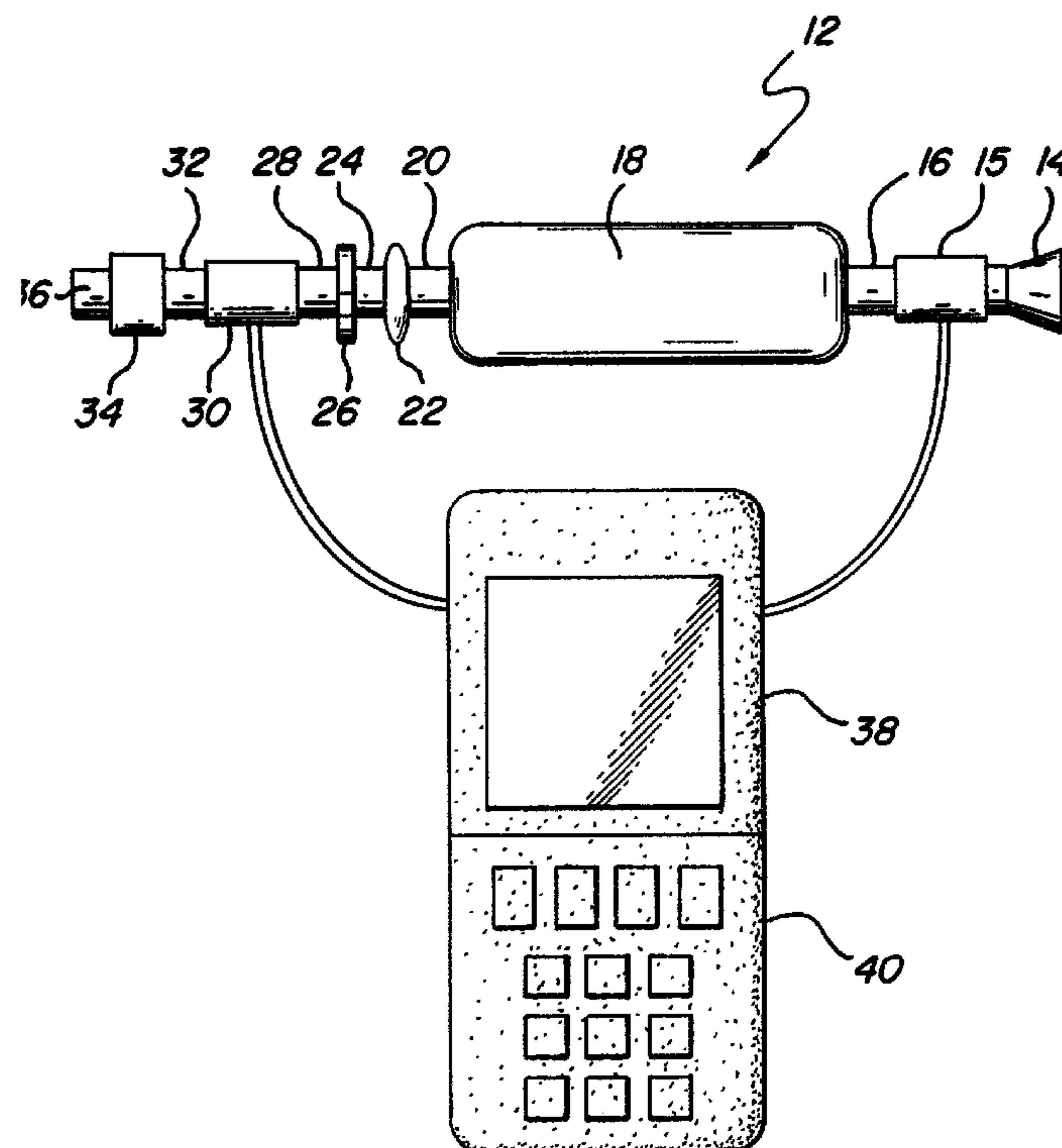




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(54) Titre : CALORIMETRE RESPIRATOIRE AVEC MONITEURS DE DEBIT BIDIRECTIONNELS
(54) Title: RESPIRATORY CALORIMETER WITH BIDIRECTIONAL FLOW MONITORS



