

[72] Inventors **Forrest M. Bird**
Palm Springs, California
(Box 817, Sandpoint, Idaho 38864);
Henry L. Pohndorf, El Cerrito, Calif.
(Box 817, Sandpoint, Idaho 38864)
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[56]

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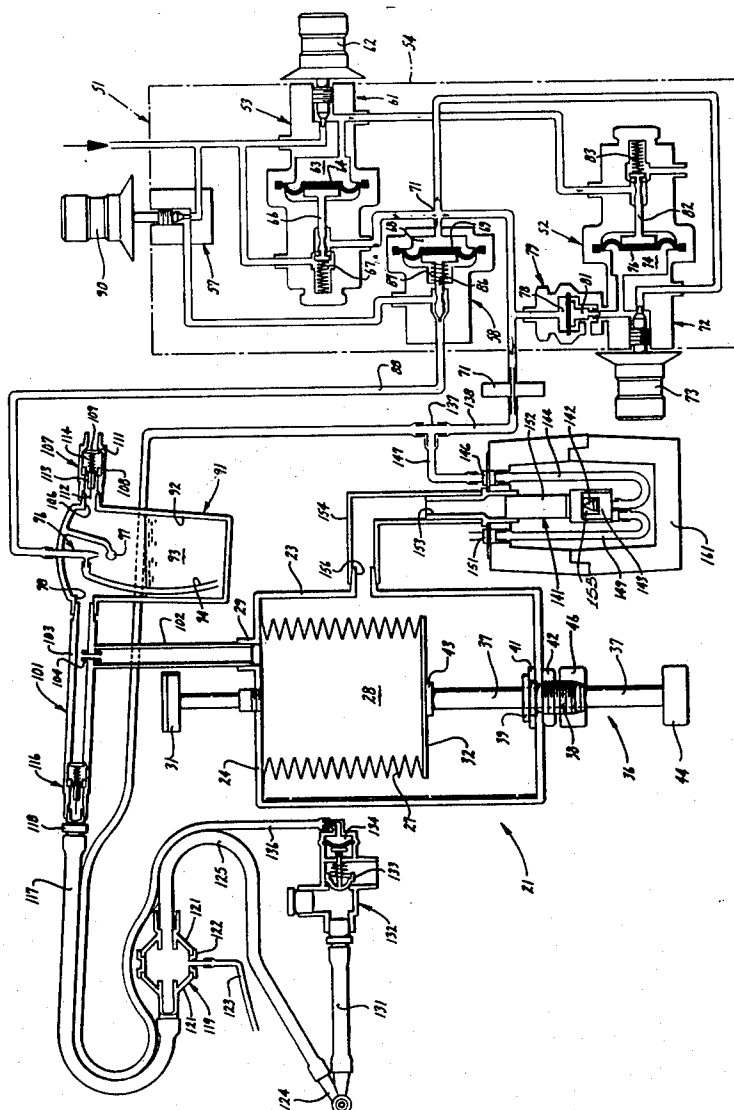
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Primary Examiner—Charles F. Rosenbaum
 Attorney—Flehr, Hohbach, Test, Albritton and Herbert

[54] **MECHANICAL VOLUME LIMITING VENTILATOR**
15 Claims, 2 Drawing Figs.

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ABSTRACT: Mechanical volume limiting ventilator having a bellows which is filled with humidified and nebulized gas during the expiratory phase for delivery to the patient during an inspiratory phase.



