust and compression stroke. The pressure in chamber 3 continues to fall and at approximately atmospheric pressure valve 21 opens under its own weight admitting fresh air as the movement of the liquid continues. Valve 14, controlled by a light spring, may also open under suction and facilitate the intake of fresh air. When valve 21 falls, link 49 is moved to the right and tension is put on spring 30 to urge rod 43 to the right. Thus at the end of this stage of the cycle there is a compressed combustible charge in chamber 2 and in chamber 3 a charge of air, and the cycle is ready to be repeated by ignition of the charge in chamber 2.

By varying the length of the portion of pipe 20 that extends into chamber 3 the amount of air compressed at each cycle may be varied, and consequently the energy developed at each cycle, may be utilized in compresing a large quantity of air to a relatively low pressure, or in compressing a small quantity of air to a relatively high pressure.

The action of the apparatus so far described may be varied to some extent by va-

rying the amount of liquid contained therein; thus reduction of the quantity of liquid is equivalent to increasing the capacity of the chambers, and increase of the quantity of liquid is equivalent to decreasing the capacity of the chambers.

Modifications of the apparatus will now be described in which at each cycle fresh liquid is admitted and rejected and firstly in connection with Fig. 3. The combustion chamber and the compressor chamber are shown in such relative position that valves 50 and 51 for liquid, one near the combustion chamber and the other near the compressor, may be conveniently placed close together with the object that their movements may be made to control one another. A tank 52 is so placed that there may be a free flow of liquid to the short pipes in which these valves are situated, which pipes are continued as at 53 and 54 to communicate with the respective chambers. As before, pipe 4 connects the pump and compressor portions of the apparatus.

In the co-pending application Serial No. 438425, a type of pump is described in which the products of combustion are expelled and a new combustible charge drawn in by means of an oscillation of liquid which occurs between a liquid supply and a combustion chamber in a manner fully described in the said application, and in the co-pending application Serial No. 444061, a pump of this type is described with reference to Fig. 3 thereof, in which the products of combustion are expelled and a new combustible charge drawn in by such means. In the present case the reciprocating liquid only makes two strokes per cycle instead of four strokes per cycle, as in the case just referred to, because when expansion has occurred in chamber 1 down to that point at which valve 50 opens, liquid flows past this valve both to follow the liquid moving in the discharge pipe and also to rise in chamber 1 to expel the burnt products and shut the exhaust valve and, on the downward motion which completes its oscillation, to draw in a fresh combustible charge. This operation requires that the level of liquid in the supply tank shall be suitably adjusted and its height must be sufficient to produce the necessary oscillation. This oscillation may be assisted by so raising the level of the liquid in the supply tank that when the oscillation occurs, the liquid rises in chamber 1 past the exhaust valve level and gives a cushion stroke followed by a cushion expansion and combustible charging stroke, in the manner fully explained in the application last mentioned.

