United States Patent

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[72] Inventors **Francis J. Eichelman**
La Grange Park;
Andrew A. Kenny, Chicago, both of, Ill.
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[73] Assignee **Chemetron Corporation**
Chicago, Ill.

[54] **ANESTHETIC APPARATUS**
18 Claims, 7 Drawing Figs.

[52] **U.S. Cl.** **128/188**
[51] **Int. Cl.** **A61m 17/00**
[50] **Field of Search** .... 128/188, 186, 187, 189, 204, 193—196, 197, 173, 173.1, 251, 113, 114

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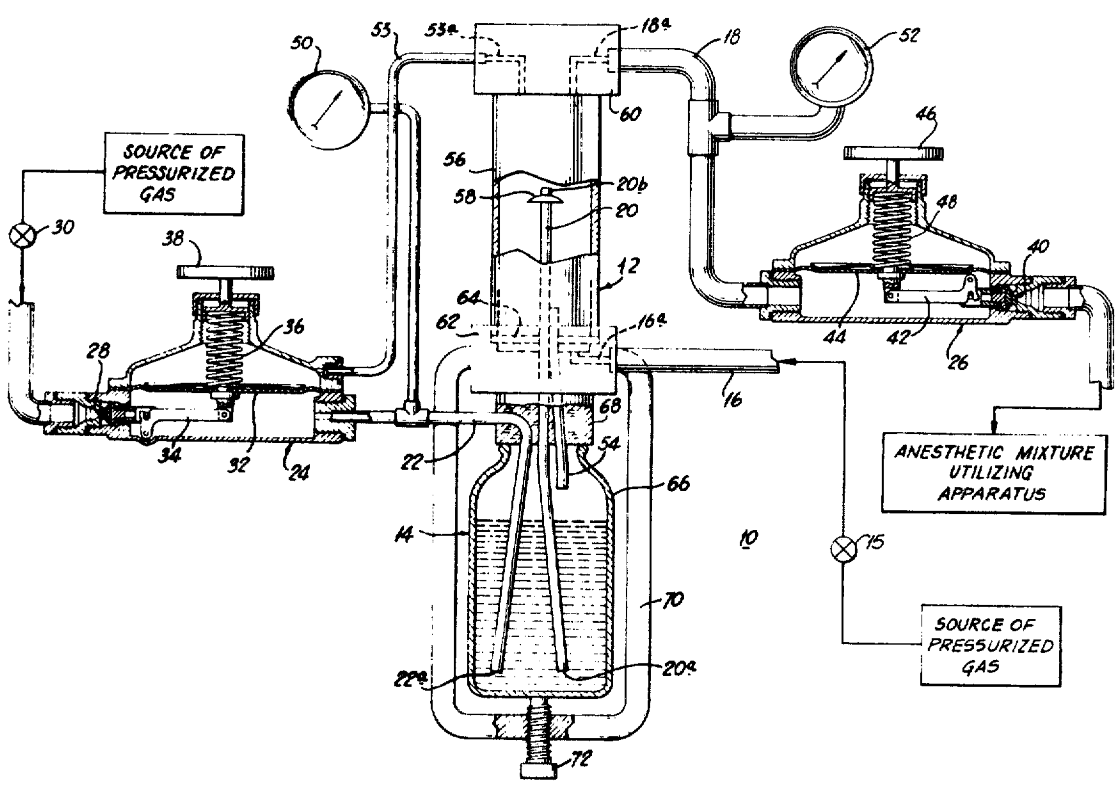
Primary Examiner—Richard A. Gaudet
Assistant Examiner—J. B. Mitchell
Attorney—Mason, Kolemainen, Rathburn and Wyss

ABSTRACT: A closed reservoir charged with a supply of liquid anesthetic material communicates via a conduit with a vaporizer chamber through which a stream of gas flows. The reservoir is pressurized by a pressure line communicating with the reservoir at a region beneath the surface of the liquid, and a pressure head is maintained independently of the level of the anesthetic material in the reservoir. The rate of flow of liquid through the conduit to the vaporizer chamber is controlled by regulating the pressure within the pressure line relative to the pressure within the pressure line relative to the pressure within the vaporizer chamber. The reservoir may be formed by an anesthetic containing bottle in sealing engagement with a support for the vaporizer to provide a compact assembly.