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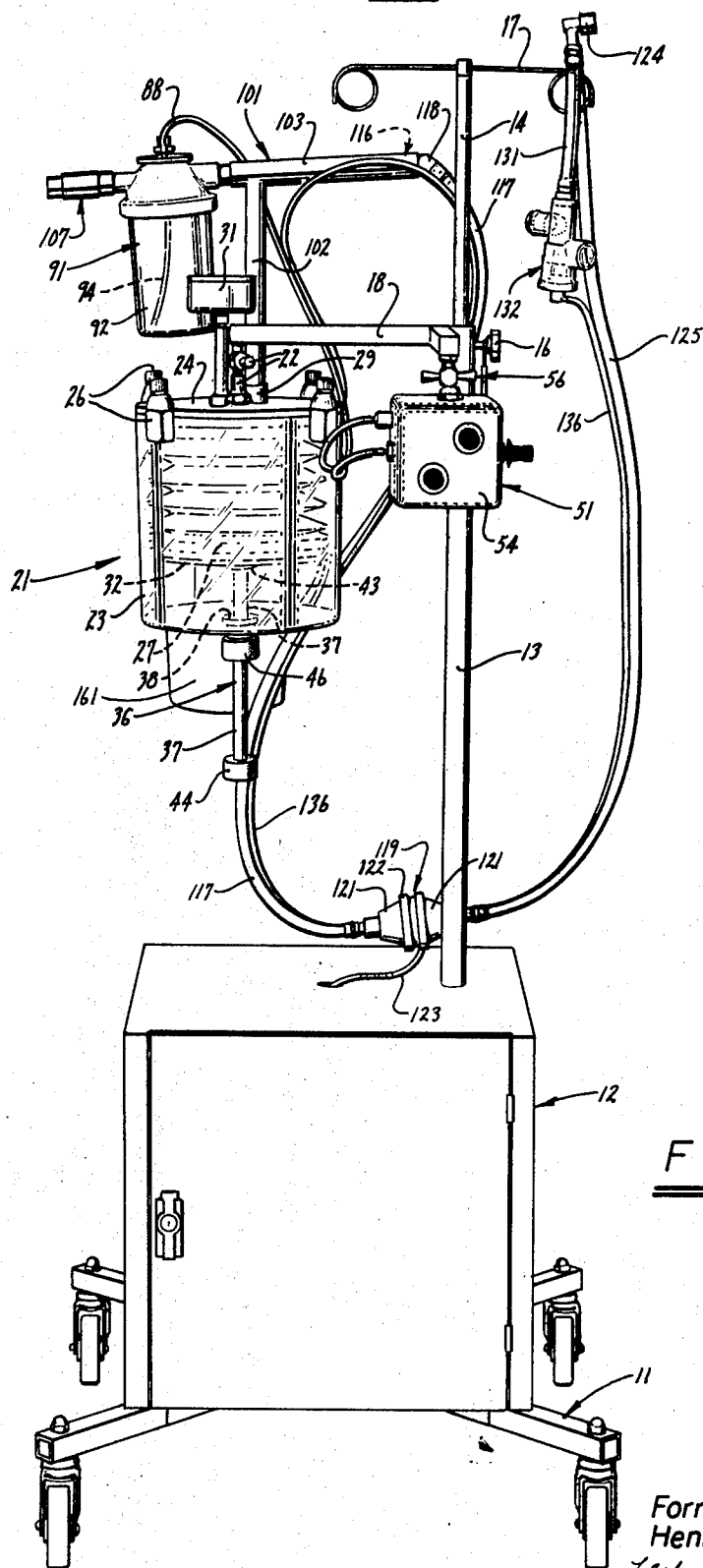