Fig. 3 shows an arrangement similar to the last cited figure but adapted to the case where the type of pump is that described in application Serial No. 438427 in which there are two combustion chambers and in which the return flow of liquid expels the burnt products from one chamber and compresses a fresh combustible charge in the other chamber. 1 and 2 are the combustion chambers and 3 is the air compressor chamber. With all the valves in the position shown and a compressed combustible charge in the top of chamber 1 and a charge of air in chamber 3, ignition occurs in chamber 1 and liquid is forced downward and outward from chamber 1 toward chamber 3. Valve 51 is normally open so that liquid can escape past it into tank 52, while kinetic energy is being imparted to the moving column of liquid. When, however, the ignited gases in chamber 1 have expanded to a suitable extent the pressure below valve 50 is equal to that above this valve, and the further expansion of these gases causes valve 50 to open against the action of spring 55 thus admitting liquid to flow into the apparatus from tank 52. Valve 50 has on its stem a pin 57 adapted to engage against one arm of rocking lever 59 which is pivoted at 60 and the other arm of which engages against pin 58 on the stem of valve 51, so that the downward movement of valve 50 causes valve 51 to shut. Thus the energy of expansion of the ignited gases has been so far mainly transformed into kinetic energy of the moving column of liquid and when valve 51 shuts, this kinetic energy is utilized in compressing the charge of air contained in chamber 3, some of which air is delivered under pressure past valve 15, but sufficient is retained to form an elastic cushion in which energy is stored for reversing the flow of the liquid. On reaching atmospheric pressure, exhaust valve 33 is opened under the action of its own weight and in chamber 2 liquid falls, causing admission valve 36 to open and draw in a fresh combustible charge into this chamber, and when the reverse flow of the column of liquid occurs due to the expansion of the elastic cushion in the top of chamber 3, valve 50 is closed by the action of its spring and remains closed owing to the pressure below the valve exceeding that above it. Liquid falls in chamber 3 and rises in chamber 1 expelling the exhaust products past exhaust valve 33 and then into chamber 2, to compress the fresh combustible charge as already explained with reference to Fig. 1. About the time when the pressure in chamber 3 reaches that of the atmosphere, valve 51 opens, also valve 14 is sucked open by the falling liquid and a fresh charge of air is drawn into chamber 3. Thus the level of liquid in chamber 3 tends to be maintained at the level of liquid in tank 52 and valve 14 shuts under the pressure of its own spring when the liquid ceases to fall in chamber 3 having substantially reached the level of the liquid in tank 52. At the end of

the reverse flow toward chambers 1 and 2 compression in chamber 2 will be completed and all the parts being once again in the position shown in Fig. 3, the cycle of operations is ready to be again started by the ignition of the fresh compressed charge in chamber 2, but the functions of chambers 1 and 2 are reversed. Valves 50 and 51 may be adjusted for high or low pressures and operate in the manner already described, with reference to the liquid supply valves in Fig. 3 of my pending application No. 444061. Several forms of valve gear for the working of the admission and exhaust valves on chambers 1 and 2 have been described in application No. 438427, and therefore no such gear is shown on the diagram.

Fig. 4 of the accompanying drawings is added to show the application of one form of the apparatus mentioned in application No. 438425. The pump in this case is fitted with an automatic change over valve which alternately closes communication between the combustion chamber and the supply pipe and between the chamber and the discharge pipe, in such a manner that there is communication between the combustion chamber and the discharge pipe during the compression of the combustible charge and during combustion and expansion. Communication is established between the chamber and the liquid supply during the oscillation of liquid which exhausts the products of combustion and takes in a fresh combustible charge.

It has been described in the said application No. 438425, how this pump may be worked in such a manner that the quantity of liquid taken in from the supply may equal the quantity of liquid discharged back into the supply and in this form also it is applicable to the present invention.

Referring to Fig. 4 it is assumed that there is a compressed combustible charge in chamber 1, valve 50 is closed and valve 51 may be either open or closed according to whether the pressure at which the compressed air has to be delivered is to be relatively high or low. Ignition, combustion and expansion now occur in chamber 1 and when expansion has proceeded until the pressure on the supply side of valve 61 exceeds the pressure in the chamber, this valve is moved into the position shown in dotted lines, and the liquid then moving with considerable velocity in the discharge pipe draws in liquid through valve 50 to follow it. In the meantime the liquid oscillates between the liquid supply tank 62 and chamber 1 expelling burnt products from the chamber and drawing in a fresh combustible charge.

Assuming that valve 51 was open when ignition occurred in chamber 1, this valve is shut by the opening of valve 50; thus the escape of liquid through valve 51 into tank 52 is cut off and the kinetic energy of the moving column of liquid is utilized in compressing air in chamber 3, some of such compressed air being delivered from the apparatus and some being retained to form the necessary elastic cushion to produce the reverse flow of liquid. When this reverse flow occurs, valves 50 and 51 are both shut and the energy of expansion of the elastic cushion in chamber 3 is utilized to compress the combustible charge in chamber 1 and to draw a fresh charge of air into chamber 3.

