Aug. 30, 1960 H. FEICHTINGER 2,950,856

GAS CONVEYING DEVICES

Filed Feb. 28, 1956 4 Sheets-Sheet 1

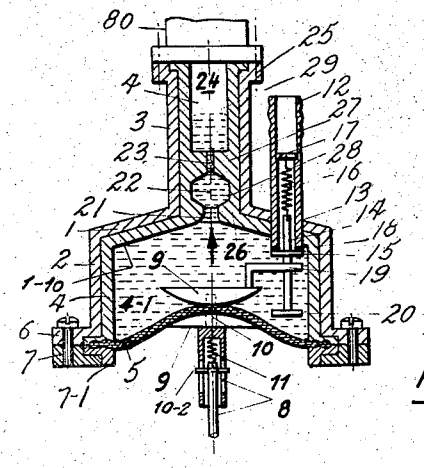


Fig. 1

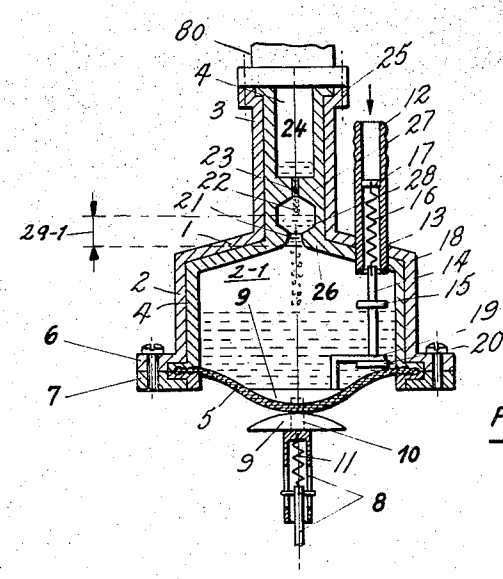


Fig. 1a

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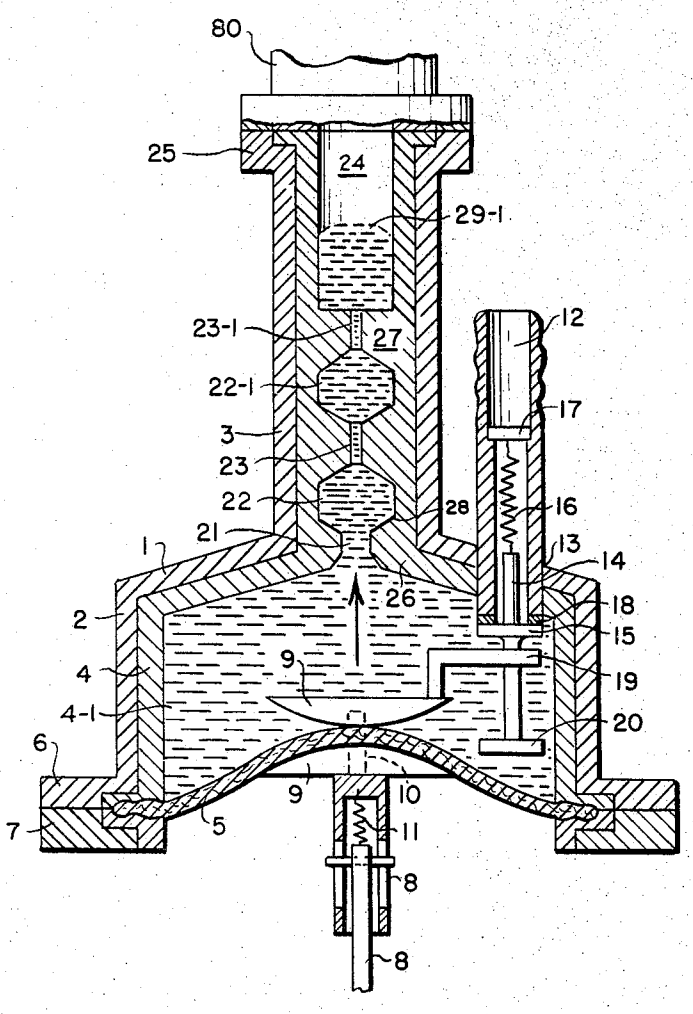


FIG. 1-b

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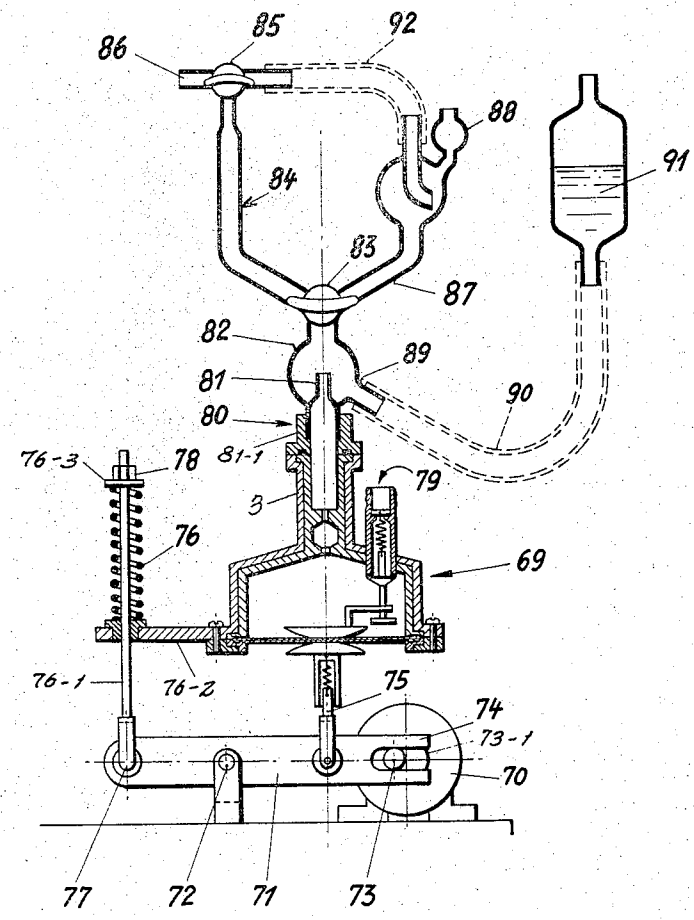
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GAS CONVEYING DEVICES