Fig. 1

INVENTORS

Forrest M. Bird
Henry L. Pohndorf

*Flehm, Hochbach, West,
Albritton & Hubert*
Attorneys

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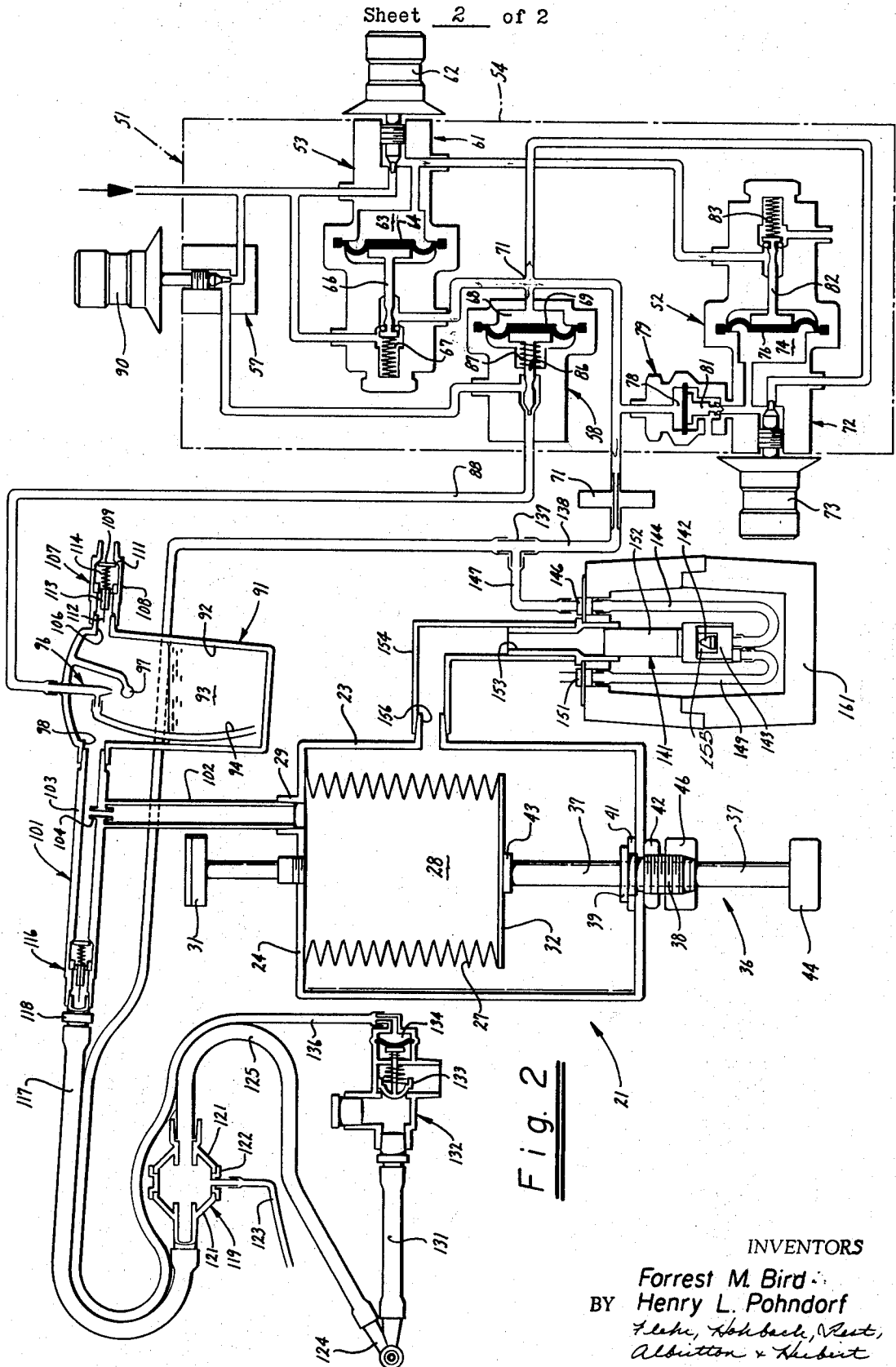


Fig. 2

INVENTORS

Forrest M. Bird
 BY Henry L. Pohndorf
*Fleke, Hohbach, Reest,
 Albitton & Herbert*
 Attorneys

MECHANICAL VOLUME LIMITING VENTILATOR

BACKGROUND OF THE INVENTION

This invention relates to mechanical volume limiting ventilators. In the past, mechanical volume limiting ventilators have been provided but, in general, these have utilized a mechanical piston to deliver predetermined volumes of air to the lungs of the patient. Such ventilators have been found to have certain limitations. For example, there has been inability to adequately humidify the inspiratory gases and to deliver medications with conventional nebulizers without altering preselected tidal volumes. In addition, the mechanical dead space has been hard to control resulting in undesirable re-breathing of exhaled gas by the patient. It often is difficult to sterilize the components of the ventilator which has led to nosocomial infections. Also such ventilators have been relatively large. In addition, they have been electrically powered which prevents their use in hyperbaric chambers in the presence of oxygen. Also, with such apparatus, it has not been possible to obtain certain desirable features such as assistance to spontaneous respiration, adjustable negative expiratory phase, expiratory retardation of exhaled gases, adjustable biphasic inspiratory flow and an adjustable apneustic plateau.

SUMMARY OF THE INVENTION

The mechanical volume limiting ventilator consists of means which forms an expansible chamber adapted to receive a gas. A patient adapter and means connecting the patient adapter to the chamber is provided. Control means is also provided for delivering gas to the chamber. Adjustable means adjusts the size to which the chamber can expand so that a controlled volume of the gas is received by the chamber. Means is provided for causing the size of the chamber to decrease to expel the gas within the chamber through the patient adapter into the airway of the patient so that there is delivered to the patient a preselected tidal volume against the changing pulmonary resistances of the lungs of the patient. Means is provided for humidifying and/or nebulizing the breathing gas before it is delivered to the patient.