When relatively low pressures are wanted, instead of valve 50 being normally closed and valve 51 open, valve 50 is normally open and valve 51 is normally closed, and the effect of this arrangement has already been described with reference to Fig. 3 of co-pending application Serial No. 444061 of which this application is a division.

For the sake of simplicity a tank has been shown extending across the inlets of valves 50 and 51, but it is found advantageous to place a partition in the tank such that the liquid must flow a considerable distance in passing between that portion of the tank which communicates with the valve 50 and that portion which communicates with valve 51. Thus a large effective cooling surface can be obtained. The arrangement is practically equivalent to two tanks connected together at their ends.

It has been assumed, in describing the cycles of the various modifications of apparatus, that there already existed a pressure in the outlet pipe at the compressor portion on the discharge side of the outlet valve equal to that at which it was desired to deliver the compressed air. This may, however, not be the case in starting the apparatus, as for instance, when a reservoir for containing the compressed air delivered has to be pumped up to the desired pressure. If the compressor started without pressure in the delivery pipe, the irregular working which would otherwise result until the desired pressure had been attained may be avoided by fitting to the outlet pipe the simple device shown in Fig. 5. A movable piston 77 is held in position in a cylinder 78 by two springs 79 and 80, and on the top side of the piston air is maintained at atmospheric pressure by holes 81 which communicate with the atmosphere, while the under side of the piston is subject to the pressure of the air in the delivery pipe 82. The piston is shown in the position which it has when there is atmospheric pressure in the pipe 82, and in this position spring 79 has moved piston 77 into its lowest position and has compressed spring 80 to such an extent that it requires a pressure below the outlet valve 15 equivalent to the desired pressure at which air is to be delivered to

open this valve. As the air compressor is set to work and air is discharged past valve 15 the pressure in pipe 82 begins to rise and the pressure on the under side of the piston gradually increases until the desired working pressure for the compressed air is reached when piston 77 has been moved upward against the pressure of spring 79. This upward movement relieves the pressure on spring 80 and the springs may be so adjusted that little or no compression now remains in spring 80. Consequently valve 15 now opens when the pressure below it is substantially equal to the pressure at which the air is to be delivered. By this arrangement the pressure at which valve 15 opens may be maintained practically constant from the starting of the apparatus until the desired pressure of delivery is attained, and thus the pressure conditions for each cycle remain the same, in spite of the varying pressure at the delivery side of the outlet valve.

Where the elastic fluid is supplied under pressure it may be supplied under such pressure by an apparatus of the kind herein described, which takes in elastic fluid at atmospheric pressure, and then compression would take place in two stages, and the double apparatus would constitute a two stage compressor.

With reference to the apparatus herein described when compressing elastic fluids the fluid has generally been assumed to be air initially at atmospheric pressure. This is not, however, necessary and any compressible fluid can be supplied to the apparatus and at pressures other than that of the atmosphere.

A device for measuring a combustible charge into the combustion chamber of the pump has already been alluded to, and a further description of it will now be given in connection with Fig. 6.

The combustion chamber 1 is fitted with the usual inlet valve 5, but the stem of this valve has a connection shown diagrammatically as a rod 83 with the stem of valve 84 placed in the combustible inlet pipe, such that when valve 5 opens valve 84 is closed. The combustible inlet pipe 87 is also connected with a measuring chamber 85 in the top of which there is a valve 86 adapted to be shut by impact of liquid upon it. Measuring chamber 85 is connected with a supply of water not shown, which is open to the atmosphere in such a manner that the normal level of water in the measuring chamber may be adjusted.

The action of the measuring apparatus is as follows:—

When valve 5 opens, valve 84 is closed and the suction in chamber 85 causes the liquid to rise therein until valve 86 shuts by the impact of liquid upon it. Thus, valves 84 and 86 being both closed, no more combustible mixture can be taken into chamber 1 and when the pressure in this chamber and in the combustible inlet pipe 87 has risen sufficiently, valve 5 will shut under the action of its spring. This movement of valve 5 opens valve 84, and further combustible mixture flows into pipe 87. Valve 86 falls by its own weight, and the liquid in chamber 85, in falling to its normal level, draws a measured quantity of combustible mixture into the chamber.

