Aug. 2, 1949. C. H. NORDELL 2,478,051

HYDRAULIC AIR COMPRESSOR

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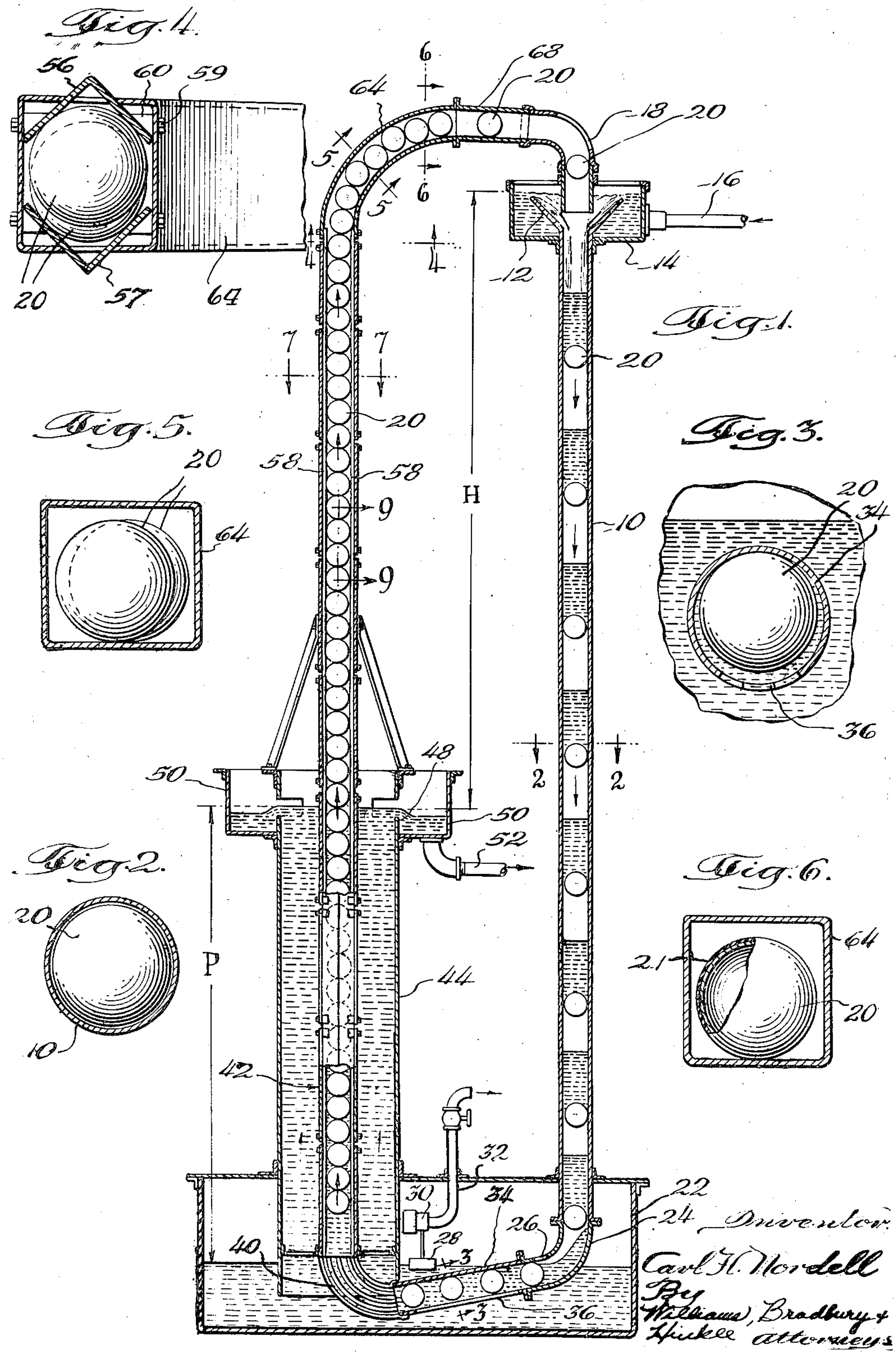

HYDRAULIC AIR COMPRESSOR

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Fig. 7.

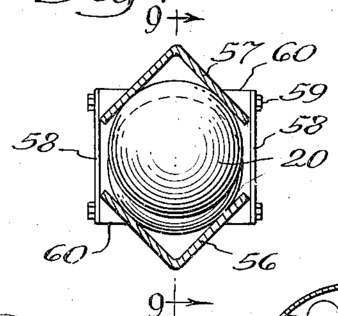


Fig. 9.

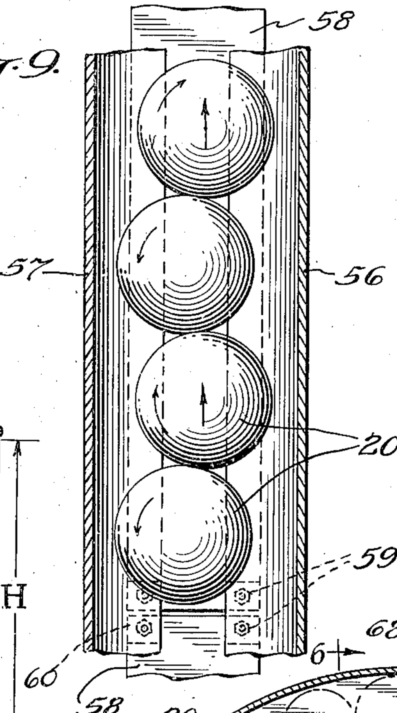
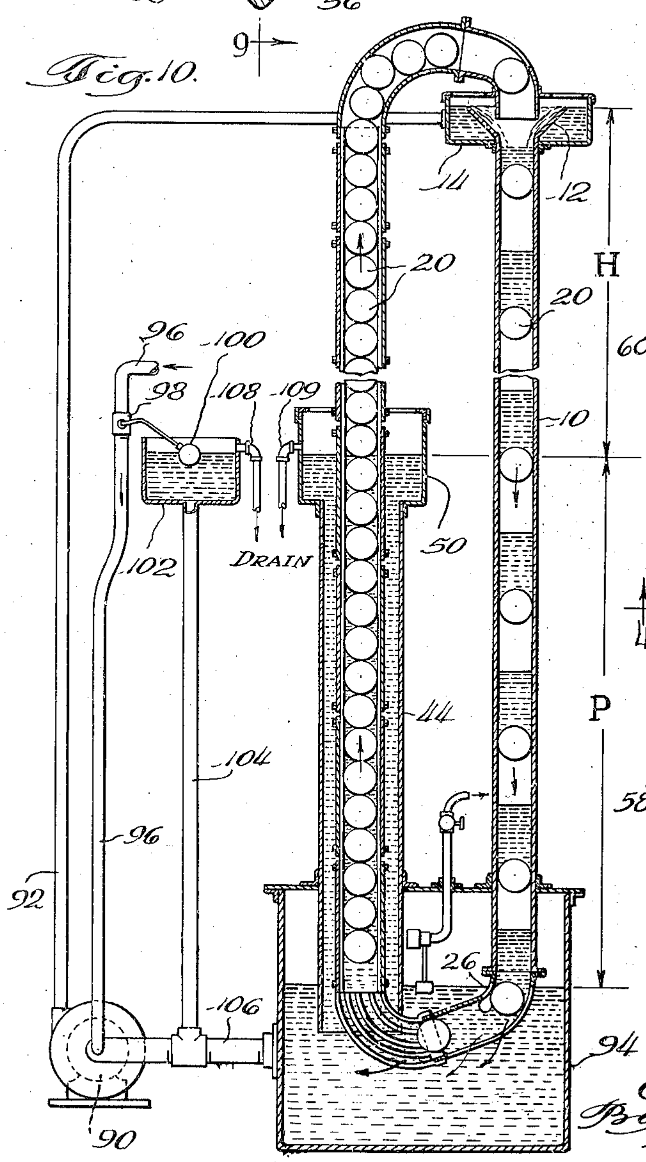


Fig. 10.



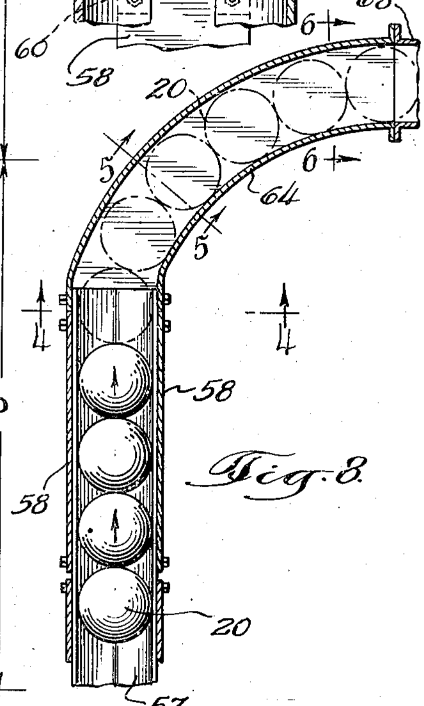


Fig. 8.

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Fig. 11.