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Fig. 2



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GAS CONVEYING DEVICES

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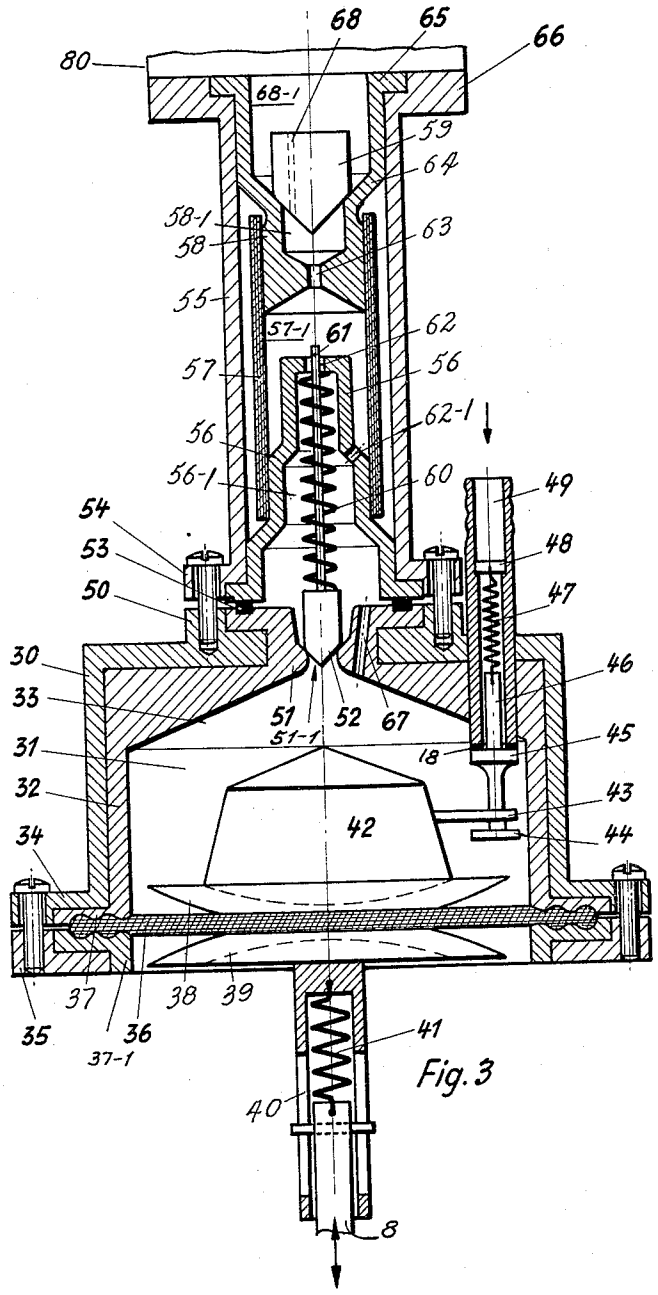


Fig. 3

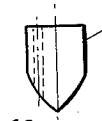


Fig. 4

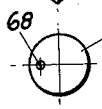


Fig. 4a

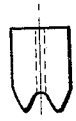


Fig. 5



Fig. 5a



Fig. 6



Fig. 6a

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2,950,856

GAS CONVEYING DEVICES

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Claims priority, application Switzerland Mar. 5, 1955

21 Claims. (Cl. 230—85)

This invention relates to gas conveying or pumping systems for conveying or pumping gases, and more particularly to such systems which make it possible to pump gases from a supply space to a receiving space without introducing impurities into the pumped gas and/or without material losses of the pumped gas.

Although it has various other applications, the devices of the invention are of particular importance in connection with the measurement and/or analysis of gases produced when melting metals or metal compositions under vacuum and the like. Heretofore known and/or used devices for pumping gases produced in such applications, are very cumbersome, operate very slowly, and have various other deficiencies.

Among the objects of the invention is a gas conveying or pumping system which assures that the gases which are to be removed, are fed or pumped at a high rate without loss of gas and without introducing into the gas any impurities, and which overcomes the various other deficiencies encountered with known and available gas-pumping devices heretofore used in such applications.

The foregoing and other objects of the invention will be best understood from the following description of exemplifications thereof, reference being had to the accompanying drawings, wherein:

Fig. 1 is a simplified cross-sectional diagrammatic view of one form of gas-pumping device exemplifying the invention, near the end of its discharge stroke;

Fig. 1–*a* is a view similar to Fig. 1, of the same device near the end of its suction stroke;

Fig. 1–*b* is a view identical with that of Fig. 1, except for an additional liquid retaining space in the gas-receiving duct structure;

Fig. 2 is a simplified diagrammatic view showing how a pump of the type described in connection with Fig. 1 is associated with the cooperating elements of a gas pump system of the invention;

Fig. 3 is a simplified cross-sectional diagrammatic view of one form of a more effective gas-pumping device exemplifying the invention, in an intermediate operating condition thereof;

Figs. 4 and 4–*a* are side and top views, respectively, of another form of movable valve member of a gas-pumping device of the invention; and

Figs. 5, 5–*a*, 6, and 6–*a*, are views similar to Figs. 4 and 4–*a*, of further modifications of movable valve members of devices of the invention.

A great many of various types of gas pumps have been proposed and used in the past. To be satisfactory for practical use, a gas pump should be simple in construction, and it should operate with a high suction velocity and reliability. In the case of vacuum pumps, they should be able to develop at their suction side a high end vacuum.

Where the gas pump is to serve as part of a gas measuring and analyzing system, it is also essential that the volume and the composition of the pumped gas shall not

be changed, that is, that contamination of the pumped gas volume by gas or vapor impurities be prevented.

The known mechanical pumps which operate against atmospheric pressure such as piston pumps, rotational oil pumps and rotational slider pumps, which proved satisfactory because of their high suction velocity and mechanical ruggedness, require lubrication media which also serve as packing media. Such lubrication media or oils, in addition to having a vapor pressure, also have the property of dissolving therein gases, and they also give up decomposition contents of the oil. As a result, pumps operating with such lubricating media are unsuitable for use in gas analyzing systems. As an example, in the case of a metal melting furnace operating under vacuum, where it is desired to analyze or measure the gases developed in the furance, the gas pump must maintain therein a certain vacuum. The vapor and dissolved gases given up by the lubricating medium of a vacuum pump limits the obtainable vacuum. Furthermore, there is also a limit to the degree of vacuum obtainable with such pumps, because they all have what is known as a "dead space," and the remnant gases retained therein at each discharge of the pump stroke are returned to the evacuated space in the subsequent suction stroke of the pump.

Heretofore, the gas pumps available for use in gas measuring and/or analyzing systems, have been very cumbersome and extremely slow in operation. In their simplest form, such pumps consist of a vertical tube, of glass for instance, with a ground inlet valve and a ground outlet valve, holding therein a column of mercury which is raised and lowered by raising and lowering a balancing column of mercury connected thereto for sucking in gas through the inlet valve in one stroke of the mercury column, and discharging the gas through the outlet valve in the opposite stroke of the mercury column. Because of the fragility of the glass column, care must be taken in raising and lowering the mercury. The ground glass valves require lubrication by lubricating media which introduce disturbing contamination into the measured and/or analyzed gas. Heretofore, these difficulties made it impossible to arrange for automatic operation of such pump.

Because of these difficulties, most gas and analyzing systems operate with mercury-drop pumps in which a continuous sequence of mercury drops which are falling within a capillary tube space, operate as pistons which advance the gas in the direction from the supply end toward the discharge end of the capillary tube. Although such mercury-drop pumps may be arranged for continuous automatic operation, they are limited by their extremely slow pumping action. Furthermore, because of the great length of their capillary glass tube, they are of excessive height and very fragile. Notwithstanding these deficiencies, they had to be used heretofore in systems for analyzing and/or measuring gases produced in vacuum melting furnaces and like applications.

Among the objects of the invention is a gas pump system, such as required for gas measuring and analyzing systems, although not limited thereto, wherein the gas pumping action is effected by periodic suction and discharge strokes of a liquid pumping body, and wherein the gas pumping action is carried on at a high rate under the elimination of the dead spaces; such pump system operating with a gas pumping action sufficient to produce a vacuum; such pump system which will produce a high end vacuum; and such pump system which will collect gases developed in melting or treating metals or other substances at high temperatures.

The heretofore available pumps required for measuring and/or analyzing gases developed by metal or other sub-

stances molten or treated at high temperatures in a vacuum furnace, had such small pumping speed that in themselves they could not provide sufficient pumping action for maintaining the space within the furnace under the required high vacuum. Furthermore, the mercury-drop pumps which had to be used in such gas measuring and analyzing systems, required an auxiliary vacuum pump for returning the drops of the mercury falling in the capillary tube back to the proper higher level. In most cases, rotary oil pumps had to be used for this purpose. These complications are avoided by the pump system of the invention, wherein a single pump serves both for maintaining the vacuum arc furnace under the required vacuum and for delivering all gases developed in the furnace space to the gas measuring and/or analyzing system.

