

[54] OPEN CIRCUIT SYSTEM FOR
RESPIRATION TESTING[75] Inventor: **Sabbo Woldring**, Schenectady, N.Y.[73] Assignee: **General Electric Company**,
Schenectady, N.Y.[22] Filed: **Aug. 27, 1973**[21] Appl. No.: **391,591**[52] U.S. Cl. **128/208**[51] Int. Cl. **A61b 5/08**[58] Field of Search 128/2.08, 2.07, 145.5-145.8,
128/DIG. 29, 2 Cof Med. Inst., V. 6, No. 2, March, April 1972, (Copy
in 128/2.08).Sackner et al., "Bag in Box System for body Ple-
thym", J. Appl. Physiol., 19(3), 534-535. (Copy in
128/2.08).*Primary Examiner*—Richard A. Gaudet*Assistant Examiner*—Lee S. Cohen*Attorney, Agent, or Firm*—Leo I. MaLossi; Joseph T.
Cohen; Jerome C. Squillaro[57] **ABSTRACT**

A spirometer-bag-in-the-box combination is provided with means for maintaining volumetric balance between the bag and the box portions of the device. An air displacement system is connected to both the bag and box portions, the air displacement system including a pair of controllably variable volumes, e.g. reciprocating pump volumes and means for alternately placing these volumes in flow communication with either the bag and box portions of the device or with the ambient (in the simplest arrangement). Thus, when connection is made to the ambient, spent air is discharged and fresh air enters the breathing circuit.

[56] **References Cited****UNITED STATES PATENTS**

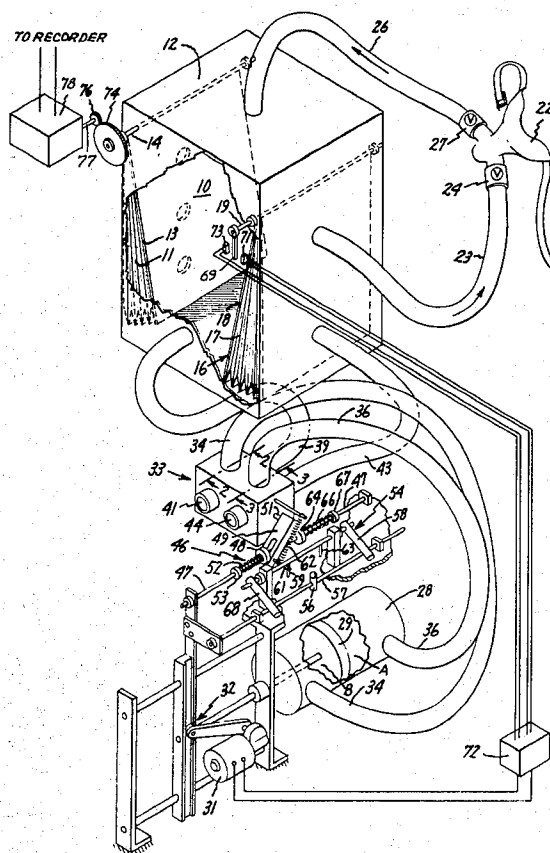
514,448	2/1894	Desant	128/145.7
2,770,232	11/1956	Falk	128/145.7
3,006,336	10/1961	Burlis et al.	128/2.08
3,166,068	1/1965	Kuban et al.	128/145.5