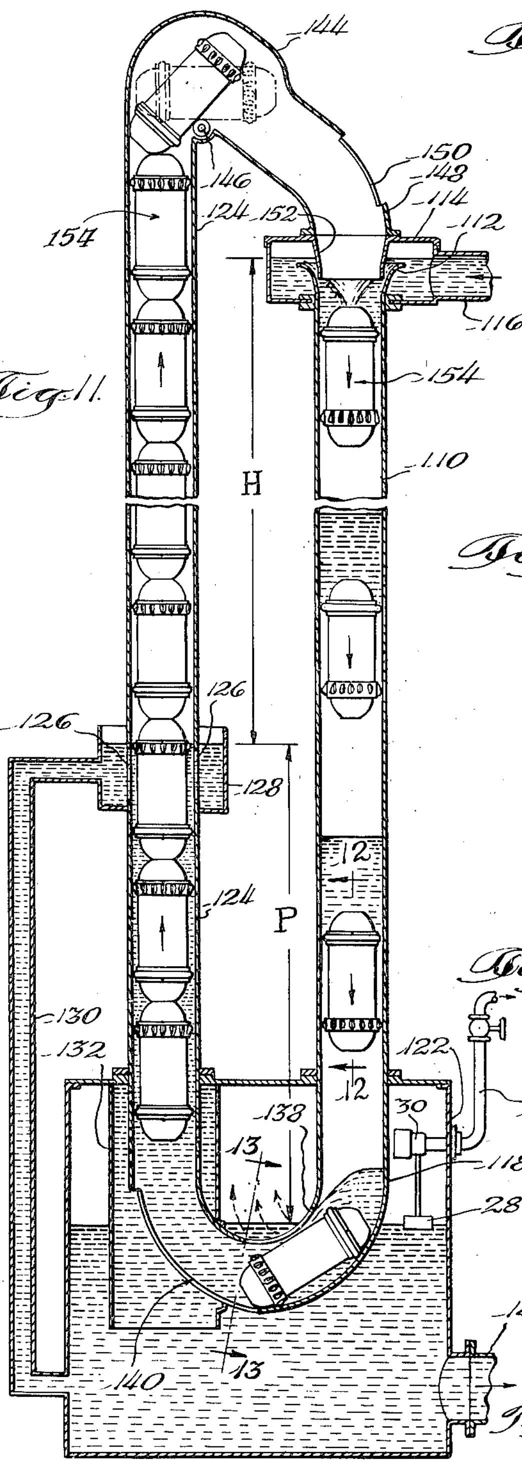

Fig. 14.

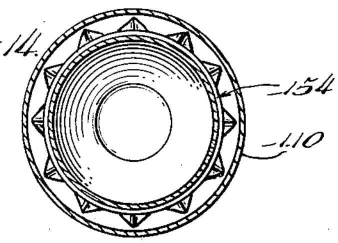

Fig. 12.

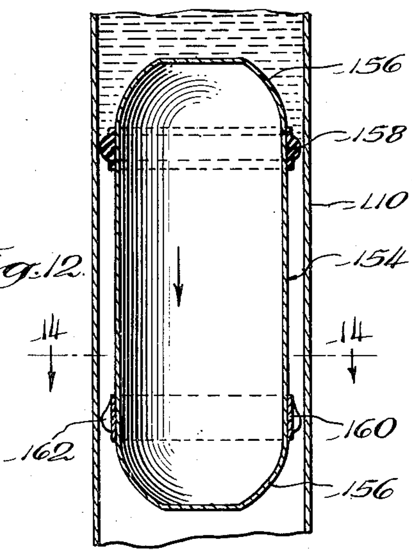

Fig. 13.

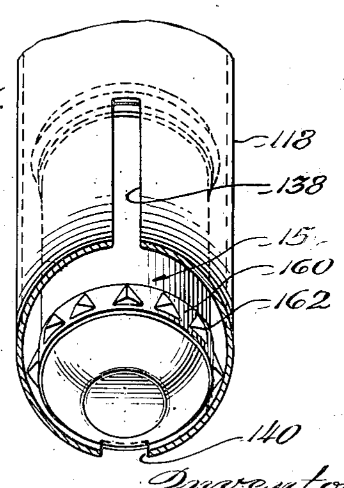

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Fig. 15.

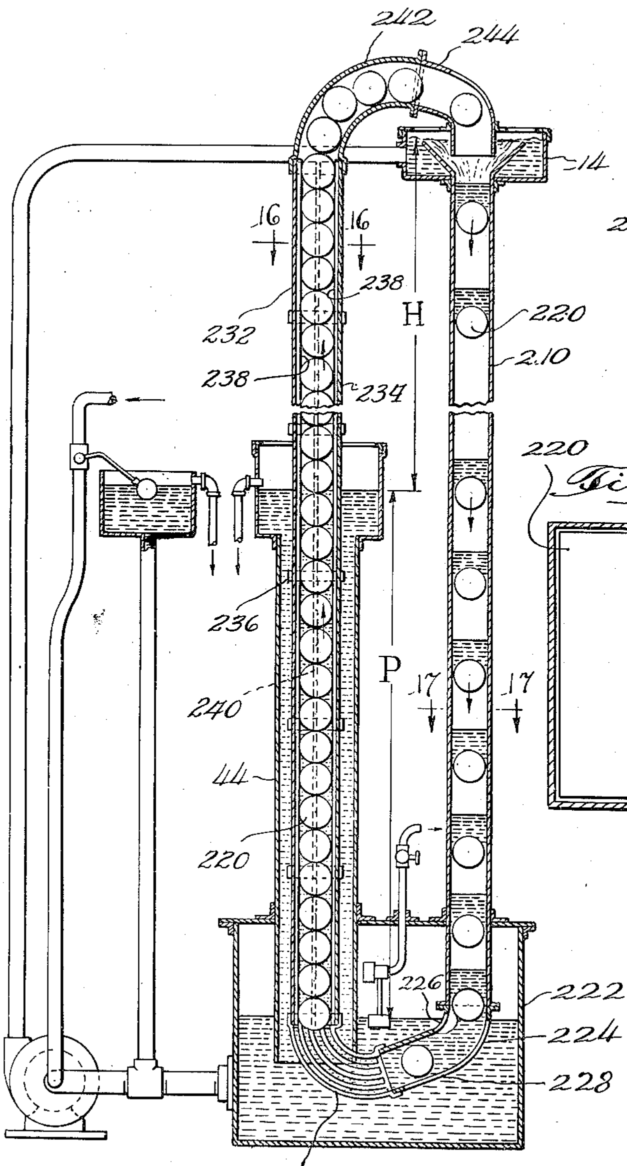

Fig. 16.

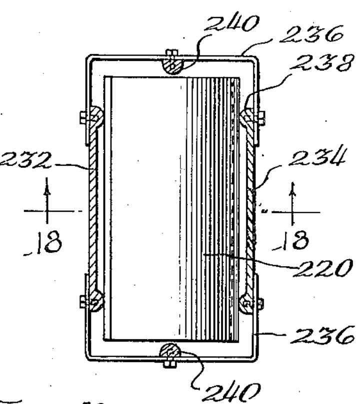

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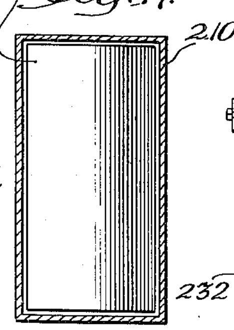
Fig. 17.



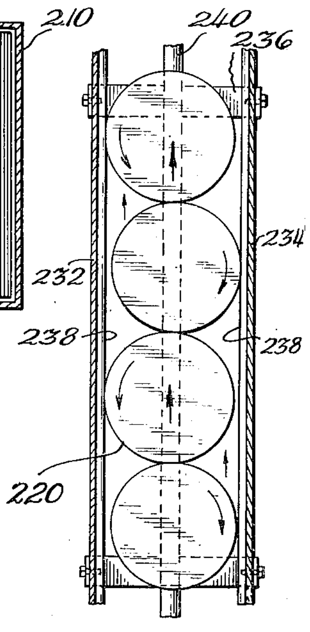


Fig. 18.

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UNITED STATES PATENT OFFICE

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HYDRAULIC AIR COMPRESSOR

Carl H. Nordell, Chicago, Ill.

Application March 24, 1944, Serial No. 527,885

36 Claims. (Cl. 230—105)

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This invention relates to the art of compressing air or other gases by forcing them down beneath the surface of a liquid to a substantial depth, and there collecting the gases in a chamber maintained under a hydraulic head.

The hydraulic air compressor is one type of apparatus which operates on this principle. This type of compressor employs the familiar aspirator principle, in which air is drawn into, and mingles with, a downwardly flowing confined stream of water, the water carrying the air to the requisite depth below the level of the water in a standpipe, the air being separated from the water and collected in a compressed air chamber located at the bottom of the falling stream of water. This method of air compression, although utilized to a slight extent, suffers from the defect that the air in the downwardly flowing stream of water moves upwardly relative to the water, and this "slip" constitutes a serious loss of energy. Other serious losses of energy are incurred in breaking up the water so as to entrain the air. These losses render hydraulic air compressors of this type inefficient and have limited commercial acceptance of this method of air compression to places where a natural flow of water under a comparatively high head has been available, as has been the case in a few mining localities.