Because of the deficiencies of the heretofore available gas-collecting pumps suitable for collecting gases from vacuum melting furnaces or the like, attempts have been made to measure and analyze the developed gases without such gas-collecting pumps. This, however, necessitated performing of the chemical analysis at the very low pressure at which a diffusion pump used for evacuating the vacuum melting furnace delivers the gas evacuated therefrom. Because of the low pressure of the gases, the gas analyzing system required elaborate apparatus including liquefied compressed air as cooling medium, whereas gas analysis under normal pressure may be carried on with established known chemical analytic methods. The identification and analysis of the gases under near-vacuum pressures is also rendered difficult because even the minutest leak may bring gas impurities into the analyzing apparatus and thereby lead to inaccurate measurement and/or analysis. Much greater time is also required for carrying on the gas analysis at such very low pressures. In contrast, the pumping system of the invention is able to measure and analyze the gases developed in vacuum metal-melting furnaces and like applications on a current basis, because it will deliver the developed gases to the analyzing apparatus at atmospheric or any other desired pressure. Furthermore, all developed gases are delivered without any loss of gas or entry of impurities, because all developed gases are advanced as gas bubbles passing through the pumping liquid of mercury contained in the pump system. Furthermore, the pump system of the invention may be combined into a unitary system with associated gas analyzing apparatus (not shown), such as described for instance, in the United States application Serial No. 529,735, filed August 22, 1955, now Patent No. 2,866,691.

The principles of the invention will now be described in connection with a simplified exemplification thereof, shown in two of its operating stages in Figs. 1 and 1–*a*, and also in Fig. 2.

It comprises a vacuum pump, generally designated 1 (Fig. 1), constituting a hollow gas or fluid guide or pump structure confining in its interior a fluid guide or pump space into which gas is pumped through inlet valve means of inlet duct 12 thereof and from which gas is discharged through outlet valve means of outlet duct 3. The hollow pump structure 1 shown, consists of an outer hollow metal backing structure or casing having a wider casing section 2 surrounding the relatively wide pump space 4–1 and from which gas is discharged into the narrower adjoining outlet duct 3. Although it may operate with other pumping liquids, the pump of the invention operates with a metallic pumping liquid consisting of mercury, and the interior surfaces of the pump structure 1 are formed of a material which is inert to or does not react with mercury, such as stainless steel. In practice, good results are obtained by making the interior surfaces of the pump structure 1 of a plastic or synthetic resin material which is gas-tight and also inert to and does not react with mercury and with the gases that are to be impelled through the space of the guide structure. Various plastic or synthetic resin materials may be used for this purpose. In practice, good results are obtained by making the interior wall surfaces of the pump structure which are in contact with the pumping liquid and with the pumped gases, of the known acrylic resins such as methyl methacrylate of the type known, for instance, under the trademarks "Lucite" and "Plexiglas," which are gas-tight and do not react or corrode when exposed to mercury or most of the pumped gases.

The hollow metallic pump structure 1 has an interior pump structure 1–10 of such synthetic resin material which is given such shape, as by molding in a conventional way, as to provide therein the wide, hollow pump space 4–1 connected through a constricted valve outlet opening or passage 21 to a wider retaining or outlet space 22 which is connected through another constricted outlet opening or passage 23 to a further wider retaining or outlet space 24 through which the pumped or impelled gases are delivered or discharged to a receiving duct 80 (Fig. 1) through which they are led to the gas measuring and analyzing apparatus (not shown). In practice, the synthetic-resin inner pump structure 1–10 may be molded in situ within the metallic exterior guide structure 1 so as to serve as an inert lining defining the pump and gas impelling spaces thereof.

The bottom wall of the pump space 4–1 is enclosed by pumping means consisting of a flexible pumping diaphragm 5 of suitable strong, flexible material such as synthetic resin or synthetic rubber such as neoprene, or both, or a combination of cemented or fused layers of synthetic rubber or synthetic resin, which may be reinforced by strong fabric such as nylon fabric, to provide a strong, flexible diaphragm capable of holding confined in the interior pump space 4–1 and of raising and lowering or moving therein a substantial quantity of liquid pumping metal such as mercury filling the same. The pumping diaphragm 5 has its periphery affixed and sealed in a gas-tight manner by clamping it between facing flanges of synthetic resin material 7–1, which are held clamped to each other by overlying metallic clamping flanges 6 of the metallic pump housing 2 and the cooperating metallic clamping flange 7 which are suitably secured to each other, as by screw bolts.

The central region of the flexible pumping diaphragm 5 has imparted thereto reciprocating stroke movements between a discharge end position indicated in Fig. 1, and an opposite suction end position indicated in Fig. 1–*a*. To this end, a reciprocating drive rod 8 is shown connected to the central portion of the flexible pumping diaphragm 5 by two inwardly curved guide plates 9 held affixed in clinging engagement aginst the opposite sides of the diaphragm, as by a screw. The desired reciprocating motion may be imparted to the rod 8 in any known manner. For instance, as indicated in Fig. 2, the reciprocating movement may be imparted to the drive rod 8 by a pivotal connection of its lower end to a swinging lever 71 pivotally mounted on a suitable pivot support 72, and a forked portion 74 engaging an eccentric pin 73 of a drive disc suitably rotated, as by a conventional drive motor 70.

The interior pump space 4–1 of the pump structure 1 contains or is filled with a body of pumping liquid, such as mercury, which performs a piston-like pumping action when it is subjected to a reciprocatory movement by the flexible pump diaphragm 5 when it is driven by the drive rod 8. The upper end of the drive rod 8 is connected to its coupling connector 10 through energy-storing, stroke-damping differential movement means, shown in the form of a spring 11, to permit the flexible diaphragm to perform its opposite pumping strokes at varying rates of motion, although the drive rod 8 is driven by a motor which rotates at a relatively uniform speed. A suitable stop shown as a pin-slot engagement 10–2, serves to limit the differential movement between the drive rod 8 and the coupling connector 10.

The supply duct 12 is shown formed of a synthetic resin material such as used for the inner pump liner 1–10, and is tightly affixed within an opening 13 of the housing walls 1, as by a suitable gas-tight cement connection. The inner open end of the supply duct 12 serves as an inlet valve opening 18 having a valve seat against which is seated a movable inlet valve member 15 arranged to be suitably guided, as by a guide rod 14, between an open and closed position to which it is suitably biased, as by a spring 16. The inlet valve member 15 remains at all times in its closed position shown in Fig. 1, except for a short period, during the end portion of the suction stroke shown in Fig. 1–*a*, when lifting arm 19 of diaphragm guide plate 9 comes into engagement with a strike portion 20 of valve rod 14 for opening the inlet valve member 15. As soon as the flexible pump diaphragm starts returning from its suction stroke end position shown in Fig. 1–*a*, the inlet valve member 15 is released and returns to its closed position shown in Fig. 1, in which it remains until near the end portion of the next suction stroke of the flexible pump diaphragm 5. The valve member 15 and its valve rod 14 may likewise be formed of synthetic resin material of the type used for the gas guide liner 1–10.

The upper surface of the pump space 4–1 tapers conically upward towards its relatively constricted valve opening or passage 31, which is designed to operate as an outlet valve although it does not have any movable valve elements. The wider outlet retaining compartment 22 is similarly connected through a relatively constricted valve outlet opening or passage 23 either to another similar wider retaining compartment or space 22–1 shown in Fig. 1–*b*, or directly to the gas discharge space 24 from which the gas is delivered to the receiving duct or guide structure 80 (Fig. 1) of the gas measuring and/or analyzing system. The additional valve outlet opening or passage 23 likewise is designed to operate without a movable valve member.