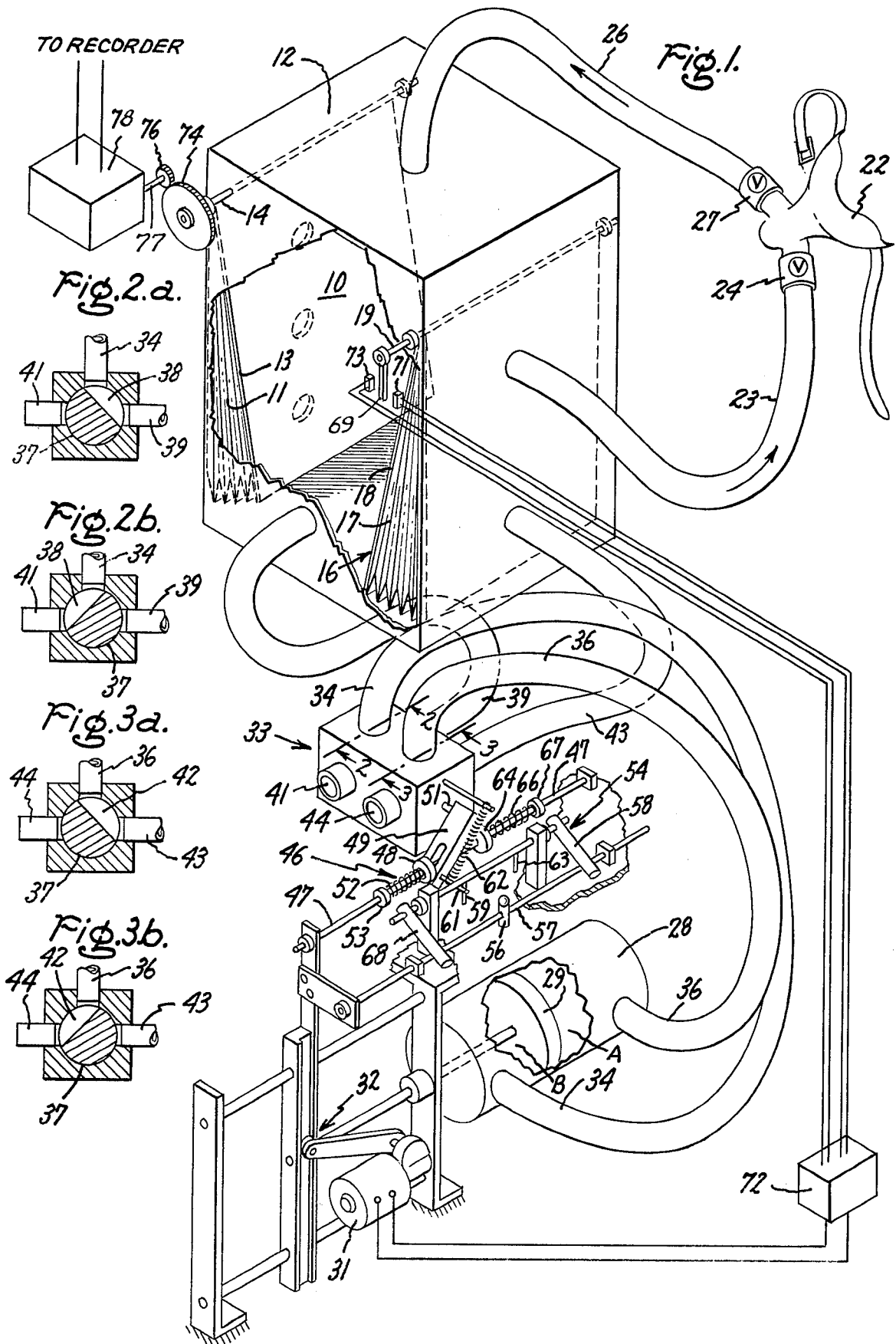
FOREIGN PATENTS OR APPLICATIONS

818,186	2/1937	France	128/145.7
741,850	7/1932	France	128/145.6
302,178	7/1968	Sweden	128/145.6
643,476	7/1962	Italy	128/145.7

OTHER PUBLICATIONS

Gisser et al., "Bag-Box Spirometer", J. Assn. for Adv.

7 Claims, 5 Drawing Figures



OPEN CIRCUIT SYSTEM FOR RESPIRATION TESTING

BACKGROUND OF THE INVENTION

Spirometry is the measurement of the volumes of breath inhaled and exhaled by a subject with the objective of determining the values of various pulmonary functions such as, vital capacity, inspiratory reserve volume, expiratory reserve volume, tidal volume, etc. These measurements, or data from which this information can be calculated, are obtained by the use of a volumetric device called a spirometer.

Spirometers fall into two general categories, the first, in which the subject inhales from and exhales into a single expandable volume (closed circuit unit) and, the second, in which the subject inhales from a first volume and exhales into a second volume, one of the first and second volumes being expandable (open circuit unit). Each of these two approaches as now known have certain disadvantages, the primary disadvantages of the latter system being the limitation inherently placed on the period of test duration (when the first volume has been emptied into the second volume by the subject).

A device for measuring various pulmonary functions over long periods of continuous operation, without carbon dioxide accumulation or oxygen depletion would be of considerable value in the treatment of patients, especially patients suffering from respiratory diseases, such as emphysema.