Various unsuccessful attempts have been made to improve upon the hydraulic air compressor by providing cups or containers for carrying the air substantially below the level of a column of liquid and there releasing the air into a compressed air chamber. In some instances, the cups or containers were to be driven by mechanical means, and in others by the flow of water. Apparatus of these types are very cumbersome, and present mechanical and other complications disproportionate to the useful work accomplished. When such cups are forced down into the pressure zone of a hydraulic column by the flow of water, provision must be made for their return to the upper end of the column by mechanical conveyor means, with such loss of energy and inflexibility of operation that this type of compressor, as well as the type in which the cups or containers are mechanically driven, have not been found commercially acceptable and are at present in either extremely limited use, or totally unused.

As distinguished from the principles of operation of these prior types of hydraulic air compressors, the method of compression employed in this invention utilizes the weight of slugs of

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water to force masses of air downwardly to the requisite depth below the level of a head of liquid. The freely flowing stream of water, which constitutes the actuating medium, is cut up into slugs by partitions introduced into the stream at regular intervals. Masses or gulps of air are introduced beneath the partitions so that each partition and its superimposed slug of water rests upon a mass of air and forces it downwardly.

These partitions or separators are made buoyant and their buoyancy serves three purposes: First, the buoyancy of the partitions makes them absolutely tight against any upward leakage of air as they move downwardly in the pipe or tube forming the compression column, while at the same time they are loose fitting in the compression column and thus move downwardly therein freely, comparatively frictionless. Second, the buoyancy of the partitions provides a force utilized to elevate them in a return column and to return them to the upper end of the compression column. Third, by virtue of the constant forces acting on the partitions due to their buoyancy when immersed in the liquid, the intervals of time between the introduction of successive partitions at the upper end of the compression column are regulated and made uniform.

For simplicity in diction, the hydraulic fluid will hereinafter be assumed to be water, and the gaseous fluid to be compressed will be assumed to be air, although it will be clear to those skilled in the art that the invention may readily be embodied in apparatus in which other hydraulic fluids are employed, and in which other gases are compressed. In fact, special and additional advantages accrue to the method and apparatus of the invention when certain liquids other than water are used, and in other uses of the invention additional advantages may accrue when the medium compressed is a gas other than air.

It is believed that the detailed description of the novel method and apparatus of the invention, and the objects to be accomplished thereby, will be more clearly understood if preceded by the following general description, in which the underlying principles of the invention are set forth.

General description and objects

In accordance with the underlying principles of the invention, freely and independently moving partitions or separators, having a specific gravity substantially less than that of the hydraulic fluid (water), are introduced at substantially equally spaced time intervals at the top of a vertical hollow compression column into which water flows uniformly at a predetermined rate, and which is open to the atmosphere, so that each separator forms a partition between alternate masses of air and slugs of water flowing downwardly by gravity through the compression column. The separators thus prevent any upward flow or "slip" of the air past the downwardly flowing slugs of water.

At the lower end of the compression column, the air, compressed by the weight of the slugs of water and partitions above it, escapes into a compressed air chamber subjected to a hydraulic "compression head." The slugs of water also discharge into this chamber. The separators are returned to the upper end of the compression column through a standpipe and return guide means by flotation due to their buoyancy, the separators being in contact with one another during their upward return movement. Such of the separators as are immersed, by their buoyancy, elevate those above them to the superior height of the upper end of the compression column.

The entire operation of the apparatus is self-governing, the amount of gas compressed adjusting itself automatically to the height of the compression column, the rate of flow of the water therethrough, and the pressure of air in the compressed air chamber, the latter pressure being dependent upon the hydrostatic head in the return standpipe.

From the foregoing, it will appear that one of the primary objects of the invention is to provide an improved, very efficient method of compressing air utilizing the weight of falling water, in which the operation is completely self-governing.

A further object is to provide an improved highly efficient hydraulic air compressor having means to separate the air and water from one another while they flow downwardly in a compression column.

A further object is to provide an improved hydraulic air compressor in which buoyant movable partitions are employed, and in which such partitions are self-returned from the lower to the upper end of the compression column by virtue of their buoyancy.

A further object is to provide an improved air compressor utilizing the hydraulic head of a liquid to be aerated, such as sewage, whereby substantial aeration of the liquid takes place incidental to its flow through the compressor, thus reducing the amount of compressed air required for the complete treatment.

A further object is to provide an improved hydraulic air compressor in which the compression takes place substantially isothermally, and in which, by the use of a hydraulic operating fluid of the desired temperature, air may be cooled as it is compressed, and excess moisture and dust removed.

A further object is to provide an improved hydraulic air compressor in which slippage of the air in the descending column of the hydraulic fluid is avoided by the provision of separators forming, in effect, downwardly moving walls extending across the column.

A further object is to provide a hydraulic air compressor having free and independently movable buoyant separators which are constructed so as to be very durable and effective and efficient in operation.

A further object is to provide a hydraulic air compressor having separators loosely fitting in the compression column through which they move, so that their motion is substantially frictionless while they are nevertheless perfectly gas-tight by virtue of being liquid sealed.

A further object is to provide various forms of improved buoyant partitions for use in hydraulic air compressors under various operating conditions.

A further object is to provide an improved hydraulic air compressor in which but a few complicated moving parts are required, which may be economically manufactured, and which will have a long, useful life.

Other objects will appear from the following description, reference being had to the accompanying drawings.

Brief description of figures

Fig. 1 is a vertical sectional view of one form of the improved hydraulic air compressor;

Figs. 2, 3, 4, 5, 6, and 7, are, respectively, transverse sectional views taken on the lines **2—2**, **3—3**, **4—4**, **5—5**, **6—6**, and **7—7**, of Fig. 1;

Fig. 8 is an enlarged vertical sectional view of the upper end of the buoyant partition return guide and elbow attached thereto;

Fig. 9 is a fragmentary longitudinal sectional view of the partition return guide, taken on the line **9—9** of Fig. 1;

Fig. 10 is a vertical sectional view of a modified form of the invention, in which the flow of water through the compressor is maintained by a centrifugal pump;

Fig. 11 is a vertical sectional view of a second modified form of the invention;

Figs. 12 and 13 are sectional views, taken on the lines **12—12** and **13—13**, respectively, of Fig. 11;

Fig. 14 is a transverse sectional view, taken on the line **14—14** of Fig. 12;

Fig. 15 is a central vertical sectional view of a further modified form of the invention;

Figs. 16 and 17 are transverse sectional views, taken on the lines **16—16** and **17—17**, respectively, of Fig. 15; and

Fig. 18 is a fragmentary sectional view taken on the line **18—18** of Fig. 16.

The hydraulic air compressor of Figs. 1 to 9

Referring to Fig. 1, the hydraulic air compressor comprises a compression column in the form of a cylindrical pipe **10**, the upper end of which has a funnel-shaped weir **12** welded or otherwise secured thereto, the weir **12** being surrounded by a head chamber **14** to which the hydraulic fluid, such as water, is supplied through a pipe **16**.

The supply of water for the inlet pipe **16** may be provided by a pump, but with reference to the description of Fig. 1 will be assumed to be furnished by a reservoir having a natural head above that of the weir **12**. The head chamber **14** is open to the atmosphere and has an elbow-shaped guide **18** secured thereto to direct hollow spherical partitions **20** into the upper end of the pipe **10**. The partitions **20** are preferably in the form of hollow imperforate metal balls buoyant enough for the column of balls to elevate itself to the requisite height, and also sufficiently buoyant to tend to rise somewhat in the compression column in order that, while water may leak downwardly past them, no gas may escape upwardly. They preferably have a non-corroding durable surface finish which resists abrasion and has a low coefficient of friction with respect to the metals, as, for example, a rubber or synthetic rubberlike composition coating **21** (Fig. 6) bonded, electrodeposited, or cemented to the metal surface.

The lower end of the pipe 10 projects into a closed compressed air chamber 22 in which the liquid and gas descending the compression column 10 are separated. The lower end of the pipe 10 is secured to an elbow 24 within the compressed air chamber 22. The elbow 24 is provided with an air discharge port 26, which may be slightly above the level of the water in the chamber 22. The water level in the chamber 22 is maintained by a float 28 controlling an air valve 30 through which the compressed air is discharged from the upper portion of the chamber 22, a pipe 32 being connected to the valve 30 to conduct the compressed air to the place of use.

A downwardly inclined pipe section 34 is secured to the elbow 24 and, as shown in Fig. 3, has a slot 36 in the bottom thereof, this slot preferably being of gradually increasing width in the direction of movement of the spherical partitions 20. The sloping pipe section 34 is connected by means of a suitable ball guiding wire or grating elbow 40 with a partition return guide structure 42.

The return guide structure 42 has its lower part located within a standpipe 44, the latter projecting through the top of the compressed air and separating chamber 22 to a point below the water level therein. The level of the water in the standpipe 44 is determined by a weir 48 over which the water spills into an annular collecting trough 50 having a discharge pipe 52 connected thereto. The pipe 52 may conduct the water to a suitable place of disposal when a natural hydraulic head is being used for the operation of the compressor, or, as will hereinafter appear, may be conducted to the inlet of a pump by which the water is elevated to the head end of the compression column 10.