The interior pump spaces of the pump structure 1 are filled with sufficient pumping liquid such as liquid mercury so that when the flexible pump diaphragm 5 is near the end of its discharge stroke, shown in Fig. 1, the pump space 4–1 and each of the wider retaining or pumping spaces 22, if two or more such retaining or pumping spaces 22 are provided, and also all other spaces of the gas discharge space 24, are filled with mercury up to the level line 29 indicating, as an example, the upper level reached by the discharged mercury within the gas discharge space 24 when the flexible pump diaphragm 5 is at the end of its discharge stroke. In some applications the mercury content of the pump system may be made large enough so that part or all of the interior space of the guide duct 80 for the gases extending to the gas measuring or gas analyzing apparatus, is filled with mercury when the flexible pump diaphragm 5 is near the end of its discharge pump stroke shown in Fig. 1.

There will now be described an example of the operation of the pump system of the invention shown in Figs. 1 and 1–*a*. It is assumed that the system is in the position shown in Fig. 1, wherein the mercury of the pump structure has been discharged by the discharge pump stroke to the uppermost level such as indicated at 29 in Fig. 1. After reaching in the discharge stroke of the reciprocating guide rod 8 the position shown in Fig. 1, the flexible pump diaphragm 5 is moved in reverse suction direction by corresponding movement of the drive rod 8. The cross-section and flow resistance of the valve outlet opening 21 is made sufficiently small and is so proportioned that the mercury filling the wider retaining space 22 above it, cannot flow fast enough into the wider pump space 4–1 and follow the lowered upper level of the volume of mercury filling the wider main pump space 4–1. As a result, there is formed in the wider pump space 4–1 a vacuum extending above the lowered upper level of the mercury volume thereof as it is brought away from valve opening 21 by the continuation of the suction stroke of the diaphragm 5 to its suction end position of Fig. 1–*a*. Although some of the mercury from the upper retaining space 22 will be drawn into the vacuum space of the main pump space 4–1, the small cross-section of the valve opening 21 and its flow resistance are so chosen as to present such impedance against the return of mercury, that it will assure that sufficient vacuum space is left in the wider pump space 4–1 when the flexible diaphragm 5 is near the end of its suction stroke, Fig. 1–*a*.

At the moment when the flexible pump diaphragm 5 reaches its downward suction end position (Fig. 1–*a*), and has thereby created a vacuum space above the mercury filling its wide pump space 4–1, the inlet valve member 15 is opened by the lifting member 19 of the diaphragm 5, thereby causing gas from the inlet duct 12 to flow through valve inlet opening into the vacuum of pump space 4–1. Thereupon the flexible diaphragm 5 is returned with an opposite discharge stroke from the position of Fig. 1–*a* to the position of Fig. 1. After releasing the inlet valve member 15 to its closed position of Fig. 1 in the initial part of its discharge movement from the end position of Fig. 1–*a*, the flexible diaphragm 5 raises the level of the mercury volume in the wide pump space 4–1 and compresses the gas enclosed therein until it is sufficient to overcome the pressure of the mercury column filling the outlet valve opening or passage 21 and cause the compressed gas bubble to rise upwardly therethrough and through the mercury filling the higher-level retaining or pump space 22 of the upwardly extending gas guide structure 3, until at the end of the discharge stroke the mercury fills all spaces of the discharge duct 3 up to the original discharge level, such as level 29 indicated in Fig. 1.

The outlet valve opening or passage 21 of the wide pump space 4–1 and the valve opening or passage 23 of the wider retaining or pumping space 22 are given sufficiently small cross-sectional areas and sufficient length and flow resistance as to assure that some of the mercury returning from an upper level will remain in and block the respective valve openings 21, 23, at least during the entire length of the suction stroke of the pump; and that the rate of the return flow of mercury through the outlet valve openings 21, 23 is sufficiently small to assure that the wider pump space 4–1 will retain therein enough unobstructed vacuum space for entry therein of gas from the inlet duct 12 when the inlet valve 15 is open near the end of the suction stroke shown in Fig. 1–*a*.

Although during the initial part of the discharge pump stroke, the rising level of the mercury in the wider pump space will not encounter any material resistance, an enormous shock-like rise of flow resistance is encountered the moment the entire pump space 4–1 adjoining the valve outlet opening 21 is filled with mercury and the mercury with the gas compressed therein is being forced upwardly through the constricted outlet valve opening 21. As a result, the mercury filling exerts a shock-like braking action on the movement of the diaphragm drive rod 8 and its associated motor drive. In order to compensate for this shock-like braking action, the drive rod 8 is connected to the diaphragm by the energy-storing, damping drive connection, including energy-storing means such as spring 11 described above, making it possible for the drive rod to perform its full discharge stroke (Fig. 2) while storing energy in the storing means such as spring 11 of the coupling connector 10, the so-stored energy providing the forces which cause the flexible pump diaphragm 5 to be brought at a slower rate to the end of its discharge stroke shown in Fig. 1.

For the proper operation of a pump system of the type described above, it is sufficient to provide it with a single pump space and a single associated discharge outlet valve such as formed by pump space 4–1 and its

outlet valve 21. By providing a pump system of the invention with two or more pump spaces and associated discharge outlet valves, there is obtained a two-stage or multiple-stage pump action which will now be explained for the case of a two-stage pump action.

Referring to Figs. 1 and 1–*a*, which show a two-stage pump of the invention, the flow resistance of the two valve outlet openings or passages 21, 23 is so proportioned that in the downward suction stroke of the pump, an evacuated space will be created not only in the main pump space 4–1, but also in the farther second pump space 22, as indicated by the mercury level line 29–1 in Fig. 1–*a*, corresponding to the condition at the end of the suction stroke (which is in downward direction, as seen in the drawings). In the immediately succeeding opposite upward pump discharge stroke, the flexible diaphragm does not have to overcome the pressure of the entire column of mercury extending above the valve openings 21, 23 in order to expel from the main pump space 4–1 the gas compressed therein. For this purpose, the upwardly moving pump diaphragm will have to develop only sufficient compression forces as to cause the compressed gas to overcome only the much smaller weight of the shorter mercury column having the upper level 29–1 of the mercury level in the next pump space 22 (Fig. 1–*a*). In the subsequent part of the discharge pump stroke—after the wider, higher-level pump space 22 is filled with mercury—the further movement of the pump diaphragm 5 has to provide only the further compression required to overcome the mercury column extending above the next valve opening 23, whereupon the compressed gas bubble is discharged and rises through the mercury column in the still farther discharge space 24.

A serially arranged multi-stage pump system of the invention, exemplified by the two-stage pump system just described, has also the advantage that any vapors present in the pumped gases are already condensed in the first compression action in the main pump space 4–1 of the pump system. As an example, if water vapor is present in the pumped gas, it would be compressed and form water drops on the walls of the main pump space 4–1. With a pump operating only with a single pump space, the water drops would again evaporate in the next succeeding suction stroke, thereby limiting the minimum end vacuum which can be produced by the pump system. However, with a two-stage pump system of the invention the accumulation of condensed vapor in the main wider pump space 4–1 is avoided, because the subsequent discharge strokes will bring the condensed water drops into the second wider mercury-retaining pump space 22 wherein the accumulation of vapor condensates has no disturbing effect on the vacuum that is to be created in the space from which the gas is pumped and which is opened only into the main pump space 4–1.