(57) Abrégé/Abstract:

A calorimeter for generating signals representative of the oxygen consumption and carbon dioxide production of a subject over a test period (12) includes two flow sensors (48, 64) and a carbon dioxide scrubber (66) connected to a patient mouthpiece (60). Inter-connections (44, 46, 52, 54, 56, 58, 62) are such that the air inhaled by the subject passes through one flow meter end the exhaled breath passes first through the other flow meter, the carbon dioxide scrubber and then through the first flow meter. The electrical output signals from the flow meters are provided to a microprocessor based computer (50) which integrates the volume differences between the inhaled gas, and the exhaled gas after the carbon dioxide has been removed from it, over the period of the test.



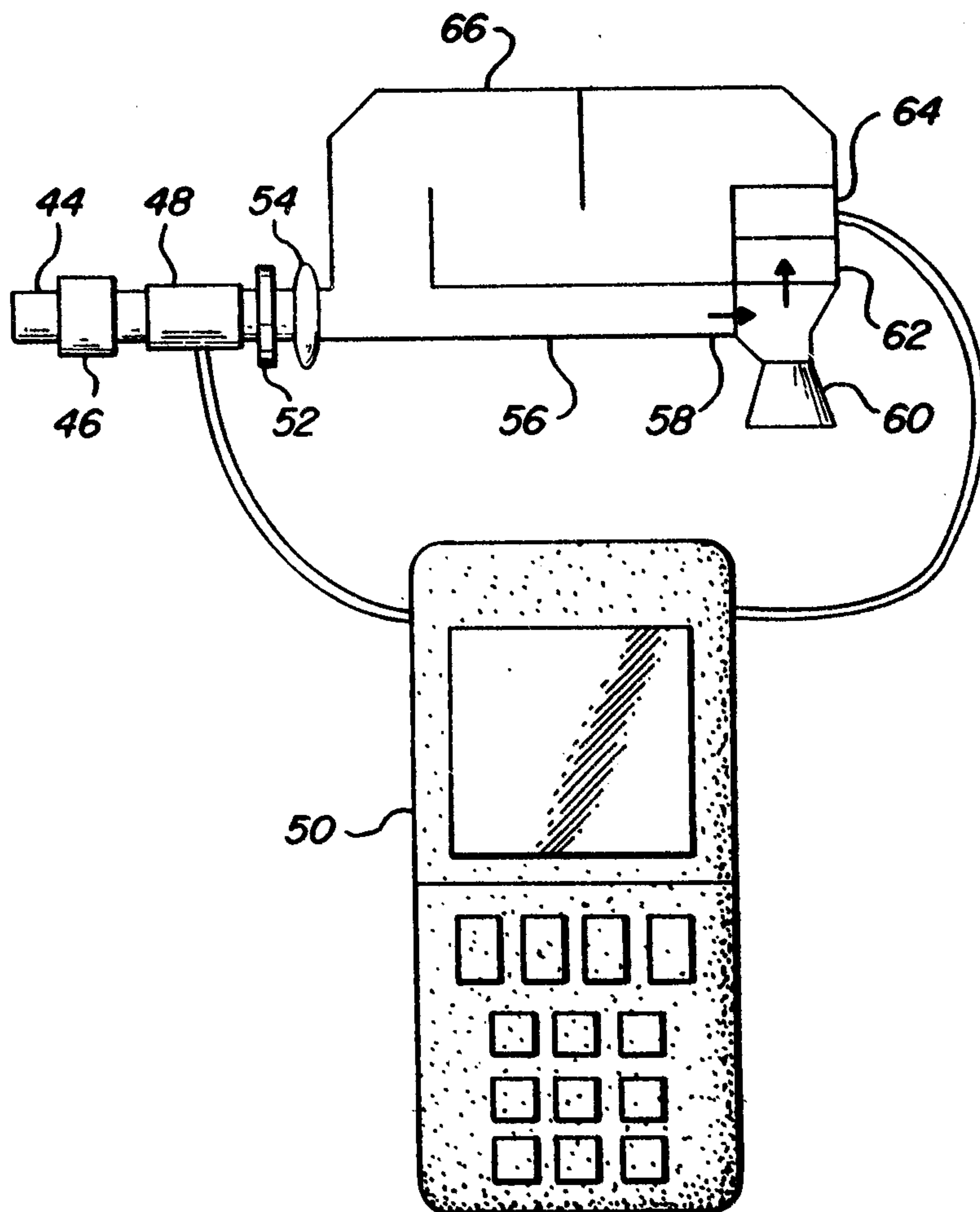


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(21) International Application Number: PCT/US92/11267 (22) International Filing Date: 29 December 1992 (29.12.92) (30) Priority data: 07/814,829 31 December 1991 (31.12.91) US (71)(72) Applicant and Inventor: MAULT, James, R. [US/US]; 4227 Pin Oak Drive, Durham, NC 27707 (US). (74) Agents: KRASS, Allen, M. et al.; 3001 W. Big Beaver, Suite 624, Troy, MI 48084 (US). (81) Designated States: CA, JP, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).		Published <i>With international search report.</i>
(54) Title: RESPIRATORY CALORIMETER WITH BIDIRECTIONAL FLOW MONITORS (57) Abstract A calorimeter for generating signals representative of the oxygen consumption and carbon dioxide production of a subject over a test period (12) includes two flow sensors (48, 64) and a carbon dioxide scrubber (66) connected to a patient mouthpiece (60). Interconnections (44, 46, 52, 54, 56, 58, 62) are such that the air inhaled by the subject passes through one flow meter and the exhaled breath passes first through the other flow meter, the carbon dioxide scrubber and then through the first flow meter. The electrical output signals from the flow meters are provided to a microprocessor based computer (50) which integrates the volume differences between the inhaled gas, and the exhaled gas after the carbon dioxide has been removed from it, over the period of the test.		



Respiratory Calorimeter with Bidirectional Flow Monitors

Field of the Invention