The partition return guide structure 42, as best shown in Figs. 1, 7, 8, and 9, comprises a pair of angles 56, 57, which are joined by spaced side plates 58. These side plates may be secured to the angles 56, 57 by means of screws 59 threaded in pads 60 welded to the angles 56, 57. The spacing between the inner surfaces of opposed plates 58 is slightly greater than the external diameter of the spherical partitions 20, so that the latter will normally not come into contact with these plates. The openings between the ends of adjacent plates 58 are provided so that any water carried upwardly by the partitions may discharge freely into the standpipe 44 and will not be carried materially above the level of the weir 48.

As best shown in Figs. 4 to 8, an elbow 64 is secured to the upper end of the return guide structure 42, this elbow being of rectangular cross section at the end adjacent the guide structure 42, as shown in Figs. 4 and 5, and tapering in width so as to be substantially square in cross section at its other end, as shown in Fig. 6. This end of the elbow 64 is suitably joined to a downwardly sloping conduit section 68, which may likewise be of square cross section, the slope being sufficient to cause the spherical partitions to roll to the elbow 18.

The center line of the elbow 64 is preferably not exactly tangential to the center line of the guide structure 42, as will be clear from Fig. 8, so that there is a slight tendency for the spherical partitions 20 to jam as they enter the elbow. This slight tendency to jam is only significant if the speed of the column tends to increase suddenly. Such sudden increases of speed or surges may occur when the apparatus is started up after a shut-down, for then a clump of separators may accumulate in the compression column. When the apparatus is started up this clump of separators is carried into the riser column and the sudden thrust of their buoyant force will produce a surge which may, under certain conditions, persist if not damped out in the elbow 64. When smooth flow establishes itself, the jamming tendency disappears and the partitions are evenly spaced as they roll down the conduit section 68.

As will be noted particularly from Figs. 7 and 9, the guide angles 56 and 57 are spaced sufficiently apart that as the spherical partitions 20 rise in the guide structure 42, alternate partitions will roll along each of these angles. The spacing of these angles is preferably such that the centers of alternate spherical partitions will lie in vertical lines the distance between which is approximately ⅛ of the diameter of these partitions. As a result of this arrangement of the guide angles 56 and 57, the partition spheres will roll against each other and up the guide, and only rolling friction will be present. The buoyancy of the spherical partitions immersed in the standpipe 44 will be sufficient rapidly to elevate the superimposed partitions to the top of the compression column.

Operation of apparatus of Figs. 1 to 9

Assuming that a supply of water is available at a natural head slightly greater than that of the weir 12, and that the flow into the head chamber 14 of the compression column is at a substantially uniform rate, the operating head available will be represented by the distance H (Fig. 1), that is, the distance between the level of water in the head chamber 14 and the level in the standpipe 44. The air in the chamber 22 will be compressed to a pressure corresponding to the compression head P, that is, the difference between the level of the water in the standpipe 44 and the level of the water in the chamber 22.

The operating head and rate of flow available, as well as the compression head desired, will determine in a large measure the relative dimensions of the different parts of the apparatus, and will likewise be factors in determining the specific gravity of the buoyant spherical partitions 20.

In Fig. 1, it is assumed that the operating head H available is somewhat more than the desired pressure head P. Under these circumstances, it will be found that it is desirable, for maximum efficiency, that the spherical partitions 20 have a specific gravity of somewhat less than 1/2. It will be pointed out hereinafter that under other operating conditions the specific gravity of the buoyant partitions may vary considerably from this value.

As the water flows over the weir 12 into the upper end of the compression column pipe 10, it is accelerated downwardly due to gravity. The flow over the weir 12 is thus insufficient to fill the pipe 10 solidly. After a certain amount of water has flowed into the pipe 10, one of the spherical partitions 20 drops into the upper end of the pipe 10 and thus blocks off a slug of water and a mass of air, since prior to this blocking operation the air could flow freely from the atmosphere into the upper end of the pipe 10. Additional water then flows into the pipe 10, resting on the spherical partition 20, and again drawing in a mass of air until the next spherical partition 20 drops into the end of the pipe 10 and forms a second separator effectually to shut in a mass of air while the liquid pouring in upon it drives the spherical partition downwardly, so that in normal operation there is a continuous stream flowing downwardly in the compression column pipe 10, consisting of a succession of masses of air, spherical partitions, and slugs of water, as clearly illustrated in Fig. 1. Thus, each mass of air is subjected to a compression force generally equal to that of the total weight of the spherical partitions 20 and the slugs of water above it. Therefore, as the masses of air flow downwardly through the compression column 10, the air is compressed until it is ejected through the port 26 into the air compression chamber 22, in which the pressure is maintained by the pressure head P.

The spherical partitions 20 may have substantial clearance with respect to the inner diameter of the pipe 10 of the compression column. For example, in a construction in which the internal diameter of the pipe 10 is 18'', these spherical partitions may be from 17.25 to 17.50'' in diameter. Such large clearances are feasible because the pressure of the air below each partition will be almost the same as the pressure of water above it and also because of the self centralizing tendency of the partitions.

The centralizing tendency of the spherical partitions may be explained by the fact that when a partition tends to move sidewardly into contact with the pipe 10, water will flow faster through the larger aperture between the partition and the wall diametrically opposite the impending point of contact, and such faster flow of water will cause a reduction of the pressure at the side of the partition adjacent the faster flowing water. The partition will therefore immediately return toward a central position under the influences of these hydraulic forces acting upon it. This phenomenon, usually known as the "Bernoulli effect" is substantially the same as that of the centering action of a rising jet against a light ball sustained thereby, a familiar example of the latter being frequently observed in the target apparatus of shooting galleries. As a result of this self-centering action of the spherical partitions as they fall in the pipe 10, friction between the partitions and the wall of the pipe 10 is practically non-existent.

This large clearance between the partitions 20 and the pipe 10 is of great advantage when the liquid used contains small particles of debris. Such particles might interfere with the smooth uninterrupted operation of the apparatus if this clearance were very small. As will be described hereinafter, this large clearance makes it possible to use sewage as the hydraulic fluid in the operation of the compressor, and the compressor is therefore usable with great advantage in sewage treatment plants.

As the downwardly flowing stream of slugs of water, masses of air, and spherical partitions reach the elbow 24, the heavier water will, due to its momentum and centrifugal force, follow the outside curve of the bend, and as previously stated, the air will thus readily be discharged through the port 26. The momentum of the slugs of water and spherical partitions will carry the latter downwardly through the pipe section 34, the bottom of which is provided with the slot 36 through which the water discharges into the chamber 22. The spherical partitions continue downwardly due to their momentum, and that of the water between them, until they reach the elbow grating 40 by which they are guided to enter the lower end of the return guide 42. The partitions, of course, move rapidly through the elbow grating 40 and into the lower end of the return guide 42 due to their buoyancy, and collect in the return guide shown in Fig. 1, in contact with one another.

As best illustrated in Figs. 7 and 9, the buoyant forces acting upon the partitions cause them in alternation to contact the guide angles 56 and 57 with which they have rolling contact. Each spherical partition has but two points of contact with its adjacent guide angle 56 or 57, and has but a single point of contact with the partition below it. Since all of the partitions ascend the return guide 42 at the same speed, they will rotate at the same speed with alternate ones rotating in opposite directions, so that only rolling friction will be present at the points of contact between the various partitions as well as between the partitions and the guide angles 56, 57.

Assuming that in the embodiment of Fig. 1 the spherical partitions have a specific gravity of less than 1/2, it will be apparent that the series of partitions 20 which are immersed in the standpipe 44 will provide a sufficient buoyant force to elevate a substantially greater number of the partitions from the level of the water in the standpipe 44 to the head of the compression column. Thus under the assumed conditions, the vertical length of the return guide 42 (and elbow 64) above the water level in the standpipe 44 may be substantially greater than the portion thereof which is immersed.

As the spherical partitions leave the upper end of the return guide structure 42 and enter the elbow 64, the axis about which they rotate will change through an angle of 90°. This change in the direction of rotation of the spherical partitions tends to some degree of sliding, but the friction loss resultant therefrom is very slight, especially if the partitions are rubber coated, since they are always wet and the coefficient of friction between wet rubber and metal is very low.

The apparatus disclosed is self-governing in all major respects, as will be pointed out in greater detail hereinafter.

Description of Fig. 10

In the embodiment of the invention shown in Fig. 10, the hydraulic air compressor of the invention is illustrated as forming part of a closed hydraulic system, but in its major features is identical with the previously described embodiment of the invention, and the same reference characters have therefore been applied to parts which correspond to those previously described. It will be noted, however, that there is provided a motor driven centrifugal pump 90, the outlet pipe 92 of which is connected to the head chamber 14. The inlet of the pump 90 is connected to a separating and air compression chamber 94, and due to the fact that the compression column 10 is located relatively closer to the standpipe 44, the chamber 94 may be made smaller and deeper than that of the previously described embodiment.

Since there will be a certain amount of loss of water from the system due to leakage or evaporation, a suitable source of make-up water connected to a pipe 96 is utilized to replenish such losses. The pipe 96 has a valve 98 controlled by a float 100 operating in response to changes in level in a tank 102, which is connected by a conduit 104 with a pipe 106, the latter connecting the separating chamber 94 with the inlet of the pump 90. Thus, whenever the water in the tank 102 drops below a predetermined lever, indicating that there is insufficient water in the system, make-up water will be supplied through the pipe 96. When the compressor is stopped, the water in the tank 102, as well as in the standpipe 44, will tend to rise and drain pipes 108, 109 are therefore provided to carry off such excess. Such loss is replenished through the pipe 96 as soon as the compressor is again placed in operation.