As explained, the gas discharge duct 3 may be provided with more than one wider liquid-retaining pumping space like that shown in Fig. 1–*b* where wider space 22–1 is arrayed above space 22 and those spaces connected to each other by valve opening or passage 23. Wider space 22–1 is connected to discharge space 24 through valve opening or passage 23–1. Thus, the arrangement shown in Figure 1–*b* accomplishes a multi-stage pump action with three pump stages operating in a manner analogous to that described above. The other reference numerals in Fig. 1–*b* are the same and refer to the same members as shown in Fig. 1. Further wider spaces (not shown) in addition to spaces 22 and 22–1 in Fig. 1–*b* may be provided if desired. With any such multi-stage pump arrangement, the mercury and the compressed gas and any vapors contained therein, are discharged by the pumping action of the mercury filling which is forced and discharged through all the serially arrayed pumping spaces and the discharge space following the last pumping space. The cross-section and the flow resistance of the valve openings to each of the series of additional wider pump spaces 22 are so proportioned that, in the return suction stroke of the pump, the returning mercury flowing back through each of the successive valve openings flows slower in each farther-away valve opening than in the valve opening that is nearer to the diaphagm, and so that mercury is retained in each of the valve openings throughout at least the entire duration of each suction stroke.

Fig. 2 shows how a pump of the invention, for instance a pump of the type described in connection with Figs. 1 and 1–*a*, is combined with other elements of a gas pumping system of the invention. In such pump systems, the suction stroke of the flexible diaphragm 5 requires a greater force than the rising discharge stroke. Suitable energy-storing means are combined with the pump drive so as to provide for the required difference in the driving forces of the suction and discharge strokes, while utilizing a motor drive, such as an electric motor, operating with substantially constant driving force.

In the form shown, the energy-storing means consists of a coiled spring 76 encircling a force-transmitting rod 76–1 through which the spring is connected to an extension of the pivotal lever 71 by means of which the rotary movement of the drive motor 70 is transformed into the reciprocatory movement of the pump drive rod 8. One end of the coiled spring 76 is suitably anchored, as by an inchor support, to one end of rod 76–1 having its other end pivotally connected at 77 to the pivot lever 71. The spring 76 is placed under sufficient initial biasing compression and has sufficient spring volume to store therein the excess driving force required for imparting through the pivot lever 71 the larger diaphragm-driving suction forces while operating with a drive motor 70 supplying substantially constant driving power. Two similar vacuum pumps such as shown in Fig. 2, may be operated in unison with a single drive, such as a single swinging lever 71 of a mechanism of the type shown in Fig. 2, the two pumps operating with complementary cycles so that when one pump performs a suction cycle, the other pump performs a discharge cycle, and vice versa.

Referring to Fig. 2, the suction side of the pump is suitably connected through inlet duct 79 to the space from which the gas is to be pumped, such as the interior of a furnace in which metal or other substances are molten or treated under vacuum and from which all gases have to be pumped to maintain therein the required vacuum during continuous prolonged metal melting or treating operations. The discharge duct 3 of the pump 69 is connected to the gas measuring and analyzing system (not shown), by gas-conveying duct elements 80 which will now be described. In the form shown, a glass duct 81 which leads into a glass or manifold vessel 82 is connected to the gas discharge duct 3 of the pump as by a metal coupling sleeve 81–1 having a flange which is suitably clamped, as by bolts, in a gas-tight manner, to the facing flange of the gas discharge duct 3. The glass vessel 82 is connected through a three-way cock or valve 83 to a gas duct 84 which in turn is connected through a three-way cock or valve 85 to a gas duct 86 leading to the gas analyzing apparatus.

To facilitate the evacuation of all spaces, such as the vacuum melting furnace and all spaces through which gas pumped from the furnace is guided and delivered to the gas analyzing apparatus, it is desirable to discharge the initially pumped-out gases, not to the gas analyzing apparatus, but into other spaces such as the surrounding atmosphere. To this end, the arrangement of Fig. 2 has a by-pass discharge duct 87 which may be connected to the gas discharge duct 80 through a three-way valve 83 so as to seal off the duct 84 and provide for flow of pumped gas into the gas duct 87, from which the gas is discharged through the discharge outlet 88. For such initial evacuating procedure, an auxiliary mercury holding vessel 91 is connected, as through a flexible hose 90, to a junction

nipple 89 of the manifold vessel 84 of the gas discharge system 80. Sufficient mercury is provided in the gas discharge system 80 so that by raising the vessel 91—when valve 83 connects manifold vessel 82 to gas duct 84 and valve 85 connects duct 84 to axiliary duct 92, shown as a flexible hose—the spaces 82 and 84 will be filled with mercury, and overflowing mercury will be returned by hose 92 into outlet duct 87. On subsequently lowering the level of the mercury vessel 91 while valve 85 is closed, the mercury filling duct 84 will flow out therefrom and create in the duct space behind it, a Torricelli vacuum into which the gases delivered by the pump 69 will be discharged. The outlet tubing 81 in manifold vessel 82 is arranged to prevent gas bubbles delivered by the gas pump 69 from flowing through hose 90 into the surrounding atmosphere.

Although gas and/or vacuum pumps of the invention, of the type described in connection with Figs. 1 and 1–*a*, which have discharge or outlet valves that operate without movable valve members, are very effective, a much greater and more rapid gas pumping capacity and action is secured if the discharge valves of pumps of the invention are designed for operation with movable valve members which close the outlet or discharge valves during the suction stroke and open them during the opposite discharge stroke.

Fig. 3 shows diagrammatically, by way of exemplification, a high-capacity gas or vacuum pump of the invention having outlet or discharge valves operating with movable valve-closing members. It comprises an outer metallic pump housing 30 surrounding a main pump space 31, lined with an inner layer or wall 32 of synthetic resin material, such as methyl methacrylate or the like, which is gas-tight and non-reacting with the pumping liquid such as mercury and gases pumped therethrough. The upper wall of the pump space lining 32 has an upwardly tapering conical wall 33 leading to the valve outlet or discharge opening having a valve seat 51. Between a lower flange 34 of the metallic pump housing 30 and a cooperating metallic clamping flange 35 secured thereto, and corresponding flange linings of synthetic resin material, is held tightly clamped the outer periphery of a flexible movable pump diaphragm 36 arranged to be moved with its large surface in a suction stroke direction and an opposite discharge stroke direction, as in the pump of Figs. 1 and 2. The synthetic resin flanges 37 and 37–1 between which the periphery of the diaphragm 36 is clamped, are readily retained in a clamped sealing position in which they form a gas-tight joint enclosure for the interior pumping space 31 of the pump. The flexible diaphragm 36 is made of suitable strong, flexible material such as synthetic resin or synthetic rubber material, for instance, in the form of superposed fused or cemented layers, with or without reinforcing fabric layers of strong material, such as nylon, embedded or combined with the synthetic resin or synthetic rubber thereof.