In general, it is an object of the present invention to provide a mechanical volume limiting ventilator with which it is possible to deliver a preselected tidal volume of breathing gas to the patient against changing pulmonary resistances in which the breathing gas has been properly humidified and nebulized.

Another object of the invention is to provide a ventilator of the above character in which it is possible to readily control the oxygen concentration of the breathing gas.

Another object of the invention is to provide a ventilator of the above character in which the mechanical airway of the apparatus is purged of all exhaled gases so that the breathing gases are delivered to the patient free of exhaled or used gases.

Another object of the invention is to provide a ventilator of the above character in which the wet circuit components can be readily disassembled and sterilized to minimize the chances of nosocomial infections.

Additional objects and features of the invention will appear from the following description and drawings as set forth below.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a perspective view of a mechanical volume limiting ventilator incorporating the present invention.

FIG. 2 is a schematic diagram of the ventilator shown in FIG. 1.

DESCRIPTION OF THE PREFERRED EMBODIMENT

As shown in FIG. 1, the mechanical volume limiting ventilator consists of a wheeled stand 11 which includes a cabinet 12 and a rigid vertical tube 13 which has telescoped therein a support rod 14 and held in a predetermined position within the tube by a screw 16. A holder 17 is mounted on the top of the rod 14. A tee bar 18 is mounted on the upper end of the

rigid tube 13. A bellows assembly 21 is connected by a fitting 22 to the tee bar 18.

The bellows assembly 21 is very similar to an assembly described in copending application Ser. No. 454,345, filed May 10, 1965 now U.S. Pat. No. 3,467,618. As disclosed therein, it consists of a cylindrical canister 23 which has a closed bottom end and an open top end formed of a suitable relatively transparent material such as plastic. A canister cover or plate 24 covers the top of the canister and is secured thereto by latching means 26 of the type particularly identified in copending application Ser. No. 454,345, filed May 10, 1965. An expansible and contractible bellows 27 is secured to the top cover or plate 24 and is provided with an open top end and a bottom closed end to provide an expansible and contractible chamber 28 within the bellows and the top plate 24. This chamber 28 is in communication with an opening provided in a fitting 29 on the top plate 24. A manometer 31 is provided for measuring the pressure within the chamber 28. A bottom or calibration plate 32 is secured to the bottom of the bellows 27 and is used in conjunction with vertical calibrations (not shown) on the canister 23 to measure the volume within the chamber 28.

Adjustment means 36 is provided for adjusting the volume of gas which can be entrained within the bellows 27 and consists of a tubular member 37 slidably mounted in a threaded split sleeve 38 formed of a suitable material such as nylon. The sleeve 38 is provided with a flange 39 which is disposed on the inner side of the bottom wall of the canister 23 and engages a washer 41 resting against the inner side of the bottom wall of the canister 23. A nut 42 is threaded onto the sleeve 38 and engages the bottom side of the bottom wall of the canister 23 to hold the sleeve 38 in place. A bumper 43 formed of a suitable material such as neoprene is mounted on the upper end of the tubular member 37 and is adapted to engage the bottom side of the lower plate 32 carried by the bellows 27. A knob 44 is mounted on the lower end of the tubular member 37 and is utilized for adjustment of the tubular member 37 vertically within the sleeve 38. The tubular member 37 is held in a predetermined place within the sleeve 38 by a collet 46 which is threaded onto the sleeve 38 and causes the sleeve 38 to frictionally engage the tubular member to hold the tubular member in a predetermined vertical position within the sleeve and to thereby prevent lowering of the bottom plate 32 of the bellows below a predetermined position as determined by the upper surface of the bumper 43.

Means is provided for delivering the gas to be breathed by the patient into the chamber 28 and consists of a controller or servo unit 51. This controller 51 is described in copending application Ser. No. 601,770, filed December 14, 1966, now abandoned includes an inspiratory cartridge 52 and an expiratory cartridge 53 which are enclosed within a case 54. The controller 51 is supported by the tee 18 by means of an inlet assembly 56 which is secured to the tee 18. The inlet fitting is adapted to be connected to the gas which is to be utilized by the patient as, for example, oxygen. This gas supply to the controller 51 is indicated by the arrow shown in FIG. 2 and is connected to the cartridges 52 and 53 in the manner indicated. The gas is also connected to a flow/pressure control assembly 57. The outlet of the flow/pressure control assembly 57 is connected to an expiratory flow cartridge 58 which is similar to the cartridge 125 shown in FIG. 11 of U.S. Letters Pat. No. 3,191,596.