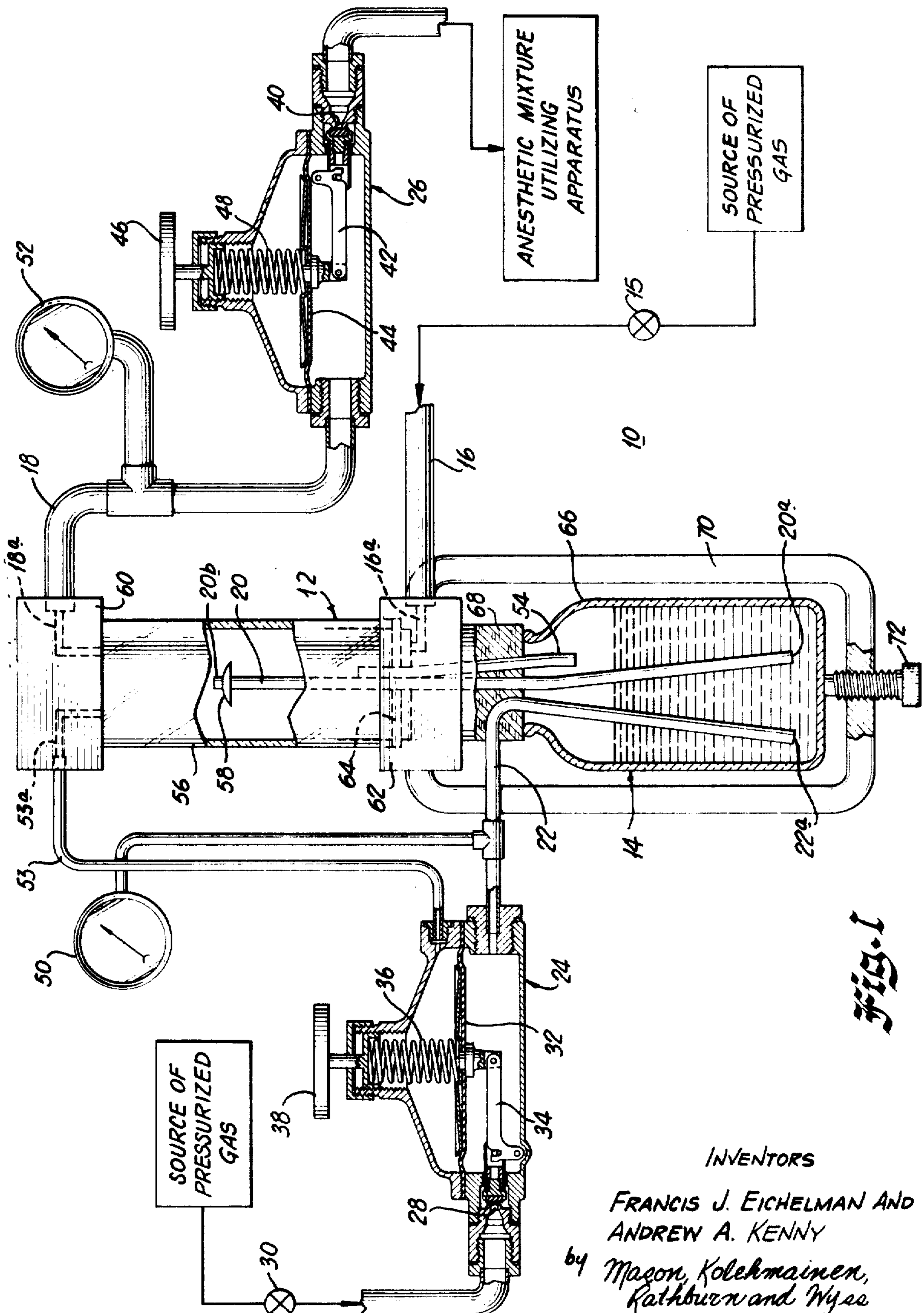


Fig. 1

INVENTORS

FRANCIS J. EICHELMAN AND
ANDREW A. KENNY

by Mason, Kolehmainen, Rathburn and Wyss
ATTORNEYS

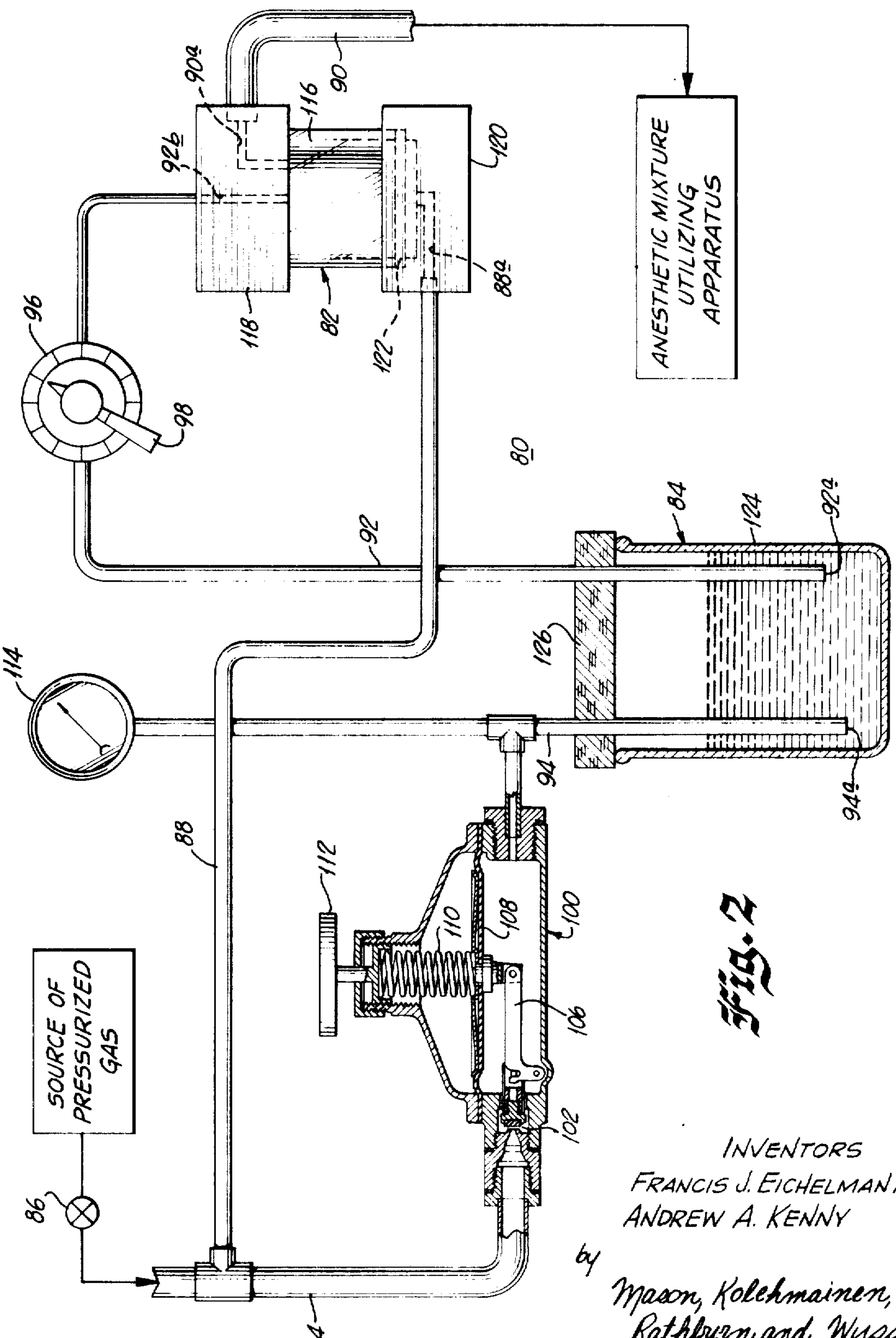


Fig. 2

INVENTORS
FRANCIS J. EICHELMAN AND
ANDREW A. KENNY

by

Mason, Kolehmainen,
Rathburn and Wyss.
ATTORNEYS

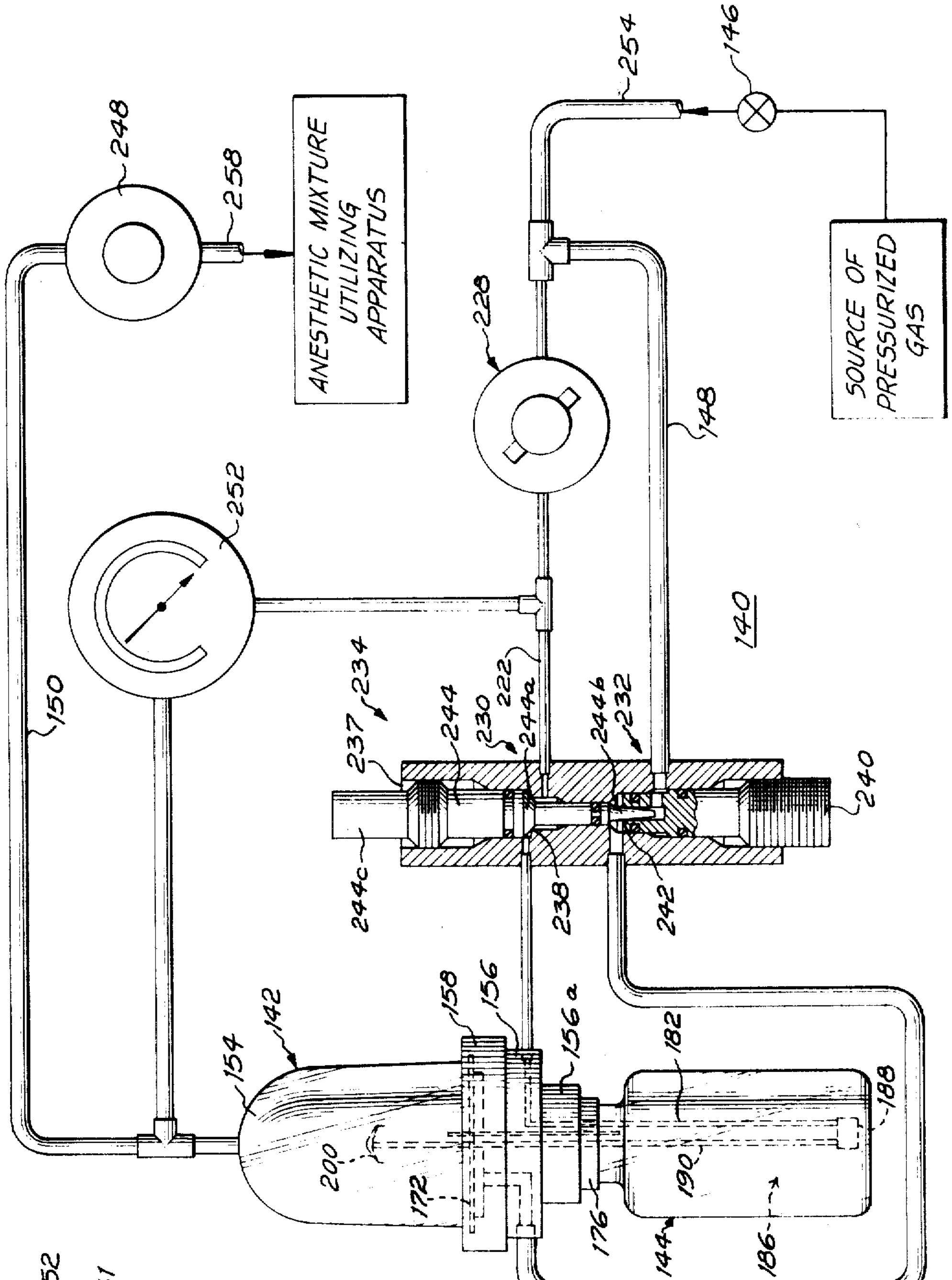


Fig. 3

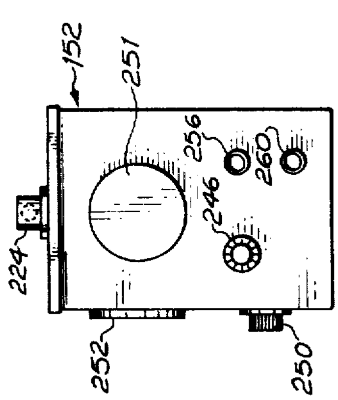


Fig. 7

INVENTORS
FRANCIS J. EICHELMAN AND
ANDREW A. KENNY
by Mason, Kolehmainen, Rathburn and Wyss
ATTORNEYS