DESCRIPTION OF THE INVENTION

This invention is a truly open circuit device for respiration testing employing a bag-in-the-box unit. In addition to the conventional mouthpiece and mouthpiece conduits connecting to the bag and box portion, this unit receives fresh air from, and discharges spent air to, a volume or volumes outside the device, e.g. the ambient, via means for maintaining substantial balance between the volumes of the bag and the box portions of the unit. A pair of controllable volume displacement means, e.g. a pair of pump volumes, are employed to provide this balance, one of these volumes being filled, while the other is being emptied, and vice versa, with the filling and emptying being conducted at substantially exactly the same volumetric rate. When reciprocating pumps or diaphragm pumps are used, one of the pump volumes is connected to first valve means and the other pump volume is connected to second valve means. In the simplest arrangement of the valve means, the first valve means is connected to the box portion of the device and is sequentially positioned to place a pump volume into flow communication with the box, then with the ambient and back to the box, this cycle being repeated. The second valve means is connected to the bag portion of the device and is sequentially positioned to place a second pump volume into flow communication with the bag portion, then with the ambient and back to the bag, this cycle being repeated. The valve means are synchronized to simultaneously provide solely pump to bag-in-the-box flow communication for both pump volumes and then to simultaneously provide solely pump to ambient flow communication for both pump volumes.

The system is, of course, readily adaptable to a more complex arrangement in which the exhaled gases are either conducted to a device, such as a mass spectrometer, for analysis thereof or are renovated by circula-

tion thereof through a scrubber for the removal of carbon dioxide, after which the scrubbed gases (with the requisite amount of oxygen added thereto) can be utilized as the input gas volume. The latter arrangement would be appropriate in the event that a radioactive gas such as xenon 131 is to be employed in the gas composition to accomplish lung tracing on the subject. Also, it may be desired to add specific gases to the input gas volume for particular purposes. Thus, as much as 80 percent of helium by volume (the balance being oxygen) may be added to measure ventilation of the lung, a trace of carbon monoxide may be introduced for measuring the diffusion coefficient of the alveolar membrane, or a trace of either nitrous oxide or acetylene may be introduced to aid in the determination of arterial blood flow.

Pumps useful for the practice of this invention are primarily of the reciprocating piston type and the use of a common piston for a pair of uniaxial pump volumes is the preferred arrangement. However, separate substantially identical (as to volumetric displacement rate) pumps may be used advantageously, for example, diaphragm pumps or rotary pumps. Properly matched rotary pumps can be used without valve means as are required with reciprocating or diaphragm pumps. Electrically driven pumps having the same volumetric displacement rate can be coordinated in their operation such that the pump volume of the first pump is filling at the same rate as the pump volume of the second pump is emptying. The effectiveness of pump operation should be such that the volume of the bag relative to the volume of the bag-in-the-box system remains stable within ± 5 ml (when the pump is on) to avoid affecting the spirometer by the pump action.

The valve means, where employed, may be in the same or separate housings. For convenience the valve means should be commonly actuated.

Materials for construction of the bag portion, box portion, conduits, spirometer, valves and pumps are conventional. Operation of the spirometer is identical to prior art operation and prior art spirometer structures and displacement measuring devices therefor may be employed. The spirometer can be located within the confines of the box as shown in the accompanying drawings or it may be disposed outside the box, but in flow communication with the internal volume thereof. In the first case, the volume of the bag-in-the-box system is the box volume less the spirometer volume. In the latter case, the volume of the bag-in-the-box system is the volume of the box plus the spirometer volume.

The principles of assembly of the various components and the interconnection thereof are set forth in the accompanying drawing by way of example. Use of this invention for respiration testing is analogous to the use of bag-in-the-box type structures now in use by physicians and clinical technicians, except that with this invention the period of testing can be extended as desired.

Other aspects and advantages of this invention will become apparent from consideration of the following portion of the specification setting forth, together with the annexed drawing, the preferred embodiment of the invention. In the drawing:

FIG. 1 is a three-dimensional view partially cut away of the preferred embodiment;

FIGS. 2a and 2b are sectional views taken on line 2-2 of FIG. 1 and

FIGS. 3a and 3b are sectional views taken on line 3—3 of FIG. 1.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Spirometer 10, which in essence constitutes an expansible volume, comprises bellows 11 connected between a pair of rigid walls, one of which is one wall of box 12 and the second, wall 13, depends from, and is rotatable about the shaft 14 supported by two other walls of box 12. Spirometer 10 is actuated whenever a change occurs in the volume of the lungs of the subject, this change being manifest either in a second expansible volume, bag 16, or in the free volume of box 12 as will be explained below. Bag 16 comprises bellows 17 disposed between a pair of rigid walls one of which is still another wall of box 12 and the second is wall 18, depending from and rotatable around shaft 19. Bellows 11 is in flow communication with the ambient.

Both expansible units 10 and 16 are shown disposed within the fixed dimensions of box 12. This arrangement for spirometer 10 is more convenient than having this unit outside the box. Also, this arrangement provides the protection of box 12 to the spirometer.