The controller 51 operates in the manner described in copending application Ser. No. 601,770, filed December 14, 1966 now abandoned. As explained therein, if it is assumed that the expiratory cartridge 53 and the inspiratory cartridge 52 are both in closed positions, the expiratory phase is in command and the expiratory cartridge 53 is activated first. The expiratory cartridge 53 includes an expiratory time assembly 61 which includes a control knob 62 for metering gas into a space 63 on one side of a diaphragm 64. The length of time required for the gas to fill the space 63 and to move the valve member 66 against the force of a spring 67 de-

termines the length of time for the expiratory phase. Upon conclusion of the expiratory phase by movement of the plunger 66 to the left as viewed in FIG. 2, gas under pressure is supplied to the space 68 on one side of the diaphragm 69 in the expiratory flow cartridge 58. It is also supplied to a connector 71. The gas is also delivered to an inspiratory time assembly 72 of the inspiratory cartridge which includes a control knob 73 to meter the flow of gas at a controlled rate into a chamber 74 on one side of a diaphragm 76 in the inspiratory time assembly 52. Gas is also supplied to a space 78 of an outlet vent assembly 79 mounted on the inspiratory cartridge 52 to keep a valve member 81 in a closed position as long as the plunger 66 of the expiratory cartridge is open.

The time required to fill the chamber 74 determines the length of the inspiratory phase. As soon as the pressure within the chamber 74 is sufficient to urge the plunger 82 to the right against the force of the spring 83, the inspiratory phase is terminated because movement of the plunger 82 causes the chamber 63 in the expiratory cartridge to be vented to the atmosphere through the inspiratory cartridge 52. The spring 67 then moves the plunger 66 to the right to interrupt the flow of gas to the expiratory flow cartridge 58 and to the inspiratory cartridge 52. Gases which have accumulated within the chamber 74 are then vented to the atmosphere through the outlet vent assembly 79 which permits the spring 83 to return the plunger 82 to its home position. This completes the cycle and the exhalation commences again.

During the time that gas under pressure is supplied to the space 68 in the expiratory flow cartridge 58, the plunger 86 is shifted to the left as viewed in FIG. 2 against the force of spring 87 to terminate the flow of gas through the flow pressure assembly 57 which includes a control knob 90 for adjusting the rate of flow through the cartridge 58 into the tubing 88.

The tubing 88 is connected to a nebulizer 91. The nebulizer is of a type described in copending application Ser. No. 447,852, filed April 12, 1965 now U.S. Pat. No. 3,353,536 issued November 21, 1967. As described therein, it consists generally of a relatively large container 92 as, for example, one which can hold 500 cc. The container 92 carries a liquid 93 which is to be nebulized by means of a tube 94 extending into the liquid and which is connected to a nozzle assembly 96. The tubing 88 is connected to the nozzle assembly 96 and is adapted to cause the gas to pass through the nozzle assembly and aspirate liquid from the tube 94 and cause the same to impinge upon a ball 97. This causes the entrained particles of liquid to be nebulized or, in other words, to be broken up into small particles as, for example, a size ranging from .5 to 4 microns. These particles are carried by the air stream through an outlet 98 provided in the nebulizer 91.

The outlet 98 is connected to one end of a rigid tee assembly 101. The tee assembly 101 consists of a vertical tubular member 102 which has its lower end mounted in the fitting 29 of the bellows assembly 21. The upper end is connected to an intermediate portion of a second tubular member 103. One end of the tubular member 103 is mounted in the outlet 98 of the nebulizer 91. A relatively short pipe or tubular member 104 having a diameter which is substantially less than the diameters of either of the tubular members 102 or 103 is mounted in the side wall of the tubular member 103 in a substantially vertical direction in registration with the tubular member 102 so that the lower extremity of the pipe 104 extends downwardly into the tubular member 102 and so that the upper extremity of the pipe 104 extends above the lower surface of the tubular member 103. The pipe 104 serves to prevent any water which may condense on the tube 103 from running down into the tube 102 and into the bellows assembly 21.