Fig. 4

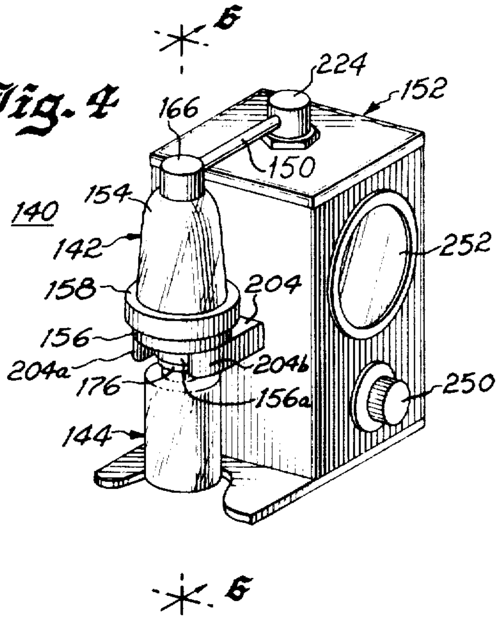


Fig. 5

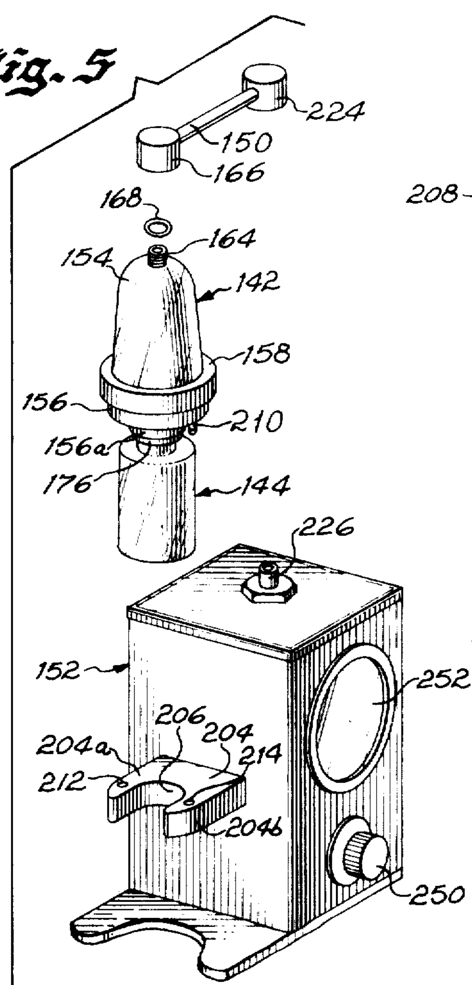
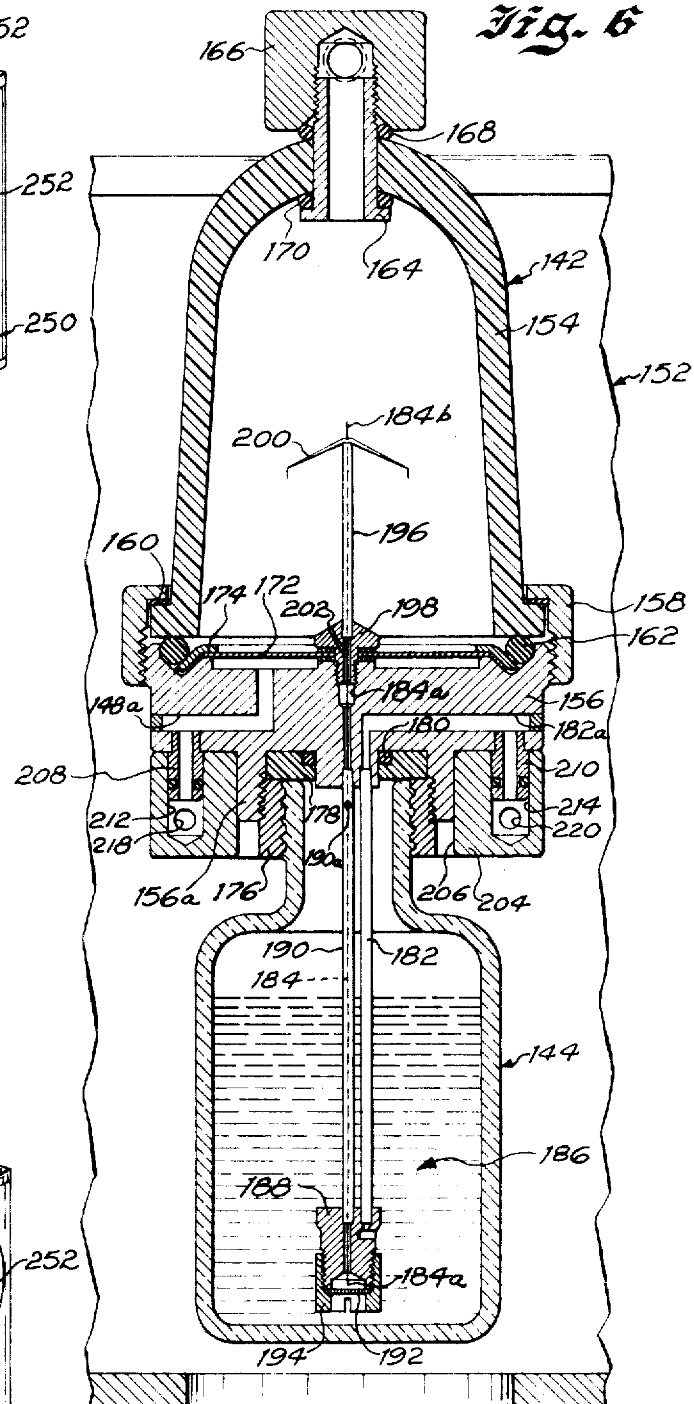


Fig. 6



INVENTORS
FRANCIS J. EICHELMAN AND
ANDREW A. KENNY

by

Mason, Kolehmainen,
Rathburn and Wyss
ATTORNEYS

ANESTHETIC APPARATUS

The present invention relates to anesthetic apparatus, and more particularly to apparatus for introducing anesthetic vapor into a gas stream for use in anesthetizing a patient.

In the process of inducing a state of anesthesia in a patient, the patient is caused to inhale a mixture of a gas, such as oxygen, and an anesthetic vapor. Several inhalation anesthetic materials are currently used, including ether, halothane (available under the trademark Fluothane), trichloroethylene, methoxyflurane (available under the trademark Penthrane) and others. The desired concentration of any given anesthetic vapor in oxygen or other gas varies in dependence upon the particular patient, and may vary over a considerable range as anesthesia is first induced and subsequently maintained at a given stage. In addition, the range of concentration varies for different materials. For example, the concentration of ether in some cases may be as high as 8 percent or more, while methoxyflurane may be administered at a concentration as low as 0.2 percent.

Anesthetic materials are customarily available in the form of volatile liquids, and various methods have been used for evaporating the liquid anesthetic into a gas stream. Anesthetic apparatus known heretofore has been subject to one or more problems, including lack of accuracy in achieving the desired concentration, particularly over the wide range of concentrations necessary for use with different anesthetic materials, undue complexity, expense, and inconvenience. One common method is to bubble a stream of gas through a supply of liquid anesthetic to produce a highly concentrated mixture. Subsequently the mixture is diluted to achieve the desired concentration. One difficulty encountered with this method arises in accurately attaining the desired concentration since the rate of evaporation varies widely with temperature and pressure conditions.

Other known methods involve the use of vaporizing apparatus through which a stream of gas is passed. A metered amount of liquid anesthetic is introduced into the vaporizing apparatus and evaporates into the gas stream. The accuracy of this arrangement is not highly dependent upon temperature and pressure conditions because all of the liquid anesthetic introduced into the vaporizing apparatus is intended to evaporate into the gas stream. However, difficulties are encountered in accurately metering the amount of liquid anesthetic which is introduced into the vaporizing apparatus, and in maintaining a constant pressure head for forcing the liquid anesthetic into the vaporizing apparatus. One example of a system of this type may be found in U.S. Pat. No. 3,128,764 issued to Wilbur R. Koehn.

Accordingly, it is an object of the present invention to provide improved anesthetic apparatus for providing a gas and anesthetic mixture which can be controlled accurately over a wide range of concentrations.

Another object is to provide improved anesthetic apparatus which is simple and convenient to operate.

A further object is to provide improved apparatus for maintaining a constant pressure head for evacuating anesthetic liquid from a container at a rate independent of a changing liquid level.

Another object is to provide an apparatus in which the anesthetic concentration can be varied over a wide range and controlled with great accuracy.

Another object of the invention is to provide improved anesthetic apparatus suitable for use with a wide variety of anesthetic materials and for use in both closed and open systems.

In brief, anesthetic apparatus constructed in accordance with the invention may include a vaporizer chamber through which flows a stream of gas to which anesthetic vapor is to be added. An anesthetic material in the liquid state is introduced into the vaporizer chamber through a conduit from a closed reservoir charged with a supply of anesthetic liquid. In accordance with an important feature of the invention, pressure within the reservoir forces the anesthetic through the conduit to the vaporizer chamber at a rate which is independent of the level of anesthetic in the reservoir. Accordingly, there is no requirement to maintain a constant level in the reservoir as in many prior art systems. In order to accomplish this result, the reservoir is pressurized by means of a pressure line communicating with the reservoir at a region beneath the surface of the anesthetic.

The rate at which liquid flows into the vaporizer chamber is regulated accurately and conveniently by varying the pressure differential existing between the vaporizer chamber and the reservoir. In accordance with a feature of the invention, the pressure differential may be controlled by regulating the pressure of the pressure line communicating with the reservoir, or by regulating the pressure within the vaporizer chamber, or both.