The flexible diaphragm 36 is guided in its up and down movement by the two facing outwardly-curved guide plates 38, 39 held clamped in clinging engagement against the opposite sides of the central region of the diaphragm 36. The upper guide plate has a displacing member occupying a substantial part of the volume of the pump space 31, to reduce the volume of pumping liquid such as mercury which has to be moved by the diaphragm 36 for performing the pumping action. The lower guide plate 39 of the flexible pumping diaphragm 36 is connected through a coupling member 40 including an energy-storing connection 41 to a reciprocating drive rod 8 for imparting to the flexible diaphragm 36 and the contents of the pump space 31 a periodic succession of alternating opposite suction strokes and discharge strokes of the pumping action similar to that described in connection with Figs. 1 and 1–*a*. A gas supply duct 49, which is suitably connected to the space which is to be evacuated or from which gas is to be pumped, has its inner end seated in the walls 30, 32 of the pump housing and suitably sealed therein in a gas-tight manner, as by cement, for pumping gas through the lower valve inlet opening 18 into the wide pump space 31. A movable inlet valve member 45 having a valve drive rod 46 is biased as by a spring 47 to a closed position in which it closes the inlet valve opening 18. The movable valve inlet member is opened only for a short time at the end portion of the suction pump stroke by engagement of a lug projection thereof with a strike arm 43 carried by the displacing member 42 of the inner diaphragm plate 38.

To the upper flange 50 of the metallic pump housing 30 is suitably detachably secured, as by bolts, a metallic duct 55 arranged to house in its interior an additional pump housing member and associated duct and valve members such as members 56, 57, 58 and 59, which are all formed of suitable inert synthetic resin or other material such as used for lining walls 32. The hollow synthetic resin member 56 forms a second pump housing surrounding a pump space 56–1 extending above the outlet relatively constricted valve outlet opening 51 of the main pump space 31. The second pump housing 56 has at its lower end a flange which is secured in a gas-tight manner to the facing flange of the synthetic-resin outlet-valve seat member 51, a packing ring of suitable packing material, such as inert synthetic rubber, is held compressed in an annular packing groove of the facing flanges, assuring a gas-tight joint between them. The second pump housing 56 has an outer part of reduced width which serves to guide the guide rod 61 of a movable outlet valve member 52 held seated in its closed position against the outlet valve seat member 51 by biasing means, such as a coil spring 60 encircling the valve guide rod 61.

In the upper part of the metallic duct 55 is held a discharge housing member 58 of similar inert synthetic resin material surrounding a relatively wide discharge space 68–1 and having a downwardly tapering valve seat against which is seated a movable valve member 59. The valve seat opening of housing member 58 against which the movable valve member is seated, opens into a pump space 58–1 which is connected through a relatively constricted valve opening 63 to the wider pump space 57–1 of a tubular duct member 57. The tubular duct member 57 is tightly joined, as by cement or elastic pressure, to the surfaces of the pump housing member 58 and pump housing member 56 around which it is clamped. The tubular duct member 57 is formed of elastic material, for instance, of superposed layers of inert synthetic rubber fused to each other, with or without interposed layers of reinforcing fabric, such as nylon, embedded or fused therebetween, and its operation will be explained more fully hereinafter.

In the pump arrangement of Fig. 3, the wall portions which form valve opening partitions between the several successively arrayed wider pump spaces 31, 56–1, 57–1, 68–1, are provided with constricted leakage openings or passages, namely leakage opening 67 in the valve seat member 51, and leakage opening 68 in valve member 59. The significance of these leakage openings 67, 68 will be explained hereinafter in connection with the operation of the pump.

The pump of Fig. 3 operates in a manner similar to that described in connection with Figs. 1 to 2. When the flexible pump diaphragm 36 is at the end of its discharge stroke, in upward direction of Fig. 3, all interior spaces of the pump including main pump space 31, and the pump spaces 56–1, 57–1, 58–1, are all filled with the mercury (or other suitable pumping liquid). In the immediately following opposite suction movement of the flexible diaphragm 36, the accompanying lowering of the upper level of the mercury volume in the wide main pump space 31, creates therein a vacuum. Although the leakage opening 67 in the valve seat 51 permits mercury to leak back from the farther pump space 56–1 into

the wide main pump space 31, the flow resistance of leakage passage 67 is designed to be sufficiently large to maintain the return leakage flow of mercury therethrough at such low rate as to prevent the mercury from filling up the vacuum space created in the wider pump space 31 and to maintain mercury in the leakage passage 67 throughout at least the entire duration of the suction stroke. The lowering of the mercury level in the wide pump space 31 caused by the return suction movement of the diaphragm 36, also creates a small vacuum space in the spaces 56–1, 57–1, 58–1, extending between valve member 52 and valve member 59, since the flow resistance of the leakage passage 67 of valve seat 51 and leakage passage 68 of upper valve member 59 are so proportioned that the mercury leaks through the leakage passage 67 of the nearer valve 52 at a higher rate than through the leakage passage 68 of the farther valve 59. On the other hand, the housing wall passages 62 and 62–1 in the housing member 56, are sufficiently large so that they do not offer material flow resistance to mercury returning therethrough to a nearer or lower level of the pump spaces into which the released mercury tends to return, their functions being described hereinafter.

When the diaphragm 36 reaches the end portion of its suction stroke (corresponding to Fig. 1–*a* of the pump of Figs. 1–2), its strike arm 43 opens for a short time the inlet valve 45 of the gas inlet duct 49, causing the vacuum in the pump space 31 to suck in gas from the spaces which are to be evacuated through the inlet duct 49. In the initial period of the immediately succeeding opposite outward discharge stroke of the diaphragm, the inlet valve 45 is released to its closed position. As a result, the gas entrapped in the main pump space 31 is compressed in the conical upper space portion thereof and expelled by the rising level of the mercury volume through the valve outlet opening 51 as the outlet valve 52 is lifted from its seat 51 by the upwardly forced mercury volume. The pressure at which outlet valve 52 opens for releasing the compressed gas and mercury into the upper pump space 56–1, is determined by the sum of the biasing forces of the spring 60 and the weight of the mercury column present in the spaces 56–1, 57–1, and 58–1 between the two valves 52 and 59 at the instant when valve 52 is opened, and any vapor pressure in these spaces. The continued upward discharge stroke of the flexible diaphragm 36 forces its mercury filling together with the compressed gas held therein to flow from the main pump space 31 into the pump space 56–1 extending beyond valve opening 51. As the mercury is thus forced into the pump space 56–1, and also into farther pump spaces 57–1 and 58–1, the upwardly forced mercury causes the gases which have been expelled into and accumulated in the farther pump space 58–1 to be compressed until upper valve member 59 is raised and the gases are expelled into the upper wider space 68–1 together with the mercury which is forced into it at the end of the upward discharge stroke of the diaphragm 36.

The pump system contains in most cases sufficient mercury so that the entire space 68–1 of the upper pump housing 64 is filled with mercury when the diaphragm 36 is near the upper end of its upward discharge stroke. However, as explained in connection with Figs. 1 and 2, the interior space of the adjoining discharge duct 80 may likewise be filled with mercury so as to contain mercury near the end of the upward diaphragm stroke, and additional pump chambers and associated valves of the type described in connection with pump chamber 68–1 and valve 59, may be provided in the interior of the upper discharge duct 80, for securing multi-stage pump action with more than two pump stages.

Pumps of the invention operating with movable valve closing members such as movable members 52, 59, described in connection with Fig. 3, are superior to pumps operating without movable valve closing members such as described in connection with Figs. 1 and 1–*a*, because pumps with movable valve members make it possible to discharge the evacuated gases at a higher speed from the pumping space and thus provide a greatly increased rate of the reciprocatory diaphragm pumping pulses and a correspondingly greater pump capacity. Notwithstanding the provision of movable valve members for closing and opening the discharge valves through which the mercury or pumping liquid and the compressed evacuated gases are discharged in each discharge stroke of the pump, all the advantages of the pump operating without such moving valve members are secured, and dead pumping spaces are avoided. This is achieved by providing each discharge valve having a valve closing member with a leakage or returning opening or passage, such as leakage passages 67, 68, through which mercury which is forcibly discharged throughout all pumping spaces in each discharge stroke, is permitted to leak back toward the first or main pumping space, such as 31, while keeping these leakage passages filled with mercury at least throughout the duration of the suction stroke in which the mercury returns into all pump spaces, and assuring that, in the discharge stroke, the mercury fills all pump spaces, thereby eliminating all dead pumping spaces. Without the provision of such return leakage passages, a pump of the type described above would cause the mercury or other pumping liquid to gradually accumulate in successively farther outward spaces of the pump system until the mercury volume which is subjected by the pump diaphragm to the reciprocating pumping pulses, would be insufficient for filling all pump spaces during the discharge stroke, resulting in creation of objectionable dead spaces which would retain some of the gas which is to be removed or evacuated.