The nebulizer 91 is provided with an inlet 106. A one-way valve assembly 107 is mounted on the inlet 106 and consists of a housing 108. A valve member 109 is mounted within the housing for movement between open and closed positions with respect to a valve seat 111. The valve member 109 is car-

ried by a valve stem 112 slidably mounted in a retaining member 113 carried by the valve body or housing 108. A spring 114 is provided on the stem and has one end engaging the valve member 109 and the other end engaging the retaining member 113 to yieldably urge the valve member 109 towards a closed position with respect to the seat 111.

A similar one-way valve 116 is mounted on the tee assembly 101 on the member 103 opposite the end where the nebulizer 91 is mounted. The one-way valve 116 is connected to a large tube 117 by an adapter 118. The other end of the tube 117 is connected to the inlet of a water trap 119. The water trap 119 consists of a pair of cone-shaped members 121 mounted on a ring 122. A drain tube 123 is carried by the ring 122. The drain tube 123 extends into the cabinet 12 where it drains into a suitable receptacle. The outlet of the water trap 119 is connected to a large tube 125 which is connected to a patient adapter 124.

The patient adapter 124 is connected by a large tube 131 to an exhalation valve assembly 132. The exhalation valve assembly 132 is substantially conventional and includes a valve member 133 which is yieldably held in a closed position by air supplied under pressure to a space 134 on one side of a diaphragm from a tube 136 connected to a tee 137 and a tube 138 to the coupling 71.

Means is provided for causing the size of the chamber 28 within the bellows to decrease or, in other words, to expel the gas contained within the chamber and consists of a venturi assembly 141 which is similar to the type described and shown in FIG. 8 of copending application Ser. No. 442,310, filed Mar. 24, 1965 now U.S. Pat. No. 3,331,368, issued July 18, 1967. The venturi assembly 141 includes a low capacity nozzle assembly 142 and a high capacity nozzle assembly 143. The low capacity nozzle assembly 142 is connected by tubing 144 to a fitting 146 which is connected by tubing 147 to the tee 137. The nozzle assembly 143 is connected to tubing 149 which is connected to a fitting 151 which alternatively may be connected to the tubing 147. During the inspiratory phase, air or gas under pressure is supplied through the tubing 147 to the nozzle assembly 142 which causes a jet of air to pass through the venturi contained within a tube 152 and to aspirate therewith additional atmospheric air through the openings 155 to supply substantial quantities of air to an outlet tube 153 which is connected by tubing 154 to an inlet fitting 156 provided on the canister 23 of the bellows assembly 21. The venturi assembly 141 is enclosed with a sound-proofing housing 161 which serves as a muffler to muffle the sound of the venturi assembly during its operation.

Operation of the mechanical volume limiting ventilator may now be briefly described as follows. Let it be assumed that the expiratory phase in the controller 51 has just commenced. As hereinbefore explained, when such is the case, gas is not being supplied to the space 68 of cartridge 58 and the spring 87 keeps the plunger to the right as viewed in FIG. 2 to permit gas to be supplied to the tube 88 at a rate controlled by adjustment of the knob 90. The gas passes through the nozzle assembly 96 into the nebulizer 91 to cause small particles of water to become entrained in the air stream which passes out of the nebulizer 91 and into the tee 101. The gas then passes down the tubular member 102 in the chamber 28 in the bellows 27. Since a positive pressure is not present within the canister 23, the bottom plate 32 attached to the bellows 27 descends by gravity. This causes a negative pressure to be created in the chamber 28 of the bellows so that the gas is drawn into the chamber 28. This filling operation during the expiratory phase continues until the bottom plate 32 comes to rest against the bumper 43 of the adjustment means 36. It can be readily seen that the volume of air or gas entrained within the bellows 28 can be readily adjusted mechanically by adjusting the position of the sliding rod 37 within the collet 46.

If insufficient gas is being supplied by the flow pressure assembly 57 to overcome the negativity being created in the chamber 28 by descent of the bellows 27, the one-way valve 107 opens and additional air is entrained from the atmosphere

through the one-way valve 107, the nebulizer 91 and into the tee 101.

It can be seen that by utilizing this arrangement, it is possible to supply oxygen to the controller 51 and then to mix this with air through the one-way valve 107 which passes through the nebulizer 91 and is humidified by the nebulizer as it passes into the tee 103. In this way, it can be seen that various oxygen concentrations can be obtained in the gases which are delivered to the chamber 28 within the bellows and to be delivered to the patient during the inspiratory phase.