Mask, or mouthpiece, 22 to be worn by the subject during respiration testing is in flow communication with the interior of bag 16 via mouthpiece conduit 23 and one-way valve 24 for the inspiration of gas therefrom and is similarly in flow communication with the free volume of box 12 (volume outside of both spirometer 10 and bag 16) via mouthpiece conduit 26 and one-way valve 27 for the expiration of gas into this free volume.

The direction of gas flow described for the entire system is exemplary and may be completely reversed, if desired.

Without the means of this invention for maintaining a reasonably stable relationship between the volume of bag 16 and the free volume in box 12, testing of the subject would be able to proceed only until the volume of bag 16 will have been depleted by the withdrawal of gas therefrom via conduit 23 during inspiration.

According to this invention, means are provided whereby the test duration is no longer limited in this manner, the means functioning to maintain reasonable stability for the bag-in-the-box system (i.e. the volume of the bag 16 plus the free volume of box 12 should not vary more than ± 5 ml). This is accomplished (a) by removing gas at a given volumetric rate from whichever volume receives the gases exhaled by the subject and (b) by introducing gas at substantially the same volumetric rate into the volume from which the subject inhales. This gas volume exchange, further, may be readily accomplished by exhausting exhaled gases to the ambient and introducing fresh air into the volume from which the subject inspires.

Stabilization of the bag/box volumetric system is preferably accomplished by the use of double-acting reciprocating pump 28, the piston 29 of which is externally driven by motor 31 via scotch yoke 32. Piston 29 separates volume A from volume B and as piston 29 moves to reduce either one of these volumes, the other volume is automatically increased at exactly the same volumetric rate. Volumes A and B are connected to multiple valve unit 33 via conduits 34 and 36, respectively. Valve unit 33 comprises a pair of valves; the

core 37 of which is rotatable to either of two positions 90° apart.

In the position shown in FIG. 2a slot 38, cut into core 37, places conduit 34 into flow communication with conduit 39. Conduit 39, in turn, is connected to and is in flow communication with the free volume of box 12. When valve core 37 has been rotated 90° counterclockwise as shown in FIG. 2b, slot 38 places conduit 34 into flow communication with the ambient via opening 41. When core 37 is in the position shown in FIG. 2a, slot 42 (also in core 37) places conduit 36 into flow communication with conduit 43 as shown in FIG. 3a. Conduit 43 is connected to and is in flow communication with the internal volume of bag 16. When core 37 is positioned as shown in FIG. 2b, slot 42 places conduit 36 into flow communication with the ambient via opening 44 as is seen in FIG. 3b. As will be described hereinbelow exhaled air is discharged from the system via opening 41, while fresh air is brought into the system via opening 44.

The position of core 37 is determined by the position of piston 29, because trip assembly 46 mounted on rod 47 is caused to reciprocate through the same cycle of movement as piston 29 being affixed to the drive unit therefore. Thus, as piston 29 moves to the right (reducing volume A and simultaneously increasing volume B at the same volumetric rate) trip assembly 46 is also moved to the right. As piston 29 continues moving to the right, lug 48 encounters throw arm 49 attached to stub shaft 51 mounted concentric with valve core 37, but is unable to move arm 49 whereupon spring 52 becomes compressed as lug 53 continues to move to the right. The fixation of arm 49 in this position is accomplished by the disposition of latching assembly 54, which is mounted for rotation only. Latch lifter 56 mounted on rod 57 (moving parallel to rod 47 and similarly mounted) serves to engage or disengage latching assembly 54. When, during the travel of trip assembly 46 the right, lifter 56 strikes lift leg 58, pin 59 is moved from in front of the pin 61, which is affixed to, and projects outwardly from, arm 49. Without restraint from pin 59, spring 52 is able to push throw arm 49 far enough to the right for overcenter spring 62 to snap arm 49 to its new position (90° counterclockwise) and hold it there until latching assembly 54 drops down. In the new disposition of parts, pin 63 will be located in latching position beside pin 61 to restrain arm 49 from movement to the left.

Similarly, when piston 29 is moved to the left, lug 64 encounters throw arm 49, spring 66 is compressed as lug 67 continues to the left. Finally, latch lifter 56 strikes lift leg 68, unlatching occurs and throw arm 59 (with valve core 37) are quickly snapped over to the earlier position, that shown in FIG. 1.

The disengagement of latch assembly 54 as piston 29 moves to the left and to the right occurs at the ends of the piston stroke so that valve core 37 is automatically repositioned in the pauses between pump strokes. This timing eliminates any compression or leakage of gas in the system by preventing movement of gas in the valve circuit during the switchover.