Another feature of the invention resides in the simplicity and convenience of the vaporizer apparatus. In certain embodiments of the invention, the closed reservoir containing the liquid anesthetic comprises the bottle or container in which the liquid anesthetic is supplied. The bottle is held in sealing relation to a support member associated with the vaporizer, and both the pressure line and the liquid conduit extend into the bottle to a point beneath the surface of the liquid anesthetic contained in the bottle. This arrangement, in addition to being extremely simple and inexpensive, reduces the evaporation waste occurring with prior art apparatus, and also makes it extremely simple to change quickly from one anesthetic material to another.

The apparatus of the present invention may also include a novel arrangement for maintaining an even pressure differential between the vaporizer chamber and the regulator by controlling the reservoir pressure in accordance with minor fluctuations within the vaporizer chamber. In addition, a restricted bleed line may extend between the reservoir and the vaporizer chamber to prevent the buildup of excess pressure within the reservoir due to accelerated evaporation of the liquid anesthetic contained therein. A dual-purpose valve with a single control may be used to control the admission of pressurized gas to the regulator, and also to regulate the gas stream passing through the vaporizer chamber.

The above and many other objects and advantages of the present invention will appear from the following detailed description of certain embodiments of the invention taken with the accompanying drawings, in which:

FIG. 1 is a diagrammatic and elevational view, partly in section, of vaporizer apparatus constructed in accordance with the invention;

FIG. 2 is a diagrammatic and elevational view, partly in section, of an alternative embodiment of the invention;

FIG. 3 is a diagrammatic and elevational view, partly in section, of another alternative embodiment of the invention;

FIG. 4 is a perspective view of a self-contained vaporizer unit including the components illustrated in FIG. 3;

FIG. 5 is an exploded view of the unit of FIG. 4;

FIG. 6 is an enlarged sectional view taken along the line 6–6 of FIG. 4; and

FIG. 7 is an elevational view of one side of the unit of FIG. 4.

Referring now to the drawings, and initially to FIG. 1, there is illustrated a liquid anesthetic vaporizing unit generally designated as 10 and constructed in accordance with the present invention. In the main, the unit 10 includes a vaporizer chamber designated as a whole by the reference numeral 12 and a closed reservoir generally designated as 14. A stream of gas to which an anesthetic vapor is to be added is conducted from a source of pressurized gas through a shutoff valve 15 and through the vaporizer chamber 12 by means of an inlet conduit 16 and an outlet conduit 18 communicating with anesthetic mixture utilizing apparatus which may, for example, be part of a closed or an open anesthetic system. In an open system a gas, such as oxygen, is passed through the vaporizer chamber 12 and mixed with a desired concentration of anesthetic vapor, and is forwarded via the outlet conduit 18 to patient breathing apparatus. In a closed system, the gaseous mixture is recycled through a closed circuit in which carbon dioxide is removed from the exhaled gas and additional oxygen combined with anesthetic vapor is added to replenish the flow.

In accordance with one important feature of the invention, liquid anesthetic is forced to flow from the closed reservoir 14 through a liquid carrying conduit 20 to the vaporizer chamber 12 at a rate which is accurately controlled and is independent of the liquid level in the reservoir 14. The reservoir 14 is initially charged with a supply of anesthetic liquid and no effort is made to maintain a constant level within the reservoir 14 as the liquid anesthetic is used. In order to provide a flow of fluid through the conduit 20 at a rate independent of the liquid level in the reservoir 14, the reservoir 14 is pressurized by means of a pressure line 22 having an end 22*a* communicating with the reservoir preferably near the bottom so as to be beneath the surface of liquid in the reservoir. Accordingly, for a given pressure in the pressure line 22, the pressure head causing evacuation of the liquid through the conduit 20 remains constant regardless of the level of liquid in the reservoir 14, and without the necessity for special control apparatus. This represents a substantial advance in convenience and simplicity over prior art arrangements wherein complicated and expensive apparatus was required to maintain a constant anesthetic level in order to maintain a constant pressure head for forcing liquid from the reservoir into the vaporizer.

More specifically, the pressure head at the lower end 20*a* of the liquid conduit 20 is made up of two components. One component of the pressure head is produced by the pressure of the vapor or gas within the reservoir 14 above the surface of the liquid contained therein. The other pressure component results from the weight of the liquid within the reservoir 14 above the lower end 20*a* of the conduit 20.

In prior art apparatus, attempts have been made to maintain a constant pressure head by maintaining the liquid level in the reservoir constant and by maintaining the pressure of the atmosphere within the reservoir constant. This approach, however, has required a complicated valving mechanism for maintaining a constant liquid level. In contrast, the present invention provides a simplified, less expensive and conveniently regulated arrangement for maintaining a constant pressure head at the lower end of the conduit 20.

In the arrangement of the present invention, the liquid level does not remain constant and the component of the pressure head caused by the liquid decreases as the liquid level falls. However, since this component of the pressure head acts on the submerged pressure line 22 as well as on the liquid conduit 20, the pressure of the gas contained within the reservoir 14 increases and compensates for the falling liquid level. Accordingly, the pressure head effective at the end 20*a* of the conduit 20 remains constant for a given pressure within the pressure line 22.

Although the lower ends 20*a* and 22*a* of the liquid conduit 20 and pressure line 22 are illustrated in FIG. 1 at approximately the same level, it will be obvious that they may be disposed at different levels if desired. A constant effective pressure head will be maintained as long as both the pressure line and the liquid conduit terminate beneath the surface of the liquid.

As noted above, the apparatus of the present invention is capable of providing accurately controlled anesthetic concentrations over a wide range. The conduit 20 is preferably of capillary size and may include a segment having an inner diameter in the neighborhood of 0.007 inch. The flow of liquid anesthetic through the conduit 20 is governed by the rules of laminar flow, in accordance with which the flow through the conduit 20 is proportional to the pressure differential existing between the lower end 20*a* of the conduit and an upper end 20*b* disposed within the vaporizer chamber 12. Since the pressure at the lower end 20*a* of the conduit 20 is determined by the pressure within the pressure line 22, the rate of flow of liquid anesthetic into the vaporizing chamber 12 is proportional to the pressure differential existing between the pressure line 22 and the interior of the vaporizer chamber 12.

In accordance with a feature of the invention, the rate of flow of liquid anesthetic through the conduit 20, and thus the percentage concentration of anesthetic vapor in the stream of gas, is accurately controlled over a broad range by controlling the pressure within the reservoir 14 relative to the pressure within the vaporizer 12. In the embodiment of the invention illustrated in FIG. 1 this is accomplished by controlling the pressure existing within the pressure line 22 by means of a pressure line regulator generally designated as 24, and controlling the pressure within the vaporizer chamber 12 by means of a back pressure regulator generally designated as 26.

More specifically, the pressure line 22 communicates with the outlet of a pressure regulated valve 28, the inlet of which is connected to a source of pressurized gas by way of a shutoff valve 30. If desired a single source may be used both for the gas stream entering the inlet conduit 16 and for supplying the regulator 24, although separate sources are indicated in FIG. 1. The pressure regulator 24 may be of any suitable type, and as illustrated includes a diaphragm 32 acted upon by the pressure within the pressure line 22 and coupled to the valve 28 by means of a linkage 34 for operating the valve to maintain a constant pressure within the pressure line 22. The pressure acting upon the diaphragm 32 is opposed by the force applied by a spring 36, and preferably the spring tension is adjustable by means of a handle 38 with which the constant pressure level to be maintained within the pressure line 22 may be varied.

The back pressure regulator 26 may be of any desired type, and is illustrated as being similar in many respects to the pressure line regulator 24. The gaseous mixture flowing from the vaporizer chamber 12 passes via the outlet conduit 18 to the inlet of a pressure regulated valve 40, the outlet of which is connected to the anesthetic mixture utilizing apparatus. The valve 40 is controlled by means of a linkage 42 and diaphragm 44 to maintain the pressure at the inlet side of the valve 40, and thus the pressure within the vaporizer chamber 12, at a constant level. The pressure within the vaporizer chamber 12 is adjusted to a desired level by means of a handle 46 controlling the tension of a spring 48 acting on the diaphragm 44.

Since the rate of flow of liquid anesthetic through the conduit 20 is determined by the pressure differential existing between the pressure line 22 and the vaporizer chamber 12, the concentration of the anesthetic in the gas stream can conveniently and accurately be adjusted by means of the handles 38 and 46 of the pressure line regulator and the back pressure regulator. It is possible with the apparatus of the present invention to regulate the pressure differential and thus the flow rate with either one of the regulators 24 and 26, the other being omitted or combined with other equipment. Alternatively, one of the regulators 24 and 26 may be permanently set or factory adjusted at a selected level and the other may be adjusted by the anesthesiologist. If desired, of course, both of the regulators may be used. For example, one of the regulators may be set at a selected level to give a certain range of flow rates, and the other used for finer adjustments within the selected range.

A pair of pressure responsive indicators 50 and 52 are connected respectively to the pressure line 22 and the outlet conduit 18 communicating with the interior of the vaporizer chamber 12. The readings of the indicators 50 and 52 indicate the pressure differential existing between the pressure line 22 and the vaporizer chamber 12, and thus the anesthetic concentration may be computed from this pressure differential. Alternatively, the indicators 50 and 52 may be provided with scales (not shown) calibrated in terms of anesthetic concentration.