The seats of valves 5 and 84 are prolonged in such a manner as to cause these valves to act partly as piston valves, so that valve 84 may be shut by the time valve 5 is open.

It will be seen that by altering the normal level of liquid in chamber 85, the quantity of the measured charge taken in can be varied.

It is well known that pistons of different areas may be used to convert high pressure energy into low pressure energy, or vice versa, and it is obvious that this fact can be utilized in connection with the present invention. Thus, if low pressure air in large volume is required the liquid, instead of rising and falling in an air compressor chamber, may act directly upon a piston 110 (Fig. 7) fitted in a turned portion of the pipe in which the liquid moves. This small piston may be connected with a larger piston 111 and the latter may move in an air compressor chamber 112. 14 and 15 are inlet and outlet valves respectively fitted in the chamber and so situated that piston 111 in moving to its top position closes both inlet and outlet and imprisons a cushion of air in the top of the chamber. Similarly, when the piston moves to its bottom position, it closes the vents to the atmosphere 158 and 159 and so cushions the air imprisoned in the bottom of the chamber and prevents the piston striking the chamber. The action of the apparatus is precisely on the same lines as when liquid rises and falls in the chamber, the only difference being that, instead of the liquid rising and shutting valve 16 in chamber 3, to imprison an air cushion which stores the energy for reversing the flow of liquid, piston 111 cuts off communication by covering the inlet and outlet pipes in chamber 112 and thus imprisons an air cushion in the top of this chamber. The air cushion in the bottom of the chamber is not intended normally to come into play as the lowest position to which the piston normally reaches is that shown in Fig. 7.

Throughout the present specification the elastic cushion which is compressed in the air compressor to furnish the energy for the return flow of liquid has been spoken of as a cushion of air, but it has been shown in application No. 438426 that in the case of the pump the elastic cushion may be ob-

tained by a piston or valve in a branch chamber opening into the combustion chamber, that side of the piston which is not presented to the chamber being acted upon by a spring or by compressed air or equivalent device. It is obvious that a like arrangement may constitute the elastic cushion in the air compressor chamber, in which case the whole or nearly the whole of the compressed air may be delivered from the air vessel at each cycle and the energy stored in the cushioning arrangement just described may be utilized to produce the reverse flow of liquid. In any case where air compressors are made of large size it is desirable to fit elastic cushions of the kind last mentioned merely as auxiliaries for the purpose of safety, so that should the cushioning pressure exceed the maximum desired the auxiliary cushioning device may come into play, the pressure behind the piston of such device being preferably such as to prevent motion of the piston until the maximum cushion pressure in the ordinary air cushion is attained.

Having thus particularly described and ascertained the nature of my said invention and the best means I know of carrying the same into practical effect I claim:—

1. The method of utilizing an expansive force of a compressed combustible charge which consists in reciprocating a liquid, the first outstroke being due to said expansive force, utilizing the momentum of the outstroke to compress an elastic fluid, discharging part of said compressed elastic fluid, utilizing the expansion of the balance of said compressed elastic fluid to cause an instroke of the liquid to entrain fresh elastic fluid and to compress a fresh combustible charge.

2. The method of utilizing an expansive force of a compressed combustible charge which consists in reciprocating a liquid, the first outstroke being due to said expansive force, utilizing the momentum of the outstroke to entrain a fresh combustible charge and to compress an elastic fluid, discharging part of said compressed elastic fluid, utilizing the expansion of the balance of said compressed elastic fluid to cause an instroke of the liquid to entrain fresh elastic fluid and to compress a fresh combustible charge.

3. The method of utilizing the expansive force of compressed combustible charges expanded alternately in two combustion chambers, which consists in reciprocating liquid, the outstroke being due to said expansive force, utilizing the momentum of the outstroke to compress and deliver compressed elastic fluid and to compress a confined elastic cushion, utilizing the expansion of the cushion to cause an instroke of the liquid to entrain fresh elastic fluid and to compress a fresh combustible charge in one combustion chamber and expel burnt products from the other.