With a pump of the type described in connection with Fig. 3, wherein the movable discharge valve member opens a relatively wide discharge opening at each discharge stroke of the pumping diaphragm, there is obtained an additional damping action of the pumping stroke of the mercury or other pumping liquid, thus reducing or removing the need for providing yieldable elastic damping action in the drive connection to the diaphragm. This is achieved by providing the space 57–1 surrounded by the elastically yieldable duct 57 with a restricted discharge opening of properly chosen flow impedance as to cause the walls of duct 57 to yield with an elastic damping action, at the moment when the impact-driven discharged mercury filling the pump space 57–1 reaches the constricted opening or passage 63 which impedes passage of the pumping liquid. The constricted outlet opening or passage 63 is given a cross-sectional area and flow impedance as to impede, brake and absorb kinetic energy of the pumping liquid which is being driven with the discharge impact stroke into the space 57–1 of the yieldable duct 57 and beyond it into discharge space 68–1, to provide the desired damping action. This damping action may also be controlled by the choice of the material and proportions of the yieldable duct 57.

The pump housing 56 of synthetic resin material may be constructed with an outward extension which lines and backs up and supports the metal duct 55 of the pump system so as to prevent its inward deformation by the large outward forces when in the suction stroke, vacuum is created in the interior space thereof.

The return leakage passages, such as exemplified by passages 67, 68, associated with the outlet or discharge valves, may be combined with the outlet valves in a variety of ways. As explained in connection with Figs. 1, 1–*a*, the outlet valve openings may be by themselves given such shape and flow properties as to provide for the required leakage return flow of the outwardly discharged mercury. Alternatively, an outlet valve operating with a movable valve member, such as described in connection with Fig. 3, may be provided with a return leakage passage formed in the valve seat portion of the

valve, such as return leakage opening 67 of valve seat 51; or there may be provided a distinct return leakage duct which forms a permanent return flow leakage path parallel to the path of the pumping liquid discharge passage through the outlet valve. Figs. 4 through 6–*a* show by way of example, different ways for combining a movable outlet valve member with a return leakage passage, in accordance with the invention. In Figs. 4 and 4–*a*, the movable valve member 59 has a return leakage passage in a side region thereof. In Figs. 5 and 5–*a*, a similar movable valve member has a return leakage passage in the central region thereof. In Figs. 6 and 6–*a*, a similar movable valve member has a return leakage passage formed by a recess along the periphery thereof.

Large-capacity pumps of the invention of the type described above in connection with Fig. 3, may be readily combined with the associated elements of a gas analyzing and measuring system of the type described in connection with Fig. 2, for instance, by replacing in Fig. 2, the pump 69 by the pump of Fig. 3.

The features and principles underlying the invention described above in connection with specific exemplifications, will suggest to those skilled in the art many other modifications thereof. It is accordingly desired that the appended claims be construed broadly and that they shall not be limited to the specific details shown and described in connection with exemplifications thereof.

I claim:

1. In a gas-conveying and pumping system for conveying gas from a gas source to a discharge space, a guide structure confining a fluid guide space having a gas inlet for receiving gas from said gas source and a gas outlet for discharging received gas in a flow direction toward siad discharge space, said guide structure having a valve inlet opening and a valve outlet opening and a pump space between said valve openings for pumping gas from said source and impelling it in said flow direction, said pump space having a relatively larger fluid-holding space than said valve inlet opening and than said valve outlet opening, a pumping liquid in said pump space, pumping means for imparting to said liquid a succession of opposite suction and discharge strokes causing pumping of gas from said gas source into said pump space during said suction stroke and pumping of gas from said pump space through said valve outlet opening in said flow direction during the discharge stroke, said guide structure confining at least one retaining space arranged to receive fluid pumped from said pump space in said flow direction, said retaining space having a relatively larger fluid-holding space than said valve outlet opening, said guide structure also confining a leakage space connecting said retaining space to said pump space and causing liquid contained in said retaining space to leak back in a direction reverse to said flow direction towards said pump space during at least each suction stroke, said leakage space being of such dimensions and having such high flow resistance and said retaining space and said pumping space each containing such volume of said liquid as to cause said leakage space to contain said liquid and block return of gas in said reverse direction from said retaining space towards said pump space throughout said suction stroke and to prevent said pump space from being completely filled by said liquid at the end of said suction stroke.

2. In a gas-conveying and pumping system for conveying gas from a gas source to a discharge space, a guide structure confining a fluid guide space having a gas inlet for receiving gas from said gas source and a gas outlet for discharging received gas in a flow direction toward said discharge space, said guide structure having a valve inlet opening and a valve outlet opening and a main pump space between said valve openings for pumping gas from said source and impelling it in said flow direction, said main pump space having a relatively larger fluid-holding space than said valve inlet opening and than said valve outlet opening, a pumping liquid in said pump space, pumping means for imparting to said liquid a succession of opposite suction and discharge strokes causing pumping of gas from said gas source into said pump space during said suction stroke and pumping of gas from said pump space through said valve outlet opening in said flow direction during the discharge stroke, said guide structure confining at least one additional pump space arranged to receive fluid pumped from said main pump space in said flow direction and to cause liquid contained therein to be actuated by said pumping means to perform said opposite strokes and pump gas in said flow direction, said additional pump space having a relatively larger fluid-holding space than said valve outlet opening, said guide structure also confining at least one retaining space arranged to receive fluid pumped from said additional pump space in said flow direction, said additional pump space having an additional valve outlet opening arranged to discharge fluid from said additional pump space into said retaining space, said additional valve outlet opening having a relatively smaller fluid-holding space than said additional pump space, said retaining space having a relatively larger fluid-holding space than said additional valve outlet opening, said guide structure also confining one leakage space connecting said additional pump space to said main pump space and an additional leakage space connecting said retaining space to said additional pump space causing liquid contained in said additional pump space and in said retaining space to leak back through said respective leakage spaces in a direction reverse to said flow direction into said pump spaces, respectively, during at least each suction stroke, each of said leakage passages being of such dimensions and having such high flow resistance and said retaining space and each of said pump spaces containing such volume of said liquid as to cause each of said leakage spaces to contain said liquid and block return of gas therethrough in said reverse direction into the respective pumping spaces throughout each of said suction strokes and to prevent said main pump space from being completely filled by said liquid at the end of each suction stroke.