It will be appreciated that due to factors such as friction and inertia associated with the elements of the back pressure regulator 26, minor pressure variations and fluctuations may exist within the vaporizer chamber 12. Although these variations are of a minor and transient character, it may be desirable to compensate for such variations in order to provide an evenly regulated flow of liquid from the reservoir 14 into the vaporizer chamber 12. In order to accomplish this, a pressure equalizing line 53 extends from the interior of the vaporizer chamber 12 to the dome portion of the pressure line regulator 24. Pressure variations existing within the vaporizer chamber 12 are communicated via the equalizing line 53 to the reverse or dome side of the diaphragm 32 automatically to control the valve 28 for maintaining a constant pressure differential between the vaporizer chamber and the reservoir.

With some anesthetic material such as ether a problem may arise when the reservoir 14 is exposed to light or temperature variations. Under some conditions it is possible for the liquid within the reservoir 14 to evaporate at an accelerated rate and for the vapor pressure within the reservoir 14 to increase to an undesirable level. Rather than controlling the external conditions affecting the rate of evaporation, it may be preferable to provide a restricted bleed line 54 extending from the upper portion of the closed reservoir 14 to the interior of the vaporizer chamber 12. This line has a very small interior diameter, and serves very gradually to vent any excess pressures that may exist within the reservoir 14 to the lower pressure region within the vaporizer chamber 12. The line is small in size, and the limited flow of gas therethrough may readily be compensated for through calibration of the system.

Referring now to the construction of the vaporizer chamber 12, the chamber includes a cylindrical wall member 56 defining an interior chamber and preferably formed of transparent material such as glass in order to permit viewing of the flow of anesthetic liquid from the conduit 20. The upper end 20*b* of the conduit 20 is provided with a drip guide 58 for causing the liquid to form droplets rather than running down the outer surface of the conduit 20 and/or into the line 54.

The upper and lower ends of the cylindrical wall 56 are closed by body members 60 and 62. The upper body member 60 includes a pair of passages 18*a* and 53*a* communicating respectively with the outlet conduit 18 and the pressure equalizing line 53, and communicating with the interior of the vaporizer chamber 12. Similarly, the lower body member 62 includes a passageway 16*a* communicating with the inlet conduit 16 and with the interior of the vaporizer chamber 12.

The vaporizer chamber 12 is divided into two regions by means of a porous metal diffusion plate or baffle 64 supported within the lower body section 62. The stream of gas entering through the inlet conduit 16 passes through the diffusion plate 64 to reach the outlet conduit 18. Liquid anesthetic emerging from the conduit 20 falls from the drip guide 58 onto the plate 64 and is completely evaporated into the stream of gas moving through the plate 64.

With the vaporizing unit 10 of the present invention it is not necessary to transfer the liquid anesthetic from its original container to a separate reservoir. In addition to being convenient, this arrangement prevents the evaporation loss, contamination, and the like suffered with known equipment during transferral of liquid anesthetic from one vessel to another. Since the liquid is kept in its original container, the possibility of confusion as to what type of anesthetic is being used is reduced.

In order to permit the original container or bottle 66 in which the anesthetic is obtained to serve as the closed reservoir in the system, the lower body member 62 supports a sealing member 68 having a lower surface against which the neck of the bottle 66 abuts. The bottle 66 is held in sealing engagement with the sealing block 68 by means of a yoke 70 pivotally supported by the lower body member 62 and a clamping bolt 72 engaging the bottom of the bottle 66. Since the pressure line 22 and the conduit 20 extend downwardly through the lower surface of the sealing block 68, the unit 10 is assembled for operation merely by positioning the bottle 66 and clamping it in place.

One of the advantages of the apparatus of the present invention is that it may be used with a high degree of accuracy over a wide range of anesthetic vapor concentration levels. Accordingly, the apparatus is well suited for use with a wide variety of different anesthetic materials which may require concentrations falling in widely varying ranges. However, if for precautionary reasons it is desired to restrict the use of the unit 10 to one particular anesthetic at one given time a suitable indexing means (not shown) may be provided on the sealing member 68 so that the unit can accept only one particular type of bottle associated with the one selected anesthetic material.

Reviewing the operation of the liquid anesthetic vaporizing unit 10, initially there is no stream of gas flowing through the vaporizer chamber 12 and the shutoff valves 15 and 30 are in the off position. In order to prepare the unit for operation, a bottle 66 of a selected anesthetic material is mounted against the sealing member 68 and clamped in place by the clamping bolt 72. The valve 15 is opened and the flow of gas through the vaporizer chamber 12 is begun. The shutoff valve 30 is opened and one or both of the regulators 24 and 26 are adjusted by means of the adjusting handles 38 and 46 to provide a desired pressure differential between the lower end 20*a* and the upper end 20*b* of the liquid conduit 20. Pressurized gas from the source of pressurized gas flows through the pressure line regulator 24, where its pressure is dropped to the selected level, and then through the pressure line 22 and into the closed reservoir 14. Pressure within the reservoir forces liquid anesthetic material through the conduit 20 to the vaporizer chamber 12 where it drips onto the diffusion plate 64.

Gas entering the vaporizer chamber 12 through the conduit 16 flows through the plate 64 and is mixed with evaporating anesthetic. The gaseous anesthetic mixture then flows through the outlet conduit 18 and through the back pressure regulator 26 to the utilizing apparatus. The back pressure regulator maintains a selected pressure level within the vaporizer chamber 12. As the liquid level drops in the reservoir 14, the pressure differential between the ends 20*a* and 20*b* of the conduit 20, as determined by the regulators 24 and 26, does not vary and the rate of flow of anesthetic remains constant.

If it is desired to change anesthetics or replace the bottle 66, the shutoff valve 30 is closed, and the pressure within the reservoir 14 drops quickly due to provision of the bleed line 54 to stop the flow of liquid through the conduit 20. Since the reservoir 14 is located below the chamber 12, there is no liquid flow in the absence of pressure within the reservoir. In addition, when the bottle 66 is removed the conduit 22 is rapidly purged of liquid by the force of gravity.

In apparatus constructed in accordance with the present invention it was found that the unit could be used with different types of anesthetics, and that the concentration of anesthetic in the gas stream could be controlled accurately over wide ranges. In addition it was observed that the flow of anesthetic remained constant even though the liquid level in the reservoir decreased due to the novel arrangement for pressurizing the reservoir with a pressure line terminating beneath the surface of the liquid.

For example, in one unit constructed in accordance with the invention, the liquid conduit 20 included a capillary size segment one-half inch in length and 0.0075 inch in diameter. The regulator 24 was adjusted so that the pressure within the line 22 was the equivalent of 24 inches of water. An oxygen gas stream was passed through the vaporizer at a rate of 1,000 cubic centimeters per minute. The reservoir 14 was charged with a supply of liquid ether, and the regulator 26 was adjusted to maintain the interior of the vaporizer at a pressure equivalent to 15.2 inches of water. Liquid ether flowed into the vaporizer at a rate equivalent to 66 cubic centimeters of vapor per minute and was evaporated into the gas stream to produce an anesthetic mixture of 6.6 percent ether vapor in oxygen.

The unit was also capable of operation with other anesthetics and at other concentrations. For example, the reservoir 14 was charged with a supply of liquid halothane and the regulator 26 was adjusted to maintain the interior of the vaporizer 12 at a pressure equivalent to 11.8 inches of water, while the other variables remained the same as in the previous example. Liquid halothane flowed into the vaporizer at a rate equivalent to 28 cubic centimeters per minute of vapor, and an anesthetic mixture of 2.8 percent of halothane vapor in oxygen was produced as the liquid evaporated into the gas stream.

It should be understood that the above examples are set forth only as an illustration of one embodiment of the invention. The specific information included here should not be taken to limit the invention, which is defined in the claims appended to the specification.

Having reference now to FIG. 2, there is illustrated an anesthetic vaporizing unit generally designated as 80 and comprising an alternative embodiment of the present invention. The unit 80 includes a vaporizer chamber designated as a whole as 82 together with a closed reservoir generally designated as 84. A stream of gas to which an anesthetic vapor is to be added is conducted from a source of pressurized gas, through a shutoff valve 86 and through a conduit 88 to the vaporizer chamber 82 where an anesthetic vapor is added to the gas stream. The anesthetic and gas mixture leaves the vaporizer chamber 82 through a conduit 90 and is supplied to suitable anesthetic mixture utilizing apparatus.

As with the unit 10 illustrated in FIG. 1 and described above, liquid anesthetic is forced to flow from the closed reservoir 84 into a submerged lower end 92*a* of a liquid conduit 92 and to the vaporizer chamber 82 at a rate of flow which is independent of the level of liquid in the reservoir 84. In accordance with the invention, the reservoir 84 is pressurized by means of a pressure line 94 having a lower end 94*a* communicating with the reservoir at a region beneath the surface of the anesthetic liquid in normal operation.