4. The method of utilizing the expansive force of compressed combustible charges expanded alternately in two combustion chambers, which consists in reciprocating liquid, the outstroke being due to said expansive force, utilizing the momentum of the outstroke to entrain fresh combustible charge in one combustion chamber and scavenging air in the other and to compress and deliver compressed elastic fluid and to compress a confined elastic cushion, utilizing the expansion of the cushion to cause an instroke of the liquid to entrain fresh elastic fluid and to compress a fresh combustible charge in one combustion chamber and expel burnt products from the other.

5. The method of utilizing an expansive force of a compressed combustible charge, which consists in reciprocating a liquid, the first outstroke being due to said expansive force, utilizing the momentum of the outstroke to compress an elastic fluid, discharging part of said compressed elastic fluid, utilizing the expansion of the balance of said compressed elastic fluid to cause an instroke of the liquid to entrain fresh elastic fluid and to compress a fresh combustible charge, and varying the volume of elastic fluid compressed by the outstroke.

6. The method of utilizing an expansive force of a compressed combustible charge, which consists in reciprocating a liquid, the first outstroke being due to said expansive force, utilizing the momentum of the outstroke to compress an elastic fluid, discharging part of said compressed elastic fluid, utilizing the expansion of the balance of said compressed elastic fluid to cause an instroke of the liquid to entrain fresh elastic fluid and to compress a fresh combustible charge, introducing to and discharging from the reciprocating liquid during each cycle to control the volume of elastic fluid compressed.

7. The method of utilizing an expansive force of a compressed combustible charge, which consists in reciprocating a liquid, the first outstroke being due to said expansive force, utilizing the momentum of the outstroke to compress an elastic fluid, discharging part of said compressed elastic fluid, utilizing the expansion of the balance of said compressed elastic fluid to cause an instroke of the liquid to entrain fresh elastic fluid and to compress a fresh combustible charge, varying the amount of elastic fluid introduced and compressed.

8. The method of utilizing an expansive force of a compressed combustible charge which consists in reciprocating a liquid, the first outstroke being due to said expansive force, utilizing the momentum of the outstroke to compress an elastic fluid, discharg-

ing part of said compressed elastic fluid, utilizing the expansion of the balance of said compressed elastic fluid to cause an instroke of the liquid to entrain fresh elastic fluid and to compress a fresh combustible charge, and separating the elastic fluid from the liquid.

9. The method of utilizing an expansive force of a compressed combustible charge which consists in reciprocating a liquid, the first outstroke being due to said expansive force, utilizing the momentum of the outstroke to compress an elastic fluid, discharging part of said compressed elastic fluid, utilizing the expansion of the balance of said compressed elastic fluid to cause an instroke of the liquid to entrain fresh elastic fluid and to compress a fresh combustible charge, and separating the elastic fluid from the liquid by interposing an independent piston.

10. The method of utilizing the force of a reciprocating column of liquid, which comprises the compression of an elastic fluid by one movement of reciprocation and the production of the opposite movement of reciprocation by the expansion of said elastic fluid acting upon a differential piston interposed between said liquid column and said elastic fluid.

11. The method of utilizing the force of a reciprocating column of liquid, which comprises the compression of an elastic fluid by one movement of reciprocation and the production of the opposite movement of reciprocation by the expansion of said elastic fluid acting upon a piston connected with a piston acting upon the liquid.

12. The method of utilizing the force of a reciprocating column of liquid, one movement of said reciprocation being due to the expansion of a primary medium, which comprises the compression of an elastic fluid by said movement of reciprocation, and the production of the opposite movement of reciprocation by the expansion of said elastic medium acting upon a piston connected with another piston acting upon the column of liquid.

In testimony whereof I have signed my name to this specification in the presence of two subscribing witnesses.

HERBERT ALFRED HUMPHREY.

Witnesses:

JOSEPH MILLARD,

WALTER I. SKERTEN.