During the time that the bellows 27 is being filled, a certain amount of the gases are being expelled through the one-way valve 116 to purge the complete mechanical air passage within the tee 101 and also the tube 117, the nebulizer 119 and the tube 123 through the exhalation valve assembly 132. In this way, all exhaled gases are eliminated from the ventilator so that they cannot be inhaled again by the patient. The arrangement of the apparatus is such that all dead space is substantially eliminated.

After the chamber 28 within the bellows 27 has been filled and after completion of the expiratory phase, the controller 51 switches to the inspiratory phase in the manner hereinbefore described to cause gas to pass through the cartridge 53 and through the tube 147 into the venturi assembly. The venturi assembly 141 supplies air to the canister 23 to cause a positive pressure to be created within the canister to cause the bellows to be raised gradually to decrease the volume of the chamber 28 so that the gas or air within the chamber 28 is expelled therefrom through the tubular member 102, the tubular member 104, the tubular member 103, through the one-way valve 116, through the large tube 117, the water trap 119, the tube 125 to the patient adapter 124, and thence to the airway of the patient. The chamber 28 is substantially emptied by this action to deliver a preselected tidal volume of gas or air to the patient against changing pulmonary resistances of the lungs of the patient.

The apparatus remains in the inspiratory phase until it is terminated by the controller 51 in the manner hereinbefore described. Upon termination of the inspiratory phase and initiation of the expiratory phase, the tubing 136 is exhausted to the atmosphere through the venturi assembly 141 and the valve member 132 is permitted to open permitting the patient to exhale to the atmosphere. At the time that this is occurring, the plunger 86 opens to permit gas to be supplied through the flow pressure assembly 57 and through the expiratory flow cartridge 58 to the nebulizer 91 in the manner hereinbefore described. Thus, it can be seen that the ventilator operates automatically under the control of the controller 51.

The mechanical volume limiting ventilator hereinbefore described has many advantages and capabilities. It has the ability to automatically select the necessary pressure to deliver a preselected tidal volume to the patient against changing pulmonary resistances of the patient. The use of the nebulizer makes it possible to properly humidify the air before it is delivered to the patient so that the air as it is delivered to the patient carries the proper amount of moisture. By the addition of medication in the nebulizer, it is possible to administer aerosolized medications to the patient. By adjustment of the flow pressure assembly 57, it is possible to regulate the amount of nebulization and the oxygen concentration in the air supplied to the patient. The nebulizing system makes it possible to produce nebulized inspiratory gases without upsetting the preselected and pre-measured volumes to be supplied to the patient. The arrangement is also such that the addition of nebulized particles to the inspiratory gases does not alter the preselected inspiratory volume.

By way of example, delivery pressures to the patient can be varied from 5 to over 150 mm Hg. The inspiratory flow rates can be varied from 5 to over 200 liters per minute.

By adjustment of the one-way reloading valve 107, it is possible to allow the patient's spontaneous inspiratory effort to entrain the ambient air through the valve or to receive assistance to his spontaneous ventilatory pattern. By adjust-

ment of the controller 51, it is possible to provide a timed inspiratory apneustic plateau following the delivery of the tidal volume by the ventilator. Although the one-way valve 107 is connected to the nebulizer 91, it can alternatively be mounted directly on the bellows assembly 21 so that atmospheric air would enter the bellows 27 directly and bypassing the nebulizer 91.

As can be seen from the drawing, the ventilator is constructed in such a manner that it can be readily disassembled. In particular, the parts which are connected in the wet circuit as, for example, the nebulizer 91, the tee 101, the tube 117, the nebulizer 119, and the tube 123, can be readily removed for sterilization to minimize chances of nosocomial infections.

The ventilator is also one which is relatively simple to operate and, in particular, in which only one control is utilized for setting the tidal volume.

We claim:

1. In a mechanical volume limiting ventilator providing non-rebreathing inspiratory and expiratory phases, means forming an expandable and contractible chamber, a patient adaptor adapted to be connected to the airway of the patient, means connecting the patient adaptor to said chamber, means for delivering a gas to said chamber, means connected to said means for delivering gas to said chamber for supplying a nebulized liquid to the gas only during the expiratory phase and before it is supplied to said chamber, adjustable means for adjusting the size to which the chamber can be expanded so that a controlled tidal volume is supplied to the patient, and means causing the size of the chamber to contract to force the gases in the chamber into the airway of the patient.