Thus, as described in detail in connection with the embodiment of FIG. 1, for a given constant pressure in the pressure line 22, the pressure head causing evacuation of liquid through the liquid conduit 92 remains constant regardless of the level of liquid in the reservoir 84.

The embodiment of the invention illustrated in FIG. 2 differs from the unit 10 described above in that the liquid conduit 92 communicates with the interior of the vaporizer chamber 82 by way of a metering valve 96. Valve 96 includes an operating handle 98 with which the valve setting may be varied between several different settings thereby to vary the resistance to the flow of liquid from the reservoir 84 to the vaporizer 82. The valve 96 may be of any known type such as a variable orifice valve, or a valve of the type in which movement of the operating handle serves to vary the effective length of a capillary size passageway.

In accordance with a feature of the invention the rate of flow of anesthetic from the reservoir 84 to the vaporizer 82, and thus the concentration of the gas anesthetic mixture, is controlled by regulating the pressure differential existing between the reservoir 84 and the vaporizer 82 and/or by operating the metering valve 96 to vary the resistance to flow between the reservoir 84 and the vaporizer 82. In the arrangement of FIG. 2, the unit 80 is illustrated as used with anesthetic mixture utilizing apparatus of a type which maintains the pressure within the vaporizer chamber 82 substantially constant, although a back pressure regulator similar to the regulator 26 of FIG. 1 could be used if desired. Accordingly, the pressure differential between the reservoir 84 and the vaporizer 82 is varied by controlling the pressure in the pressure line 94 with a pressure line regulator generally designated as 100 and including a pressure regulated valve 102 having its inlet connected through a conduit 104 to the shutoff valve 86, and having its outlet connected to the pressure line 94. The valve 102 is controlled by a linkage 106 operated by a diaphragm 108 acted upon by the pressure within the pressure line 94 in opposition to a spring 110, the tension of which is adjustable by means of a handle 112.

Since the rate of flow of liquid anesthetic to the conduit 92, for any particular setting of the metering valve 96, is proportional to the pressure differential existing between the reservoir 84 and the vaporizer 82, the rate of flow may be adjusted by operation of the handle 112 to a setting which provides the desired constant pressure within the pressure line 94. A pressure responsive indicator 114 communicates with the pressure line 94 to provide a pressure reading or, if desired, a direct reading of the pressure differential existing between the reservoir 84 and the vaporizer chamber 82.

Referring now more specifically to the construction of the vaporizer chamber 82, this chamber may be constructed in any suitable fashion and is illustrated as including a transparent cylindrical wall 116 having its upper and lower ends closed by body members 118 and 120. The body members are provided with suitable passageways 88*a*, 90*a* and 92*b* communicating between the interior of the vaporizer chamber and the conduits 88, 90 and 92 respectively.

In order to evaporate the liquid anesthetic reaching the vaporizer chamber into the flowing gas stream a porous metal diffusion plate or baffle 122 divides the vaporizer chamber 82 into two regions. The stream of gas entering through the conduit 88 passes through the plate 122 and through the conduit 90 to the anesthetic mixture utilizing apparatus. Liquid anesthetic entering the vaporizer chamber 82 from the conduit 92 falls onto the plate 122 and is completely evaporated into the gas stream flowing through plate 122.

The liquid reservoir 84 of the unit 80 may be of any desired construction and as illustrated includes a container 124 closed by means of a sealing member 126 held against the container 124 by a suitable clamp or other means (not shown). It should be appreciated that if desired the unit 80 of FIG. 2, may include an arrangement such as illustrated in the unit 10 of FIG. 1 wherein the reservoir comprises the original container of the liquid anesthetic and wherein the reservoir and the vaporizer chamber are combined in a single unit. In addition, the unit 80 may be provided with a restricted bleed conduit and with a pressure equalizing line similar to the conduit 54 and line 53 of the unit illustrated in FIG. 1.

In the operation of the unit 80, when it is desired to provide a mixture of gas and anesthetic the shutoff valve 86 is opened so that a stream of gas flows through the vaporizer chamber 82 and to the anesthetic mixture utilizing apparatus. The reservoir 84 is charged with a supply of anesthetic liquid, and the metering valve 96 as well as the pressure line regulator 100 are adjusted to selected settings for producing the desired concentration of liquid anesthetic in the gas stream. The liquid anesthetic is evacuated from the reservoir 84 through the liquid conduit 92 and into the vaporizer chamber 82 where the liquid evaporates completely into the gas stream. The effective pressure head within the reservoir 84 causing the evacuation of the liquid remains constant as the liquid level falls due to the fact that the reservoir is pressurized by the pressure line 94 which terminates at a point beneath the surface of the liquid.

Having reference now to FIGS. 3—7, there is illustrated a liquid anesthetic vaporizing unit designated as a whole by the reference numeral 140 and comprising a further embodiment of the present invention. As best shown in FIG. 3, wherein the unit 140 is illustrated in somewhat schematic form, the unit in general includes a vaporizer chamber generally designated as 142 together with a liquid anesthetic reservoir generally designated as 144. A stream of gas to which an anesthetic vapor is to be added is conducted from a source of pressurized gas through a conventional shutoff valve 146 and through a conduit 148 and into the vaporizer chamber 142. Within the vaporizer chamber, a liquid anesthetic is vaporized and mixed with the stream of gas, and the mixture of gas and an anesthetic is conducted to an anesthetic mixture utilizing apparatus by way of a conduit 150.

As with the units described above in connection with FIGS. 1 and 2, the unit 140 operates to supply a uniform anesthetic concentration regardless of the level of liquid anesthetic in the reservoir **144**. Furthermore the concentration is accurately controlled and is variable over a wide range. In addition, and in accordance with further features of the invention, the unit is conveniently arranged in a compact package with all controls and connections readily accessible. Furthermore a single-manual control serves to operate a novel dual-purpose valve to control both the admission of pressurized gas to the reservoir and to control the volume of gas flow into the vaporizer through conduit **148**.

As best shown in FIGS. **4** and **5**, the unit **140** shown schematically in FIG. **3** comprises a compact assembly including a housing **152** with the vaporizer chamber **142** and the liquid anesthetic reservoir **144** mounted in an accessible location on the exterior thereof. This construction has the advantage that much of the apparatus is safely enclosed within the housing **152**, while the reservoir **144**, chamber **142** and the necessary controls are readily accessible to an operator.

Proceeding now to a more detailed description of the reservoir **144** and the vaporizer chamber **142**, these elements are best illustrated in FIG. **6**. The vaporizer chamber comprises a somewhat bell-shaped enclosure **154** preferably formed of glass or other transparent material. The enclosure **154** is held in position over a base member **156** by a threaded clamp ring **158**. The interior of the vaporizer chamber enclosure **154** is sealed by a pair of sealing gaskets **160** and **162** held in compression by the clamp ring **158**. The upper portion of the vaporizer enclosure **154** is communicated with the conduit **150** by means of a fitting **164** threadedly connected to an elbow **166**. A pair of seals **168** and **170** are held in compression against the wall of the enclosure **154** by engagement between the fitting **164** and the elbow **166**.

In order to admit a stream of gas to the lower portion of the vaporizer chamber from the conduit **148**, the base member **156** includes a passageway **148*a*** extending from the lower surface of the base member **156** to the interior of the vaporizer chamber **142**. A porous metal diffusion plate or baffle **172** extends across the vaporizer chamber **142** between the passageway **148*a*** and the fitting **164** in order to accomplish the evaporation of liquid anesthetic into the flowing gas stream. The baffle **172** is held in place by means of a pressure ring **174** held in place by means of the seal **162**.

In accordance with a feature of the present invention, the reservoir **144** advantageously and conveniently comprises the original container or bottle in which the liquid anesthetic is supplied. As noted above, this arrangement greatly simplifies handling and use of the anesthetic vaporizing unit. The bottle is readily inserted into place on the unit **140** by threading the neck of the bottle into an adapter member **176** which is in turn threaded into an extension **156*a*** of the base member **156**. The lip of the bottle is sealed by engagement with a sealing block or member **178** supporting an O-ring **180**. It should be understood that various adapter members **176** may be provided for mating with different types of bottles containing different anesthetic materials. Thus the vaporizer unit is universally adaptable, and the adapter member **176** serves to prevent the use of an anesthetic material other than the material intended for use by the operator. In addition, since the chamber **142** and the reservoir **144** are supported on the base member **156**, a unitary, compact and easily handled subassembly is made possible.

As is the case with the liquid anesthetic vaporizer units **10** and **80** described previously, evacuation of the liquid anesthetic material contained within the reservoir **144** is accomplished by the introduction of pressurized gas into the vaporizer chamber at a level normally beneath the surface of the liquid. In this manner the rate of flow, and thus the concentration, is maintained independent of the level of liquid contained within the reservoir. The pressurized gas is introduced into the reservoir through a conduit **182**, while liquid anesthetic material is discharged from the reservoir vaporized chamber through a liquid capillary conduit **184**. In accordance with a feature of the invention, the conduits **182** and **184** are part of a unitary assembly supported on the base member **156** and designated as a whole by the reference numeral **186**.