5 This invention relates to indirect calorimeters for measuring respiratory oxygen consumption and carbon dioxide production and more particularly to such a calorimeter employing bidirectional flow meters for measurement of the inhaled and exhaled gases and a CO₂ scrubber which removes CO₂ from the exhaled gas to allow the
10 computation of the difference between the inhaled gas volume and the volume of the scrubbed exhaled gas to calculate oxygen consumption, and the difference between the exhaled gas volumes before and after scrubbing to
15 calculate CO₂ production.

Background of the Invention

My United States Patent No. 4,917,708, issued April 17, 1990, discloses an indirect calorimeter, or oxygen consumption meter, which may be used to measure the
20 resting energy expenditure of a subject. This measurement is important for determination of the proper caloric content for feedings of hospitalized patients and also is useful in connection with weight loss diets since the basal energy requirement may vary during the period of the diet.
25 Similarly, knowledge of caloric expenditure and oxygen consumption during exercise are useful for cardiac rehabilitation and athletic training.

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That patent discloses a calorimeter which utilizes a unidirectional flow meter operative to generate electrical signals proportional to the respiratory gases passing through it, a carbon dioxide scrubber operative to
5 remove CO₂ from the exhaled gas and valving and conduits connecting the flow meter and the scrubber between a source of respiratory gases, which may be either the ambient air or some form of positive pressure ventilator, and a patient mouthpiece. The inhaled air has a negligible content of
10 carbon dioxide and the exhaled gas contains lung-contributed carbon dioxide of essentially the same volume as the oxygen consumed by the subject. Accordingly, the difference in volumes between the inhaled and scrubbed exhaled gases passed through the flow meter provides an
15 indication of patient's oxygen consumption. By integrating these differences over a test period, which may last for several minutes, an accurate measurement of the subject's oxygen consumption during the trial may be obtained.

My U.S. Patent No. 5,179,958, issued January 19,
20 1993, discloses a calorimeter utilizing a bidirectional flow meter which passes the inhaled gases before they are scrubbed for CO₂ and the exhaled gases after they are scrubbed, resulting in a simplified design and the potential for disposability after a single use, eliminating the requirement
25 for sterilization.