The compressor of Fig. 10 operates in the same manner as that shown in Figs. 1 to 9, but, since it employs a closed hydraulic system, it may be used where a limited supply of water is available. The compressor of Fig. 10 may also be used for compressing air which is to be cooled and scrubbed. When used for this purpose, the valve 98 may be arranged so as continuously to supply a small amount of fresh cold water so that the water circulating in the system will be maintained at the required low temperature. When the air to be compressed is at a high temperature and relatively high humidity, a substantial portion of the water vapor in the air may be removed by the cooling effected as the air passes through the compressor. Thus, it is unnecessary to provide water sprays or other after-coolers to lower the temperature and decrease the water vapor content of the compressed air. In many uses of the compressor, this advantage of the apparatus is of considerable significance.

Description of Figs. 11 to 14

The embodiment of the invention shown in Figs. 11 to 14 is adapted for use when the operating head H is either great or small relative to the compression head P. If it is great, the buoyancy of the partitions must be relatively high so as to make it possible for the buoyant forces acting on the immersed partitions to elevate the partitions above them to the top of the return guide, and if it is small their specific gravity must be high or unnecessary work will be done in forcing too-buoyant partitions below the hydraulic compression head. As will be more fully explained hereinafter, there are certain limitations in the use of spherical partitions, due to their shape, which make it inadvisable to vary their specific gravity greatly from 1/2, and it is for this reason that under some conditions it is desirable to use partitions of a non-spherical shape, as shown in Fig. 11.

In Fig. 11, the compression column is formed by a cylindrical pipe 110 having a flared weir 112 at the upper end thereof, the weir being located within a head chamber 114 to which the hydraulic operating fluid is supplied through a conduit 116. The pipe 110 may be welded to a 180° bend 118, located within the compressed air and separating chamber 122, the return bend 118 being joined to a return pipe 124. The pipe 124 has a plurality of openings 126 leading to a standpipe chamber 128. The chamber 128 is connected by a conduit 130 with the lower portion of separating chamber 122.

A standpipe section 132 is secured to the top of the sealed chamber 122 and projects beneath the level of the water therein so as to prevent the escape of air upwardly through the return pipe 124. The compressed air is conveyed from the chamber 122 through a pipe 136. The bend 118 is provided with an elongated air escape port 138 along the inner surface of the bend and a water discharge slot 140 along the outer return portion of the bend. Water is drawn from the separating chamber 122 through a conduit 142 either to a hydraulic pump by which it is again discharged into the conduit 116, or in the event that a natural hydraulic head is being utilized for operation of the apparatus, the conduit 142 may lead to a suitable place for the discharge of the water.

At the upper end of the return pipe 124 there is located a suitable partition reversing structure 144 at the inner apex of which there is a freely rotatable roller 146, being preferably mounted on anti-friction bearings. The reversing guide structure 144 includes an elbow portion 148 which has an opening 150 therein and is secured to the head chamber 114. A partition centering and guiding element 152 may be formed integrally with the top of the head chamber 114 so as to cause the partitions to enter the compression column pipe 110 in axial alignment therewith.

The partitions 154 employed in the embodiment of Fig. 11 are of generally elongated cylindrical shape, having flattened dome-shaped ends 156. A girdle 158, which is preferably made of rubber or similar material, is bonded or otherwise firmly secured to the partition. This girdle 158 is preferably formed so as to have a limited zonal area adjacent the walls of the pipe 10 and the location of this zone of minimum clearance is determined by the degree of buoyancy of the partition as a whole. The zone of minimum clearance between the partition and the pipe 110 should be so located on the generally cylindrical partition that the water displaced by the portion of the partition above this zone substantially equals the total weight of the partition, to maintain the liquid-gas interface at this zone, as will hereinafter be explained in detail.

On the partition 154 there is also provided a band 160, preferably of rubber or similar material, firmly secured to the cylindrical portion of the partition, this band having a plurality of projections 162 spaced therealong at close intervals, these projections likewise being of rubberlike material. These projections, acting in conjunction with the girdle 158, effectively guide and align the partition 154 in compression column 110 and return pipe 124. The spaces between the projections 162 are of sufficient cross sectional area that any water which might leak past the girdle 158 will flow freely past the cylindrical portion of the partition and thus the space between the cylindrical portion of the partition 154 and the pipe 110 below the girdle 158 will normally contain air. As a result, the girdle 158 forms in effect a seal between the slug of water above the partition and the mass of air beneath the partition. The provision of the girdle 158 and the band 160 with its projections 162, is also of advantage in that the diameter of the bend 118 may be substantially the same as that of the pipe 110 and yet permit the partitions to pass freely through the bend.

The apparatus of Figs. 11 to 14 operates in generally the same manner as the previously described embodiments, and where the operating head H is high and the compression head P is relatively low, the partitions 154 may be made of very low specific gravity and thus will possess sufficient buoyancy that a small number of the partitions immersed in the return pipe 124 will be able to elevate the unimmersed partitions above them to a relatively great height, yet they will not tend to rise rapidly through the superimposed slug of water when in the compression column.

Where the operating head is low and the compression head high, the girdle may be set low and thus provide sufficient buoyancy to the partitions when in the compression column to keep these relatively heavy partitions from falling out of their superimposed slugs of water. It is obvious that in extreme cases of this kind, the girdle 158 may be adjacent to the lower end of the partition 154 and the band 160 adjacent to the upper end.

Description of Figs. 15 to 18

The embodiment of the invention shown in Figs. 15 to 18 is quite similar to that illustrated in Fig. 10, and the same reference characters previously used have therefore been applied to the corresponding parts. The compression column is, however, formed by a rectangular pipe 210, while the partitions 220 are in the form of hollow cylinders which may be provided with a rubberlike coating in the manner described with reference to the partitions 20. The length of these cylinders may be upward of twice their diameter. The elbow 224 within the compressed air chamber 222 has an air discharge port 226 and may have its outer portion provided with a water discharge slot 228. The elbow grill 230 is likewise of rectangular cross section so as to guide the cylindrical partitions 220 to the lower end of the return guide.

The return guide comprises a pair of formed rail strips 232, 234, which are secured together in spaced relation at intervals by U-shaped brackets 236. Each of the rail strips 232, 234 has a pair of longitudinally extending ribs 238 which form rolling bearing surfaces for the cylindrical partitions 220. A pair of guide rails 240 are supported by the bracket 236, there being adequate clearance between the rails 240 and the ends of the cylindrical partitions 220 so the contact of the partitions with the rails 240 will be of a sporadic nature, the rails 240 providing safety means to keep the partitions rolling on the ribs 238 of the rail strips 232, 234.

The cylindrical partitions are pushed from the upper ends of the guide rails 232, 234, 240, and pass through an elbow 242, into an apertured elbow 244 leading into the head chamber 14.

As illustrated in Fig. 18, the cylindrical partitions will roll alternately in opposite directions and against opposite guide rails as they rise in the return guide structure, and thus friction will be reduced to a minimum since substantially the only friction present will be rolling friction. As in the previously described embodiments utilizing the sperical partitions, the specific gravity of the cylindrical partitions 220 should be in the order of 1/2. There may be some leakage of water past the partitions, but in most cases this will not materially decrease the overall efficiency of the apparatus.

The embodiment of the invention of Figs. 15 to 18 is of particular utility where the operating head H, and compression head P as well, are relatively low, and a large volume of operating water is available.

Principles of construction and operation

In all of the embodiments of the invention disclosed there are certain underlying principles which are employed and which contribute to the high efficiency of the apparatus.

1. The partitions are imperforate and of constant bouyancy, irrespective of the depth at which they are immersed.

2. The partitions are free to move relative to one another. Thus they are widely spaced as they enter the upper end of the compression column and approach one another as the masses of air below them are compressed, and in the return guide are in contact with one another so that the buoyant forces acting thereon are effective to elevate the unimmersed partitions to the top of the compression column. The buoyant forces should be just sufficient (with a reasonable factor of safety) to elevate the partitions to the top of the compression column since any greater buoyant forces would result merely in the loss of energy in the compression column, due to their being forced further than necessary below the level of the water in the standpipe. The required specific gravity of the partitions is therefor determined by the ratio of the compression head to the operating head.

3. The partitions should have adequate clearance in the compression column so as to reduce friction to a minimum, and should have a limited zone of minimum clearance with respect to the compression column pipe so that there is a fairly well defined location of the interface between the mass of air beneath the partition and the slug of water above it.