3. In a gas-conveying and pumping system for conveying gas from a gas source to a discharge space, a guide structure confining a fluid guide space having a gas inlet for receiving gas from said gas source and a gas outlet for discharging received gas in a flow direction toward said discharge space, said guide structure having a valve inlet opening and a valve outlet opening and a main pump space between said valve openings for pumping gas from said source and impelling it in said flow direction, said main pump space having a relatively larger fluid-holding space than said valve inlet opening and than said valve outlet opening, a pumping liquid in said pump space, pumping means for imparting to said liquid a succession of opposite suction and discharge strokes causing pumping of gas from said gas source into said pump space during said suction stroke and pumping of gas from said pump space through said valve outlet opening in said flow direction during the discharge stroke, said guide structure confining at least two successively arranged additional pump spaces arranged to successively receive fluid pumped from said main pump space in said flow direction and to cause liquid contained in each of said additional pump spaces to be actuated by said pumping means to perform said opposite strokes and pump gas in said flow direction, said guide structure also confining at least one retaining space arranged to receive fluid pumped from the last of said additional pump spaces in said flow direction, each of said additional pump spaces being connected to the next successive additional pump space through a respective additional valve outlet opening, and the last of said additional pump spaces being connected through a further valve outlet opening to said retaining space for successively passing pumped fluid

through each of said pump spaces in said flow direction toward said retaining space, each of said additional pump spaces having a relatively larger fluid-holding space than the valve outlet opening through which it receives pumped fluid from a preceding pump space, said further valve outlet opening having a relatively smaller fluid-holding space than the pump space from which fluid passes into said retaining space, said guide structure also confining one leakage space connecting the first of said additional pump spaces to said main pump space, and also additional leakage spaces for connecting each of the next successive of said additional pump spaces through one respective leakage space to the preceding additional pump space, and said retaining space to the last of said additional pump spaces, and causing liquid from each of said additional pump spaces to leak back in a direction reverse to said flow direction through the associated leakage space to the preceding pump space and to cause liquid from said retaining space to leak back in said reverse direction through the associated leakage space to the last of said additional pump spaces, each of said leakage spaces being of such dimensions and having such high flow resistance and said retaining space and each of said pumping spaces containing such volume of said liquid as to cause each of said leakage spaces to contain said liquid and to block return of gas therethrough in said reverse direction into the respective pumping spaces throughout each of said suction strokes and to prevent said main pump space from being completely filled by said liquid at the end of each suction stroke.

4. In a gas-conveying and pumping system as claimed in claim 1, said pumping means including a flexible diaphragm movable with a reciprocating motion and having at least a portion exposed to said pump space for periodically moving said liquid.

5. In a gas-conveying and pumping system as claimed in claim 3, each of said valve outlet openings having a movable valve member operative to close its respective outlet opening during at least a portion of the suction stroke.

6. In a gas-conveying and pumping system as claimed in claim 1, a movable valve member at said valve outlet opening operative to close said outlet opening during at least a portion of the suction stroke.

7. In a gas-conveying and pumping system as claimed in claim 6, said guide structure having said leakage space in a wall portion thereof other than said valve member.

8. In a gas-conveying and pumping system as claimed in claim 1, a movable valve member at said valve outlet opening operative to close said outlet opening during at least a portion of the suction cycle, said valve member having formed therein said leakage space.

9. In a gas-conveying and pumping system as claimed in claim 2, said pumping means including a flexible diaphragm movable with a reciprocating motion and having at least a portion exposed to said pump space for periodically moving said liquid.

10. In a gas-conveying and pumping system as claimed in claim 3, each of said valve outlet openings having a movable valve member operative to close its respective outlet opening during at least a portion of the suction stroke, the region of the guide structure of at least one of said valve outlet openings having said leakage space in a wall region thereof other than the movable valve member thereof.

11. In a gas-conveying and pumping system as claimed in claim 2, the dimensions and the flow impedance of the leakage spaces returning said liquid to said main pump space and said additional pump space being so proportioned that the pumping liquid returns to said additional pump space through its leakage space of said discharge opening at a slower rate than it returns to the main pump space through its leakage space.

12. In a gas-conveying and pumping system as claimed in claim 1, said pumping means including a flexible diaphragm movable with a reciprocating motion and having at least a portion exposed to said pump space for periodically moving liquid, and a yieldable energy-storing coupling connection through which external forces impart to said diaphragm its periodical movement with opposite driving strokes.

13. In a gas-conveying and pumping system as claimed in claim 2, said pumping means including a flexible diaphragm movable with a reciprocating motion and having at least a portion exposed to said pump space for periodically moving liquid, and a yieldable energy-storing coupling connection through which external forces impart to said diaphragm its periodical movement with opposite driving strokes.

14. In a gas-conveying and pumping system as claimed in claim 2, each of said valve outlet openings having a movable valve member operative to close its respective opening during at least a portion of the suction stroke.

15. In a gas-conveying and pumping system as claimed in claim 14, the dimensions and the flow impedance of the leakage spaces returning said liquid to said main pump space and said additional pump space being so proportioned that the pumping liquid returns to said additional pump space through its leakage space at a slower rate than it returns to said main pump space through its leakage space.

16. In a gas-conveying and pumping system as claimed in claim 1, interior surface portions of said guide structure that are exposed to said gases being of wall material which is inert and free from gases that may escape therefrom into evacuated spaces surrounded thereby.

17. In a gas-conveying and pumping system as claimed in claim 1, said pumping means including a flexible diaphragm movable with a reciprocating motion and having at least a portion exposed to said pump space for periodically moving liquid, the interior wall surfaces of said guide structure and the interior wall of said diaphragm facing said pump space being formed of inert material which is free from gases that may escape therefrom into evacuated spaces surrounded thereby.

18. In a gas-conveying and pumping system as claimed in claim 2, said pumping means including a flexible diaphragm movable with a reciprocating motion and having at least a portion exposed to said pump space for periodically moving liquid, the interior wall surfaces of said guide structure and the interior wall of said diaphragm facing said pump space being formed of an inert material which is free from gases that may escape therefrom into evacuated spaces surrounded thereby.

19. In a gas-conveying and pumping system for conveying gas from a gas source to a discharge space, a guide structure confining a fluid guide space having a gas inlet for receiving gas from said gas source and a gas outlet for discharging received gas in a flow direction toward said discharge space, said guide structure having inlet valve means and outlet valve means and a relatively wide pump space between said inlet valve means and said outlet valve means for pumping gas from said source through said inlet valve means and impelling it in said flow direction through said outlet valve means, a pumping liquid in said pump space, pumping means for imparting to said liquid a succession of opposite suction and discharge strokes causing pumping of gas from said gas source into said pump space during said suction stroke and pumping of gas from said pump space through said outlet valve means in said flow direction during the discharge stroke, said guide structure confining at least one retaining space arranged to receive fluid pumped from said pump space in said flow direction, said retaining space having a relatively larger fluid-holding space than the opening of said outlet valve means through which it receives fluid from said pump space, said outlet valve means having associated therewith a leakage space connecting said retaining space to said pump space during a suction stroke for causing

liquid contained in said retaining space to leak back in a direction reverse to said flow direction towards said pump space during at least each suction stroke, said leakage space being of such dimensions and having such high flow resistance and said retaining space and said pumping space each containing such volume of said liquid as to cause said leakage space to contain said liquid and block return of gas in said reverse direction from said retaining space towards said pump space throughout said suction stroke and to prevent said pump space from being completely filled by said liquid at the end of said suction stroke.

20. In a gas-conveying and pumping system as claimed in claim 2, each of said valve outlet openings having a movable valve member operative to close its respective outlet opening during at least a portion of the suction stroke, at least one of said valve members having formed therein the leakage space through which said liquid leaks back to the pump space from which it is discharged.

21. In a gas-conveying and pumping system as claimed in claim 3, each of said valve outlet openings having a movable valve member operative to close its respective outlet opening during at least a portion of the suction stroke, at least one of said valve members having formed therein the leakage space through which said liquid leaks back to the pump space from which it is discharged.

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