More specifically, and referring in particular to FIG. **6**, the pressurized gas conduit **182** communicates with a passageway **182*a*** formed within the base member **156**. The upper end of the conduit **182** is attached to the base member **156**, while its lower end is attached to a fitting **188** having an outlet opening into the reservoir **144**. The liquid conduit **184** extends through a passageway **184*a*** in the base member **156** between the reservoir **144** and the vaporizer chamber **142**. Within the reservoir **144**, the liquid conduit **182**, which is of small, capillary size, is preferably protected by a jacket member or tube **190** having its ends connected to the base member **156** and to the fitting **188**. Fluid is admitted to the lower end **184*a*** of liquid conduit **184** through a filter screen **192** held in place on fitting **188** by a threaded cap **194**.

In order to protect the upper portion of the liquid conduit **184** within the vaporizer chamber **142**, a jacket or tube **196** is provided The lowermost end of jacket **196** is attached to a fitting **198** threaded into the base member **156** through the porous metal diffusion plate **172**. The uppermost end of the jacket **196** supports a drip guide **200** for guiding liquid anesthetic material emerging from the upper end **184*b*** of the liquid conduit **184** outwardly of the jacket **196** so that it descends onto the diffusion plate **172**.

In order to prevent excess pressure buildup within the anesthetic reservoir **144** due to evaporation of the liquid anesthetic, there is provided a bleed passage from the reservoir **144** to the vaporizer **142**. In the event of a pressure buildup, gas can flow from the reservoir through a small hole **190*a*** in the jacket **190** and into the passage **184*a*** in the base member **156**. This gas is then vented into the vaporizer chamber through a small passage **202** in the fitting **198**.

When pressurized gas is admitted to the reservoir **144** through the passageway **182*a*** and the conduit **182**, the reservoir becomes pressurized and liquid anesthetic material is discharged from the vaporizer through the filter screen **192** and the capillary conduit **184** into the vaporizer chamber **142** where it is deposited upon the diffusion plate or baffle **172**. A stream of gas to which anesthetic gas is to be mixed enters the vaporizer chamber through the passageway **148*a*** and passes through the porous plate or baffle **172**. Liquid anesthetic material reaching the diffusion plate is evaporated into the gas stream, and the anesthetic and gas mixture is discharged from the vaporizer chamber **142** through the fitting **162**, elbow **166** and conduit **150**.

One aspect of the present invention resides in the convenient manner in which the base member **156** together with the vaporizer chamber **142** and the reservoir **144** can be quickly connected to and detached from the housing **152**. Referring now more particularly to FIGS. **4** and **5**, the housing includes a laterally extending support arm **204** defining a recess **206** complementary in shape to the projection **156*a*** of the base member **156**. This recess is flanked by a pair of extensions **204*a*** and **204*b*** of the arm **204**. In order to mount the base member **156** together with the vaporizer chamber **142**, the base member **156** is merely dropped into place on the arm **204**.

In order to make connections between the internal passageways **148*a*** and **182*a*** of the base member **156**, each passageway communicates with a quick release nipple **208** and **210** respectively. The nipples **208** and **210** are slidingly received within recesses **212** and **214** formed in the arm extensions **204*a*** and **204*b***. The recesses **212** and **214** are communicated by way of passageways **218** and **220** (FIG. **6**) respectively with the conduit **148** and a pressure line conduit **222** illustrated only in FIG. **3**.

In order releasably to interconnect the conduit **150** with the housing **152**, the conduit **150** is connected to a slipfit connector **224** engageable with a nipple **226** (FIG. **5**). Consequently, the entire vaporizer assembly can readily be attached and detached from the housing **152** at will.

Returning to FIG. 3, it can be seen that pressurized gas for supplying the pressure line **222** is obtained from a source of pressurized gas by way of the shutoff valve **146**. A pressure regulator generally designated as **228** serves to regulate the pressure within the pressure line **222** and may if desired be of the construction of the regulator **24** illustrated in more detail in FIG. **1**. In addition, flow of pressurized gas through the pressure line **222** is controlled by a shutoff valve generally designated as **230**. In addition, the volume of flow of gas through the conduit **148** may be regulated by means of throttling valve generally designated as **232**.

In accordance with an important feature of the present invention, the shutoff valve **230** in the pressure line **222** and the throttling valve **232** in the conduit **148** are combined into a single-valve assembly operable by means of a single-manual control. An important advantage of this novel arrangement is that gas is admitted to the vaporizer chamber at the time the reservoir is pressurized so that the vaporizer cannot be flooded or subjected to excess liquid anesthetic. More specifically, and as illustrated in FIG. 3, there is provided a single dual-purpose valve generally designated as **234** including a central bore **237** defining a valve seat **238** for the shutoff valve **230**. In addition, the bore **237** receives an adjustable threaded plug **240** defining a seat **242** for the throttling valve **232**.

A valve member **244** is threaded into the opposite end of the bore **237** in order to control the opening and closing of both valves **230** and **232**. The valve member **244** includes a first tapered valve surface **244*a*** engageable with seat **238** and a second tapered valve surface **244*b*** engageable with seat **242**. An operating shaft **244*c*** of the valve body member **244** is adapted to be provided with an operating handle **246** (FIG. 7) for moving the valve surfaces **244*a*** and **244*b*** into and out of engagement with the seats **238** and **242**. The plug **240** is preferably adjusted so that when the valve **230** is fully closed, the valve **232** is closed as well.

Upon rotation of the handle **246** to open valves **230** and **232**, the pressure line shutoff valve **230** opens rapidly to a fully open position due to the relatively abrupt taper of surface **244*a***. However, due to the relatively gradual taper of surface **244*b***, the throttling valve **232** opens only gradually. Consequently, it is possible for the single-operating handle **246** to control the dual-purpose valve member for both the shutoff valve and the throttling valve functions.

In accordance with a feature of the invention, the rate of flow of anesthetic liquid through the liquid conduit **184**, and thus the concentration of the anesthetic mixture provided by the unit **140** is controlled by controlling the pressure differential existing between opposite ends of the liquid conduit **184**. The pressure regulator **228** controls the pressure of gas admitted to the reservoir **144** through the pressure line **222**. In a similar manner, a back pressure regulator **248** controls the pressure existing within the conduit **150**, and thus the pressure within the vaporizer chamber **142** at the uppermost end of the liquid conduit **184**. If desired, the back pressure regulator **248** may be similar in construction to the regulator **26** illustrated in detail in FIG. 1.

Control of the rate of flow of liquid anesthetic material through the liquid conduit **184** is achieved through adjustment of one or both of the pressure regulators **228** and **248**. In the illustrated embodiment of the invention, the back pressure regulator **248** is normally adjusted by the operator to vary the flow rate and thus the concentration, while the pressure line regulator **228** is normally preadjusted or factory adjusted at a given level. In order conveniently to adjust the rate of flow, an operating knob **250** for the regulator **248** is positioned in an accessible position of the face of the housing **152**. The regulator **228** may be located behind a removable plate **251** on a sidewall of the housing **152** (FIG. 7). A differential pressure gauge **252** is connected between the pressure line **222** and the conduit **150** (FIG. 3) and gives a pressure reading proportional to the rate of flow through the liquid conduit **184**. Conveniently, this pressure gauge is located on the housing **152** above the adjustment knob **250**. It should be understood that if desired a flow indicator could be included in the system, for example in the conduit **148** or the conduit **150**, in accordance with known practice.

Convenient attachment of the conduit **148** and the regulator **228** to a conduit **254** (FIG. 3) leading to a source of pressurized gas by way of the conventional shutoff valve **146** is made possible by a quick release tube fitting **256** located on the face of the housing **152** (FIG. 7). The use of a single source of gas assures that the vaporizer receives a gas flow whenever the reservoir is pressurized. Connection of the back pressure regulator **248** by way of a conduit **258** to a anesthetic mixture utilizing apparatus is made possible by another tube fitting **260** on the housing **152**.

The operation of the liquid anesthetic vaporizing unit **140** will be apparent to those skilled in the art from the preceding detailed description. Reviewing the operation, it is assumed initially that the shutoff valve **146**, the valve **230** and the valve **232** are all in their closed positions and the unit **140** is not in operation. To prepare the unit for operation, a bottle of a selected liquid anesthetic is attached to the base member **156** by means of a mating adapter **176**. The vaporizer unit is connected to the housing **152** of the unit **140** either before of after the bottle of anesthetic is attached to the base member **156**.