4. This zone of minimum clearance should, if possible, be at such place relative to the vertical dimensions of the partition as it descends the compression column, that the water displaced by that portion of the partition above such zone is substantially equal to, but never less than, the weight of the partition. Under these circumstances, the partition will not fall out of the slug of water above it, and there will be no substantial leakage either of water downwardly past this zone of minimum clearance, and no leakage of air in the opposite direction. When the partitions are of spherical shape, or of the cylindrical shape of Figs. 15 to 18, the geometrical shape necessarily determines the zone of minimum clearance between the partition and the walls of the compression column pipe. Thus theoretical considerations indicate that these types of partitions should have a specific gravity of somewhat less than 1/2. But of the operating head is considerably greater than the pressure head, the specific gravity of these types of partitions must be considerably less than 1/2, in order than their buoyancy may re-elevate them. This results in some tendency of leakage of water downwardly past the partitions as they tend to rise up through the superimposed slug of water, but this, unless extreme, will usually not result in a serious decrease in the efficiency of the apparatus. However, if the operating head greatly exceeds the compression head, so that the partitions must be made extremely buoyant, the spherical partitions or cylindrical partitions of Figs. 15 to 18, especially if large clearances are desirable, may permit more downward flow of water than is desirable, in which case partitions of the type shown in Figs. 11–14 may be used instead, as will be discussed in more detail hereinafter.

In general, that portion of the partition which lies above the zone of minimum clearance between it and the walls of the compression column pipe, should displace water equaling the weight of the partition. For the sake of simplicity, the reasons for this will be explained on the assumption that static conditions prevail. On this assumption, it will then be apparent that the mass of air beneath the partition must be at the same pressure as the water at the interface between this air and the slug of water above it. For, if the weight of the partition exactly equals the weight of the water displaced by the portion of the partition above the interface at the zone of minimum clearance, the sum of the downwardly directed forces acting on the air, namely, the weight of the water slug plus the weight of the partition, will place the air under a pressure exactly equal to the water pressure at the interface. Hence, under the assumed conditions, water cannot flow downwardly, nor air upwardly, past the zone of minimum clearance between the partition and the compression column pipe. This tendency against intermixture is aided by the surface tension at the interface.

Considered as a dynamic system, it will be clear that these conclusions must be modified to some extent to take into account the effects of friction and the effects of changes in velocity of the partitions and the slugs of water as they descend the compression column. When the partition is moving downwardly there is some tendency for the slug of water to be left behind because it is retarded by friction in the pipe. If the downward motion were very rapid, this adherence of the water to the walls of the pipe might result in the leakage of air upward past the zone of minimum clearance, and this would be very destructive of efficiency. For this reason the specific gravity of the partitions should be slightly less than would be indicated by the considerations expressed in the preceding paragraph, so that the air pressure acting on the partitions descending in the compression column will force these lightened partitions upwardly into the superimposed slugs of water. This will result in some downward leakage of water past the interface, but such leakage can readily be held within very small limits, so that in general, the overall loss of efficiency from this source is in the neighborhood of 1% to 3%. This slight leakage serves a useful purpose in helping to cool the air as it is being compressed and therefore should not, in most cases, be entirely eliminated. By cooling the air as it is being compressed, the compression is substantially isothermal, and consequently of considerably higher efficiency than if the air were not cooled.

5. At the bottom of the compression column the momentum of the partitions and the slugs of water behind them carries the partitions down below the level of the water in the compressed air chamber, and the centrifugal force due to this momentum carries the slugs of water outwardly at the elbow while the air escapes through a port at the inner portion of the bend.

6. The partition return guide in each instance is constructed for minimum friction of the partitions on their guides. In all embodiments except that of Figs. 11 to 14, the partitions roll freely up the return guide while in the construction of Figs. 11 to 13, the partitions are provided with the rubber girdle and rubber band which have a low coefficient of friction with respect to the guiding surfaces. The return guides are in each instance vertical so that the contact of the partitions with the guides is light. In the embodiment of Figs. 11 to 14, the ends of the partitions are flattened so that the ascending partitions are necessarily in vertical alignment and the guiding tube therefor serves more as a means for preventing the partitions from falling out of line than as a slide bearing for the partitions.

7. The partitions descend the compression column at high speed and move upwardly in the return guide at a comparatively low speed. For example, in Fig. 1 the partitions 20 are spaced six to eight diameters apart, whereas in the return guide they are in contact with one another and spaced slightly less than one diameter apart. Hence, since the same number of partitions must travel through the compression column and the return guide, their velocity in the return guide will be between one-sixth and one-eighth of their average velocity in traveling through the compression column. Therefore, the partitions rising through the water in the standpipe move relatively slowly, and the resistance to their movement offered by the water is correspondingly slight. This is an additional factor which contributes to the overall high efficiency of the compressor.

8. The operation of the compressor is self-governing in all major respects. As one of the partitions enters the lower end of the return guide, the force due to its buoyancy is added to the buoyant forces of the other immersed partitions, and this added force is sufficient to cause ejection of the partition at the top of the return guide to cause it to roll or slide to the head of the compression column. As the partitions succeed one another rapidly, the column is in continuous motion at a rate of speed governed by the supply of partitions to its lower end.

The regularity with which the partitions are supplied to the upper end of the compression column is also completely self-governing by conditions inherent in the partition return guide. For instance, if the speed at which the partitions descend in the compression column is increased, the buoyant partitions will be supplied more rapidly to the return guide. This quickly produces an increased buoyancy in the column of partitions in the return guide and the increased lifting effect thus produced accelerates the partitions and supplies them more rapidly to the top of the compression column. The inertia of the rising column of partitions is sufficient to insure regularity of timing, since the velocity of the partitions in the return column tends strongly to remain constant for a given set of operating conditions.

If the rate of flow of the water into the head chamber at the top of the compression column is increased, the partitions will, for a brief interval, receive more superimposed water and less air. This added weight will cause the rate of descent of the partitions in the compression column to increase, and they will be supplied more rapidly to the return guides. This will increase the rate of ascent of the partitions in the return guide so that the partitions will very soon thereafter be delivered to the head of the compression column at shorter, but nevertheless regular, time intervals, and the original ratio of the volumes of the slugs of water to masses of air beneath the partitions will reestablish itself promptly. There are some friction losses in the system as a whole, so that violent fluctuations in the speed of operation are damped, and therefore there will be no tendency toward hunting.

9. In the treatment of sewage, particularly by the activated sludge process, or other processes in which aeration of the sewage plays a part, it is necessary to compress considerable quantities of air for dispersal through the sewage in the aeration tanks. In many such sewage plants, due to the terrain on which the plant is located,

there is a natural fall (hydraulic head) of the sewage available between the sewer by which the sewage is conveyed to the plant and the point at which the liquid effluent is discharged. In such plants, this natural head of the sewage may be utilized, through the use of hydraulic air compressors of the type disclosed herein, to compress air to supply all, or at least a part, of the compressed air needed for complete aeration in the purifying process. When air compressors of the invention are used in a plant of this type, it is desirable that the sewage to be aerated be used as the hydraulic fluid for the operation of the hydraulic air compressors, because in the course of its flow through such compressors, the sewage will absorb a considerable amount of oxygen from the air being compressed and thus decrease the amount of air which must be supplied to the aeration tanks.

Since sewage may contain various solid particles of debris, it is desirable that the partitions of the hydraulic air compressors for such use have the maximum feasible clearance between them and the walls of the compression column, so that the possibility of interference with their regular movement through the compressor, by particles of debris, may be avoided.

In air compressors thus used in sewage treatment plants, it may be desirable to make the partitions slightly more buoyant than would otherwise be required, so as to assure that there will be some leakage of the sewage past the zone of minimum clearance and thereby permit some sewage to leak past the partitions and fall through the masses of compressed air beneath the partitions, thereby increasing the surface area of the liquid sewage which comes into contact with the air. Furthermore, the air in the separating chamber at the bottom of the compression column being under pressure, further facilitates the absorption of oxygen by the sewage. Of course, the inner walls of the compression column will have a film of the liquid sewage temporarily adhering thereto, which film will also come in contact with the masses of air being compressed. In this way substantial aeration of the sewage may take place as an incident to utilizing the sewage as the actuating fluid of the compressor. This advantage or saving will obtain both when a natural hydraulic head is being utilized and when the sewage to be aerated is circulated through the compressor by pumping.

10. When the hydraulic air compressor is to be used in air conditioning systems, considerations similar to those above set forth with reference to sewage systems will determine the particular design of the compressor to be employed, since in such systems it is also desirable that the water and air come into contact with one another so that dust, other foreign particles, and soluble deleterious gases (e. g., SO_2 and CO_2) be removed from the air, and further, that the air be cooled by the water while the air is being compressed. In such installations, after-coolers need not be employed to reduce the temperature and remove water vapor. Similarly, in some chemical processes in which it is desirable to cause a gas to dissolve in a liquid, the liquid may be used as the hydraulic fluid of the compressor and thus cause a substantial amount of the gas to be dissolved in the liquid during the course of the compression of the gas. In this way the advantageous properties of the compressor may be utilized in full.

Each of the several embodiments of the invention disclosed has particular utility for meeting certain operating conditions which may be encountered in practice. In general, due to their simplicity, the compressors using the spherical partitions will be preferred, and these forms of the compressor may ordinarily be used very efficiently when the operating head does not differ too greatly from the compression head, so that partitions having the ideal specific gravity of something less than 1/2 will serve to elevate themselves to the required height in the return guide.

The type of partition shown in Figs. 15–18 will serve well under these same ratios of operating and compression heads, and will handle a larger quantity of water and air in a single unit since the compression column is of greater cross sectional area for partitions of a given diameter. Obviously, there is a practical limitation to the magnitude of the diameter of partition that may be used, for as their diameter is increased there is room for fewer and fewer of them in the compression column, leading to jerky and uneven operation. Large capacities can always be obtained, however, by installing a plurality of compressors in parallel.