2. A ventilator as in claim 1 together with automatic control means connected to the chamber so that the chamber is being filled during the expiratory phase and is being emptied during the inspiratory phase.

3. A ventilator as in claim 2 wherein said control means includes valve means operable to effect filling of the chamber during the expiratory phase.

4. A ventilator as in claim 1 wherein said means connecting the patient adaptor to the chamber includes a tee shaped member having three openings with one of the openings connected into said chamber, a one-way valve connected to another of the openings leading to the patient adaptor and the other of the openings being connected to the means for supplying a nebulized liquid.

5. A ventilator as in claim 4 wherein said tee-shaped member is formed of first and second tubular members joined together at substantially right angles to each other and an additional tubular member mounted in the side wall of the first tubular member and having one end in alignment with and in communication with the second tubular member and having the other end extending above the side wall of the one tubular member.

6. A ventilator as in claim 1 together with means for flushing used gases from the means connecting the patient adaptor to said chamber during the inspiratory phase to prevent reinhalation of exhaled gases.

7. A ventilator as in claim 1 wherein said means for delivering a gas to said chamber includes a flow pressure assembly for controlling the rate of flow of gas to said means for supplying a nebulized liquid for controlling the rate of nebulization.

8. In a ventilator providing non-rebreathing inspiratory and expiratory phases, a rigid canister, an expansible and collapsible bellows mounted in said canister and forming a chamber inside the bellows, a patient adaptor adapted to be connected to the airway of the patient, connecting means connecting the patient adaptor to the chamber within the bellows, automatic control means for supplying gas to the chamber, means connected intermediate the control means and the chamber for nebulizing the gas only during the expiratory phase and before it is delivered to the chamber, and means controlled by the control means for supplying gas to the canister to cause the bellows to be contracted to expel the gases contained therein into the airway of the patient.

9. A ventilator as in claim 8 together with an adjustable

member carried by the canister and adapted to engage the lower extremity of the bellows to prevent downward movement of the bellows and means for retaining the slidable member in an adjusted position so that a preselected tidal volume is applied to the airway of the patient during each cycle of operation of the ventilator.

10. A ventilator as in claim 8 wherein said means connecting the patient adapter to the chamber within the bellows includes a tee shaped member having three ports, one of the ports being connected to the chamber in the bellows, another of the ports being adapted for connection to the airway of the patient, and the other of the ports being connected to the control means.

11. A ventilator as in claim 8 together with one-way valve means in communication with the chamber in the bellows for permitting atmospheric air to enter in the chamber.

12. A ventilator as in claim 8 together with nebulizing means in communication with said chamber for nebulizing a liquid and supplying it to the chamber without changing the pre-measured volume to be delivered by the bellows.

13. In a ventilator, a rigid canister, and expansible and collapsible bellows mounted in said canister and forming a chamber inside the bellows, a patient adapter adapted to be connected to the airway of a patient, connecting means connecting the patient adapter to the chamber within the bellows, automatic control means for supplying gas to the chamber,

nebulizing means connected to said chamber, one-way valve means connected to said nebulizing means to permit atmospheric air to enter said nebulizing means, and means controlled by said control means for supplying gas to said canister to cause said bellows to be contracted to expel the gases contained therein into the airway of the patient.

14. A ventilator as in claim 13 together with an additional one-way valve connected intermediate said patient adapter and said chamber and arranged to prevent the flow of exhalation gases from the patient into the chamber.

15. In a mechanical volume limiting ventilator, means forming an expandable and contractible chamber, a patient adaptor adapted to be connected to the airway of the patient, means connecting the patient adaptor to said chamber, means for delivering a gas to said chamber, means connected to said means delivering gas to said chamber for supplying a nebulized liquid to the gas before it is supplied to said chamber, including a flow pressure assembly for controlling the rate of flow of gas to said means for supplying a nebulized liquid for controlling the rate of nebulization and including means for delivering a certain proportion of air, adjustable means for adjusting the size to which the chamber can be expanded so that a controlled tidal volume is supplied to the patient, and means for causing the size of the chamber to contract to force the gases in the chamber into the airway of the patient.

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