In order to begin operation, the shutoff valve **146** is opened to admit pressurized gas to the unit **140** through the fitting **256** on the face of housing **152**. The operating handle **246** for the valves **230** and **232** is then opened in order to fully open the shutoff valve **230** and to open the throttling valve **232** in order that the flow through the conduit **148** is at the desired rate. The back pressure regulator **248** is adjusted through a manipulation of knob **250** until the reading of gauge **252** indicates that the desired rate of flow of liquid anesthetic is established.

Pressurized gas then flows from conduit **148** through the vaporizer chamber and by way of conduit **150** through the back pressure regulator **248** to the anesthetic mixture utilizing apparatus. Simultaneously, pressure admitted to the reservoir by way of conduit **222** pressurizes the reservoir and forces liquid anesthetic material through the liquid conduit **184** into the reservoir chamber where it is evaporated into the gas stream.

In a liquid anesthetic vaporizing unit similar to the unit **140** and constructed in accordance with the present invention, it was found that various anesthetic liquids such as ether, halothane, trichloroethylene and methoxyflurane could be mixed with oxygen at extremely accurate and widely variable concentration levels. It was found that the rate of flow of the anesthetic material into the vaporizer chamber could be accurately controlled, independently of the liquid level, by control of the pressure drop between the pressure line **222** and the conduit **150** as shown by the reading of the pressure gauge **252**. This pressure drop could readily be controlled by adjustment of the regulator **248**.

For example, it was found that the relationship of anesthetic flow for various anesthetic liquids to pressure drop was approximately represented by the following equations:

$$F_e=-20+4\delta P$$

$$F_h=-21.5+1.7\delta P$$

$$F_t=-21+1.9\delta P$$

$$F_m=-6.75+0.78\delta P$$

In these equations F_e, F_h, F_t and F_m represent the flow of ether, halothane, trichloroethylene and methoxyflurane respectively, expressed in cubic centimeters per minute of the vapor, while δP represents the pressure drop between the pressure line conduit **222** and the outlet conduit **150** expressed in inches of water. Since the flow through the conduit **184** is governed by the rules of laminar flow, the flow is a substantially linear function of the pressure drop within the operative range of pressures which may be from about 15 to about 80 or more inches of water.

It can thus be seen that the concentration of the anesthetic and gas mixture can be accurately and conveniently controlled through a wide range of concentrations simply by adjustment of the pressure drop and the rate of gas flow through the vaporizer chamber. For example, if ether is used and the valve **232** is adjusted to permit oxygen to flow through the vaporizer chamber **142** at a rate of about 2,000 cubic centimeters per minute, while the pressure drop is adjusted to about 45 inches of water, concentration of about 8 percent of ether in oxygen is obtained. In contrast, if methoxyflurane is used and oxygen is conducted through the vaporizer chamber at a rate of about 6,000 cubic centimeters per minute, while the pressure drop is maintained at about 20 inches of water, a concentration of about 0.34 percent is obtained.

It should be understood that these specific examples are included as illustrative of one particular embodiment of the invention only, and should not be taken to limit the scope of the invention.

While the present invention has been described in connection with the details of particular embodiments thereof, various other modifications and embodiments may be devised by those skilled in the art. The present invention is not limited to the details of the described embodiments except as included in the appended claims.

What I claim as new and desire to be secured by Letters Patent of the United States is:

1. Anesthetic vaporizer for adding anesthetic vapor to a stream of gas in order to provide an anesthetizing gaseous mixture, said vaporizer comprising:
  - means defining a passageway for the stream of gas;
  - said passageway defining means including a vaporizer chamber through which the stream of gas flows;
  - a closed reservoir adapted to be charged with a supply of anesthetic in the liquid state;
  - a conduit having one end disposed within said reservoir and having another end communicating with said vaporizer chamber, said one end terminating at a point below the normal operating level of the liquid; and
  - means for pressurizing said reservoir for gradually evacuating the supply of liquid from said reservoir into said vaporizer chamber through said conduit at a rate independent of the level of liquid in said reservoir;
  - said pressurizing means including a pressure line for introducing a pressurized gas into said reservoir and communicating with said reservoir at a region beneath the surface of the liquid anesthetic contained therein.

2. The vaporizer of claim 1 further comprising adjustable means for controlling the pressure differential between said region and the interior of said vaporizer chamber, thereby to control the rate of flow of liquid through said conduit.

3. The vaporizer of claim 2, said adjustable means comprising a pressure regulator connected to said pressure line for regulating the pressure at said region.

4. The vaporizer of claim 2, said adjustable means comprising a pressure regulator communicating with said passageway defining means for regulating the pressure within said vaporizer chamber.

5. The vaporizer of claim 3, said adjustable means further comprising an additional pressure regulator communicating with said passageway defining means for regulating the pressure within said vaporizer chamber.

6. The vaporizer of claim 1 further comprising a metering valve in said conduit between said vaporizer and said closed reservoir for varying the resistance to the flow of liquid anesthetic through said conduit.

7. The vaporizer of claim 6 further comprising adjustable means for controlling the pressure differential between said region and the interior of said vaporizer chamber.

8. A liquid anesthetic vaporizing unit for adding anesthetic material to a stream of gas comprising a container adapted to contain a supply of liquid anesthetic material, a vaporizer including wall means defining an evaporation chamber, a first passage in said wall means for conducting the stream of gas into said chamber, a second passage in said wall means for conducting the stream of gas from said chamber, sealing means supported by said wall means, a conduit having a first portion extending outwardly from said wall means and having a second portion communicating with said chamber for introducing anesthetic material into said chamber said first portion terminating within said chamber at a point below the normal operating level of the liquid, means for holding said container against said sealing means with the first portion of said conduit extending into said container, a second conduit extending outwardly from said sealing means and received within said container terminating at a point below the normal operating level of the liquid, and means for introducing pressurized gas into said second conduit for pressurizing the region bounded by said container and said sealing means.

9. The unit of claim 8, further comprising means defining a bleed passageway extending from said container to said chamber for venting excess pressures from said container into said chamber.

10. Anesthetic vaporizer for adding anesthetic vapor to a stream of gas in order to provide an anesthetizing gaseous mixture, said vaporizer comprising:
  - a vaporizer chamber;
  - inlet and outlet passageways for conducting the stream of gas through said vaporizer chamber;
  - a reservoir for holding a supply of liquid anesthetic material;
  - a conduit extending from said reservoir to said vaporizer chamber for conducting liquid anesthetic to said vaporizer chamber for evaporation into the stream of gas one end of said conduit terminating below the normal operating level of the liquid;
  - a pressure line communicating with said reservoir for pressurizing said reservoir thereby to force liquid anesthetic to flow through said conduit one end of said pressure line terminating within said reservoir at a point below the normal operating level of the liquid; and
  - pressure regulating means connected to said outlet passageway for controlling the pressure within said vaporizer chamber, thereby to control the rate of flow of liquid anesthetic through said conduit.

11. The anesthetic vaporizer of claim 10 further comprising an additional pressure regulator connected to said pressure line for controlling the pressure within said pressure line.

12. The anesthetic vaporizer of claim 11 further comprising a pressure equalizing line extending between said vaporizer chamber and said additional pressure regulator for compensating for pressure variations within said vaporizer chamber.

13. A method of producing a mixture of a gas and the vapor of a liquid anesthetic material from a reservoir comprising the steps of:
  - passing a stream of gas through a vaporizing chamber communicating with the reservoir through a conduit which terminates at one end within said reservoir below the normal operating level of the liquid; and
  - adding pressurized gas to said reservoir at a point below the surface of the liquid anesthetic material contained therein in order to force the liquid anesthetic material through said conduit at a rate of flow substantially independent of the liquid level.

14. The method of claim 13 further comprising controlling the pressure difference between the pressure of said point and the pressure at said vaporizing chamber in order to meter the flow through said conduit.

15. The method of claim 13 wherein the step of controlling the pressure difference includes the steps of regulating the pressure of said pressurized gas, and regulating the pressure of said stream of gas.

16. Apparatus for producing a mixture of anesthetic and gas comprising a reservoir for a supply of anesthetic in liquid form, a vaporizer chamber, first conduit means for passing a stream of gas through said chamber, a liquid passageway for discharging liquid anesthetic from said reservoir into said chamber for evaporation into said stream of gas one end of said passageway terminating at a point below the normal

operating level of the liquid, second conduit means for passing a stream of pressurized gas into said reservoir for forcing said liquid anesthetic into said liquid passage one end of said second conduit means terminating at a point below the normal operating level of the liquid, and a control valve assembly for controlling flow through said first and second conduits means, said control valve assembly comprising a first valve in said first conduit means, a second valve in said second conduit means, and a single manually operated means for simultaneously opening both said first and second valves.

17. The apparatus of claim **16**, said valve assembly including a valve bore, first and second seats in said bore, and a single valve member movable in said bore having first and second valve seating surfaces engageable with said first and second seats to close said first and second valves.

18. The apparatus of claim **17**, said first and second valve seating surfaces being constructed and arranged with respect to said first and second seats so that said first valve is a shutoff valve and said second valve is a throttling valve.