When the actuating fluid of the compressors is elevated by a pump the operating head may, of course, be so selected as to obtain very high efficiencies with these types of compressors. However, when the operating head differs greatly from the compression head, as is often the case when a natural head of water is to be used, partitions of the form shown in Figs. 11–14 may be used to better advantage, since then buoyancy in the compression column is adjustable, as has been described. The buoyancy of the immersed partitions in the return guide must be sufficient, of course, to elevate the superimposed partitions to the head of the compression column. This very high buoyancy for large operating heads or very low buoyancy for low operating heads is compensated for in the compression column by positioning the girdle so that the interface is made to occur at the point where the displacement of that portion of the partition above this plane, in the superimposed slug of water, is just slightly greater than the weight of the partition. Obviously, if the partitions are very light the girdle will set very high on the partition in the descending position, while if the partition is comparatively heavy it will set correspondingly low.

The foot piece shown as 118 in Fig. 11 may be used with the spherical partitions, or with the cylindrical partitions of Figs. 15–18, and presents certain advantages in handling fluids, such as sewage, containing debris which might wrap itself around grating elbows of the type shown at 40 in Fig. 1.

While I have shown and described particular embodiments of the invention, it will be apparent to those skilled in the art that numerous variations and modifications may be made without departing from the underlying principles of the invention herein set forth. Thus, for example, the buoyant partitions may be made in solid form of suitable low density material. I therefore desire, by the following claims, to include within the scope of my invention all such variations and modifications by which substantially the results of the invention may be obtained, by the use of substantially the same or equivalent means.

I claim:

1. In a hydraulic air compressor, the combi-

nation of a vertical tube forming a compression column, means supplying a stream of hydraulic actuating fluid and air to the upper end of said tube, a liquid and air separating chamber connected to the lower end of said tube, means controlling the escape of air from said chamber to maintain a relatively constant liquid level therein, a standpipe connected to said separating chamber and having an opening below the level of the liquid therein, a plurality of similar free buoyant partitions for separating masses of air from slugs of the hydraulic fluid flowing downwardly in said tube, apertured means for guiding said partitions from the lower end of said tube into the lower end of said standpipe, and means extending through said standpipe for guiding said partitions to the upper end of said tube.

2. A hydraulic air compressor having a compression column, means for supplying a hydraulic and a gaseous fluid at the upper end of said column for flow downwardly therethrough, a plurality of free buoyant partitions, means for introducing said partitions at the upper end of said column for falling downwardly therethrough, said partitions being of a size substantially to form walls across said column to separate the hydraulic and gaseous fluids flowing downwardly therein and thereby to prevent appreciable slippage of the gaseous fluid upwardly past the descending hydraulic fluid, a chamber at the lower end of said column to separate said fluids, means to maintain said chamber under relatively constant pressure, and means utilizing the buoyancy of said partitions for returning them to said partition introducing means at the upper end of said column.

3. The combination set forth in claim 2, in which said compression column is in the form of a cylindrical pipe and said partitions are spherical in shape and of diameter slightly less than the internal diameter of said pipe.

4. The combination set forth in claim 2, in which the upper end of said column is funnel-shaped to form a weir and a head chamber is provided to conduct the hydraulic fluid to said weir.

5. The combination set forth in claim 2, in which said partitions are spherical in shape and each of them weighs less than one-half of the weight of the hydraulic fluid displaced thereby.

6. The combination set forth in claim 2, in which said partitions are spherical in shape and each weighs between one-third and one-half of the weight of an equal volume of the hydraulic fluid used in the compressor.

7. The combination set forth in claim 2 in which each of said partitions comprises a hollow metal ball having an external surface coating of a rubber-like material resistant to abrasion and having a low coefficient of friction with wet metals.

8. The combination set forth in claim 2 in which said compression column is in the form of a pipe of hollow rectangular cross section, in which each of said partitions comprises a right cylindrical element the dimensions of the diametral cross section of which are slightly less than the corresponding internal dimensions of said pipe, and in which said partition introducing means operates on said partitions with their axes horizontal.

9. A free partition for use in a hydraulic air compressor comprising a generally cylindrical imperforate element having a zone of greater diameter than that of the major portion of the length of the element, the weight of said element being of the order of the weight of hydraulic fluid which is displaced by the portion of said element which lies between one end thereof and said increased diameter zone.

10. The combination set forth in claim 9 in which said zone of greater diameter is formed by rubber-like girdle firmly secured to said element.

11. The combination set forth in claim 9 in which said zone of greater diameter is near one end of said element and in which there are spaced radially outwardly extending projections near the other end of said element.

12. The combination set forth in claim 9 in which said element has dome-shaped ends, each having a central flat external surface of substantial area perpendicular to the axis of the element.

13. The combination set forth in claim 9 in which the extremities of said element are formed by central flat external surfaces perpendicular to the axis of the element.

14. A free partition type hydraulic air compressor having a hollow compression column, and a plurality of partitions for separating masses of air in said column from superimposed slugs of hydraulic fluid, each of said partitions having a zone of maximum cross sectional area similar in shape to the cross section of the interior of said compression column but of sufficiently smaller dimensions to provide substantial clearance between the partition and the compression column, the weight of each of said partitions being substantially equal to the weight of the hydraulic fluid displaced by the portion of the partition above the zone of maximum cross sectional area.

15. A hydraulic air compressor comprising a plurality of buoyant partitions, means for guiding said partitions for movement through a closed path, said means including an imperforate vertical compression column, a vertical return guide, and connections respectively between the upper and lower ends of said column and guide; means for supply air and water to the upper end of said compression column, an air and water separating chamber at the lower end of said compression column, a standpipe extending from below the water level in said chamber to a substantial elevation, said standpipe maintaining a predetermined water level in said return guide, and means for conveyeing compressed air from said separating chamber.

16. In a hydraulic air compressor, the combination of a plurality of free partitions of generally circular cross section, and a return guide for the partitions comprising a structure forming two pairs of parallel contact surfaces extending the length of said guide for engagement with said partitions, the surfaces of each pair being positioned to permit free rolling of the partitions thereagainst, and the two pairs of surfaces being spaced apart a distance such that one of said partitions cannot simultaneously contact more than one of said pairs of surfaces.

17. In a hydraulic air compressor, the combination of a plurality of free spherical partitions and a return guide for the partitions, comprising a pair of angle irons, means to secure said angle irons together in parallel relation with their outer corner edges directed away from each other, the spacing between the inner surfaces of said angles being sufficiently great that one of said spherical partitions cannot simultaneously contact more than two of the four inwardly facing surfaces of said angle.

18. In a hydraulic air compressor, the combination of a plurality of similar spherical partitions, and a return guide in which the partitions are pushed upwardly in contact with one another, said guide comprising a vertical rail structure maintaining the centers of all of the partitions in a single plane with the centers of alternate partitions disposed in a first line and the interposed partitions in a line spaced from said first line by a distance less than one-fourth the diameter of said partitions, whereby said partitions will roll along said rail structure and against each other without appreciable relative sliding movement.

19. A hydraulic air compressor comprising, a hollow pipe compression column having its upper end open to the atmosphere, means for supplying a hydraulic fluid and air at the top of said column, a plurality of buoyant free partitions, said partitions being movable downwardly through said column, means for conveying said partitions from the lower end to the upper end of said column, a closed chamber connected to the bottom of said column for separating air from the hydraulic fluid, and means forming a conduit for the discharge of the hydraulic fluid from said chamber and for maintaining the fluid in said chamber at a predetermined pressure.

20. A hydraulic air compressor having a compression column, means for supplying a hydraulic and a gaseous fluid at the upper end of said column for flow downwardly therethrough, a plurality of buoyant partitions, and means for supplying a series of said partitions at the upper end of said column for falling downwardly therethrough at spaced intervals, said partitions having their dimensions transversely of the direction of their travel through the column slightly less than the corresponding internal dimensions of the column, to provide substantial peripheral clearance to enable the partitions to fall downwardly in the column without contacting the walls thereof.

21. In a hydraulic air compressor, the combination of a vertical compression column, means to introduce water and air at the upper end of said column, a plurality of spherical buoyant partitions, means for dropping said partitions into the upper end of said column coaxially therewith at substantially regular time intervals, said partitions being of slightly lesser diameter than the internal diameter of said column, whereby said partitions will form separators between the air and water admitted to said column and flowing downwardly therein, an air-tight air separating chamber connected to the lower end of said column, means to maintain the water in said chamber at a relatively constant level, a standpipe extending below said level, a partition return guide extending upwardly through said standpipe, means for transferring said partitions from the lower end of said column to the lower end of said return guide, said last named means having air and water outlet ports, and means providing a track for the transfer of said partitions from the upper end of said return guide to the upper end of said column.

22. A hydraulic air compressor comprising, a compression column having its upper end open to the atmosphere, means for supplying a stream of hydraulic fluid into the top of said column, a plurality of buoyant partition elements, said elements being slidable downwardly through said column with a slight amount of clearance, means for conducting said elements one after another to the upper end of said column, a riser guide structure communicating at its upper end with said conducting means, means for guiding said elements from the lower end of said column to the lower end of said riser guide structure, a chamber for separating air from the hydraulic fluid at the bottom of said column and guide structure, and means for controlling the discharge of compressed air from said chamber.