In operation, as the subject inhales from bag 16 and exhales into the free volume of box 12, the volume in bag 16 is gradually depleted and wall 18 moves to the right. This causes counterclockwise rotation of shaft 19 and crank arm 69 affixed thereof. When arm 69 is rotated far enough to activate microswitch 71, operation

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of the motor 31 is initiated via appropriate switch mechanism 72 and pumping is begun.

While the pump is operating, whenever piston 29 is moved to the right the gas content in volume A passes via conduit 36, valve slot 42 and conduit 43 into the volume of bag 16. At the same time and at the same volumetric rate, exhaled gases are removed from the free volume of box 12 via conduit 39, valve slot 38 and conduit 34 to enter volume B as it expands to B_{max} . When piston 29 reaches the end of its stroke, valve core 37 is repositioned as described hereinabove.

Upon return of piston 29 to the left, the volume of exhaled gases in volume B is discharged to the ambient via conduit 34, valve slot 38 and opening 41. Simultaneously, fresh air enters volume A via opening 44, valve slot 42 and conduit 36. Similarly, at the end of the pump stroke to the left, when volume A has become volume A_{max} (end of piston stroke), valve core 37 is repositioned clockwise 90° preparatory to repeating the displacement of gas volumes in accordance with the above description. The pumping action continues, gradually expanding the volume of bag 16, until arm 69 encounters microswitch 73, the actuation of which serves to disconnect, and thereby stop, motor 31. If desired, the motor circuit can be provided with timing means to automatically switch the motor off, after a preset volume has been pumped.

As the subject inhales or exhales, the volume of the bag-in-the-box system (volume of bag 16 plus the free volume of box 12) is changed, causing spirometer 10 to react thereto. The extent of displacement of wall 13 and the consequent rotation of shaft 14 is transmitted via large gear 74, small gear 76 and shaft 77 to appropriate conventional electrical circuitry in container 78. In essence the rotational displacement of shaft 14 is applied to mechanoelectrical transducer (not shown), the output of which is applied to an electrical recorder or display system, not shown, in the conventional manner for testing with a spirometer.

This invention lends itself to increased hygienic operation particularly by the use of a disposable inflatable bag suspended in the box into which bag the patient exhales and from which gas is removed via the exhaust pump.

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

1. An open-circuit device for respiration testing comprising in combination:

- a. a first enclosure of fixed dimension,
- b. a spirometer connected to said enclosure so as to be actuated by changes in gas volume occurring within the confines of said first enclosure,
- c. a second enclosure having expansible/contractible wall area, said second enclosure being located within said first enclosure,
- d. a mouthpiece adapted to be worn by the subject to

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be tested, a first conduit connected between said mouthpiece and said first enclosure and a second conduit connected between said mouthpiece and said second enclosure, first valve means connected in one of said first and second conduits to provide flow only to said mouthpiece and second valve means connected in the other of said first and second conduits to provide flow only away from said mouthpiece,

- e. first means for controllably displacing a gaseous volume, said volume displacing means being connected to said first enclosure,
- f. a second means for controllably displacing a gaseous volume, said volume displacing means being connected to said second enclosure, said first and second volume displacement means being synchronized to simultaneously remove gas from one of said enclosures and introduce gas into the other of said enclosure with the volumetric rates of removal and introduction being substantially equal, said first and second conduits being connected to direct exhaled breath to said one of said enclosures and enable inhalation from said other of said enclosures and
- g. means responsive to the expansion and contraction of said second enclosure for controlling simultaneous intermittent operation of said first and second volume displacement means.

2. The respiration testing device recited in claim 1 wherein the controllable volume displacement means are a pair of reciprocating pumps, and means for allowing each pump to be intermittently in flow communication with the respective enclosures.

3. The respiration testing device recited in claim 2 wherein the reciprocating pumps have means for allowing each pump to be intermittently in flow communication with the ambient, one pump being adapted to discharge exhaled gases thereto and the other pump being adapted to take in fresh gas therefrom.

4. The respiration testing device recited in claim 2 wherein two-position valve means are connected between the pumps and the respective enclosures to effectuate intermittent pump/enclosure flow communication.

5. The respiration testing device recited in claim 1 wherein the controllable volume displacement means comprises a double-acting reciprocating pump having a commonly actuated pair of pump volumes.

6. The respiration testing device recited in claim 1 wherein the spirometer is disposed within the first enclosure.

7. The respiration testing device recited in claim 1 wherein the second enclosure comprises a hinged wall and a bellows.

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