23. A hydraulic air compressor comprising a downflow column, means for introducing water and air at the upper end of said column, means for admitting free buoyant partitions to the upper end of said column to separate the air and water flowing downwardly in said column, a chamber at the lower end of said column for separating the water from the air compressed thereby, means for maintaining said chamber under a predetermined hydraulic head, and means utilizing the buoyancy of said partitions to return them to the upper end of said column.

24. In a hydraulic air compressor, the combination of a plurality of free spherical partitions, and partition return means comprising a pair of opposed vertically extending angles secured together in spaced relation, the spacing between said angles being sufficient to permit the partitions to roll upwardly against them in alternately staggered arrangement whereby the partitions will roll along said angles and having rolling contact with each other.

25. In a hydraulic air compressor, the combination of a plurality of free spherical partitions, and partition return guide means comprising, means providing four vertical guiding surfaces for contact with said spherical partitions, said surfaces being, in transverse cross section, positioned at the corners of a rectangle having one pair of its opposed sides substantially equal in length to the sides of a square inscribed in a circle having a diameter equal to that of the partitions, and the other pair of opposed sides of length exceeding that of the first sides by an amount in the order of one-eighth of said diameter.

26. A partition for use in a hydraulic air compressor having a hollow substantially rectilinear vertical compression column, comprising, a body buoyant in the hydraulic fluid used in the compressor as a seal for the body and as a mass resting on the body to force it downwardly against air pressure, said body having its portion of greatest transverse cross sectional area located at a horizontal zone intermediate its ends, said zone of greatest cross sectional area being located in a position such that the weight of the hydraulic fluid displaced by the portion of the body above said zone substantially equals the total weight of the body.

27. In a hydraulic air compressor having a hollow substantially rectilinear vertical compression column, means supplying a hydraulic fluid to the top of the column, and a body buoyant in the hydraulic fluid used in the compressor, said body having its portion of greatest transverse cross sectional area located at a horizontal zone intermediate its ends, said zone of greatest cross sectional area being located in a position such that the weight of the hydraulic fluid displaced by the portion of the body above said zone substantially equals the total weight of the body, the portion below said zone providing sufficient clearance from the walls of the column that air below said body may readily displace hydraulic fluid from the space surrounding the lower portion of the body.

28. A hydraulic air compressor having a com-

pression column open to the atmosphere at its upper end, a pump supplying water to the upper end of said column for flow downwardly therethrough, a plurality of free buoyant partitions, means for introducing said partitions at regular time intervals into the upper end of said column for falling downwardly therethrough, said partitions being of a size substantially to form walls across said column to keep separate the water and air flowing downwardly therein and thereby to prevent appreciable slippage of the air upwardly past the descending water, a chamber at the lower end of said column to segregate the air and water, means comprising a standpipe to maintain said chamber under relatively constant pressure, means for guiding said partitions from the lower end of said compression column to the lower end of said standpipe, and means utilizing the buoyancy of said partitions in said standpipe for returning them to said partition introducing means at the upper end of said column.

29. A hydraulic air compressor having a compression column, means for admitting a hydraulic and a gaseous fluid to the upper end of said column for flow downwardly therethrough, a plurality of free buoyant partitions, means for introducing said partitions at the upper end of said column for falling downwardly therethrough, said partitions being of a size substantially to form walls across said column to divide the hydraulic from the gaseous fluids flowing downwardly therein and thereby to prevent appreciable slippage of the gaseous fluid upwardly past the descending hydraulic fluid, means forming a chamber at the lower end of said column to segregate said fluids, means to maintain said chamber under relatively constant pressure, means utilizing the buoyancy of said partitions for returning them to said partition introducing means at the upper end of said column, and a pump having its inlet connected to said chamber for withdrawing hydraulic fluid from said chamber and elevating it to said admitting means at the upper end of said column.

30. In a hydraulic air compressor, the combination of a tubular compression column extending from a height above a water level to a depth below that level, an arcuate bend at the lower end of said column, said bend having an air discharge port at its inner side, a separating chamber surrounding said bend, means comprising a standpipe for maintaining said chamber under pressure, means to supply air and water to the upper end of said compression column for gravitational downward flow therethrough, means for supplying a succession of buoyant partitions to the upper end of said column to prevent intermixture of masses of air with superimposed slugs of water moving downwardly in said column, and means utilizing the buoyancy of said partitions as the sole motive force for elevating said partitions from said bend to the upper end of said column.

31. A hydraulic air compressor comprising, a downflow pipe, a return guide, and guide connections between the respective ends of said pipe and guide, means for supplying water and air to the upper end of said downflow pipe, a separating chamber communicating with the lower end of said downflow pipe, means for maintaining water in the lower portion of said return guide to provide a predetermined hydraulic pressure head on the contents of said chamber, and a plurality of buoyant partitions circulating freely through the circuit comprising said downflow pipe, said return guide, and said guide connections, there being a sufficient number of said partitions to substantially fill said return guide with the partitions in contact with one another and at the same time to provide a plurality of partitions moving downwardly in said downflow pipe in spaced relation separating substantial masses of air from superimposed slugs of water.

32. In an apparatus for causing a gas and a liquid to come into intimate contact while compressing the gas, the combination of a vertical compression column, means supplying the liquid to the upper end of said column at a rate controlled to prevent the upper end of said column from becoming completely filled with the liquid, means admitting the gas to the upper end of the compression column, a plurality of buoyant partitions, and means for introducing said partitions into the upper end of said column at spaced intervals, each of said partitions having a zone of maximum cross sectional area of dimensions substantially less than the corresponding dimensions of the internal cross sectional area of said compression column but of similar configuration so as to provide substantial clearance between said zone and the walls of said column, the weight of each of said partitions being slightly less than the weight of the liquid displaced by that portion of the partition above said zone as the partition falls through the column, whereby said partitions form imperfect separators between masses of the gas beneath and the slugs of liquid above them and allow some of the liquid to leak past them to mix with the masses of air beneath the partitions.

33. In a hydraulic gas compressor, a vertical compression column, a vertical riser adjacent thereto, an apertured bend connecting the lower ends of said column and riser, a guide connecting the upper end of said riser to the upper end of said column, means supplying hydraulic actuating fluid continuously to the upper end of said compression column, the upper end of said compression column being open to inflow of the gas to be compressed, a plurality of partitions of size sufficient to separate slugs of water from masses of gas flowing downwardly in said compression column, an enclosed chamber communicating with said bend to receive compressed gas from the aperture in said bend, and a standpipe extending around the lower portion of said riser and forming the main passageway for the escape of the hydraulic fluid from said chamber, there being a sufficient number of partitions to form a stack in said riser, said stack of partitions in said riser being contiguous and forced upwardly by the hydraulic forces acting upon such of said partitions as are immersed in the standpipe surrounded portion of the riser to elevate the partitions to a level above the top of said compression column so that they may gravitate thereto along said guide.

34. In a hydraulic air compressor, a vertical pipe-like compression column, a vertical riser adjacent thereto, said riser and said column having their corresponding ends connected together, means supplying hydraulic actuating fluid continuously to the upper end of said compression column, the upper end of said compression column being open to inflow of the air to be compressed, a plurality of partitions of size and shape to separate slugs of water from masses of air flowing downwardly in said compression column, an enclosed chamber surrounding the lower ends of column and riser and communicating with the lower end of said column to receive compressed

air therefrom, and means providing a standpipe extending around the lower portion only of said riser and forming a passageway for the escape of the hydraulic fluid from the lower end of said compression column, there being a sufficient number of partitions to form a stack in said riser, said stack of partitions in said riser being contiguous and forced upwardly by the hydraulic forces acting upon such of said partitions as are immersed in the portion of the riser through which the hydraulic fluid flows upwardly, thereby to elevate the partitions to the top of said compression column.

35. A hydraulic air compressor having a hollow substantially rectilinear vertical compression column extending from an upper liquid level to a predetermined depth below a lower liquid level, the difference in head between said upper level and said lower level constituting the operating head, and the difference in head between said lower level and said predetermined depth constituting the compression head, and a plurality of partitions movable through said column, each of said partitions being of sufficient buoyancy to float in the hydraulic fluid with the ratio of the displacement of its unsubmerged portion to its submerged portion somewhat greater than the ratio of the sum of said operating and compression heads to the compression head.

36. A hydraulic compressor for an aeriform body comprising a hollow compression column having its upper end open to the source of said aeriform body, means for supplying a hydraulic fluid to the open end of the column at a rate

insufficient to fill the said end, means for introducing free buoyant partitions in succession into the open end of the column to momentarily arrest the supply of hydraulic fluid to the column and trap a slug of said aeriform body beneath each partition, said partitions and the trapped slugs being forced downwardly through the column by the force generated by the hydraulic fluid passing through the column, a closed chamber connected to the bottom of said column into which the partitions and slugs are forced by the fluid and in which the aeriform body separates and is compressed, means utilizing the buoyancies of said partitions to return them to the upper end of the column, and separate means for withdrawing hydraulic fluid and the said compressed aeriform body from the closed chamber.

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