One embodiment of that invention employs a capnometer disposed in the flow path between the subject's mouthpiece and the CO₂ scrubber so that the exhaled gases are passed through the capnometer before being scrubbed.

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The capnometer generates an electrical signal which is a function of the CO_2 concentration of the exhaled gases. The electrical output of the capnometer, along with the flow meter signal, may be used to generate the ratio of carbon dioxide to consumed oxygen, or the Respiratory Quotient (RQ) as well as the Resting Energy Expenditure (REE), another important measure of a subject's metabolism.

Summary of the Invention

The present invention is directed toward a calorimeter which generates a signal proportional to the carbon dioxide production of the subject without the need for a capnometer, through use of a second flow meter which is disposed in the flow path between the subject's mouthpiece and the CO_2 scrubber. The volume of CO_2 production is calculated by subtracting the exhaled volume which passes out of the scrubber from the exhaled volume which passes into the scrubber. The volume of oxygen consumed may be calculated by subtracting the exhaled volume after it has passed through the scrubber from the inhaled volume.

In one embodiment of the invention both the inhaled and exhaled volumes are passed through the scrubber. In an alternate embodiment of the invention, valve means are provided with conduits to direct the inhaled volume to the mouthpiece without passing it through either the scrubber or the second flow meter, and the exhaled volume is passed first through the second flow meter, then through the scrubber and then through the first

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flow meter. This configuration minimizes the volume of exhaled air that remains in the scrubber after exhalation that is necessarily inhaled before air from the source is inhaled, thereby removing any limitation on the size of the
5 scrubber.

Other objectives, advantages and applications of the present invention will be made apparent by the following detailed descriptions of two preferred embodiments of the invention. The descriptions make
10 reference to the accompanying drawings in which:

Brief Description of the Drawings

FIGURE 1 is a schematic diagram of a first embodiment of my invention wherein a first bidirectional flow meter is connected in series with a carbon dioxide
15 scrubber, a second flow meter and the patient mouthpiece so that both inhaled and exhaled gases pass through the scrubber and the inhaled gases pass through the first flow meter in one direction before being scrubbed and pass
through the first flow meter in the opposite direction
20 after being scrubbed; and

FIGURE 2 represents an alternative embodiment of my invention employing a pair of one-way valves interconnected with the elements so that only the exhaled gases are passed through the scrubber and the inhaled gases
25 are passed directly from the first flow meter to the patient mouthpiece.

Detailed Description of the Preferred Embodiments

The embodiment of the invention illustrated in Figure 1, generally indicated at 12, employs a mouthpiece 14 adapted to engage the inner surfaces of the user's mouth so as to form the sole passage for inhaling and exhaling air passing through the mouth. A nose clamp of conventional construction (not shown) may be employed in connection with a mouthpiece 14 to assure that all respiratory gas passes through the mouthpiece. In alternative configurations a mask that engages the nose as well as the mouth might be employed or a endotracheal tube.

The mouthpiece connects directly to a flow meter 15. The flow meter is preferably of the pressure differential type such as manufactured by Medical Graphics Corporation of St. Paul, Minnesota under the trademark "MEDGRAPHICS." Alternatively, other forms of flow transducers might be used such as differential temperature types.

A conduit 16 connects the flow meter 15 to one end of a carbon dioxide scrubber 18. The scrubber 18 is a container having a central gas passageway filled with a carbon dioxide absorbent material such as sodium hydroxide or calcium hydroxide. Such absorbent materials may include sodium hydroxide and calcium hydroxide admixed with silica in a form known as "SODALYME." Another absorbent material which may be used is "BARALYME" which comprises a mixture of barium hydroxide and calcium hydroxide.

The other end of the scrubber is connected by a conduit 20 to an artificial nose 22 which constitutes a

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moisture-absorbing filter such as a filter formed of fibrous elements or a sponge. The artificial nose 22 acts to absorb water vapor from gases passing through it if the water vapor content of the gases is higher than the level of moisture contained in the filter or to add water vapor to the gases if the filter vapor level is higher than that of the gases.

The artificial nose 22 is connected via conduit 24 to a bacterial filter 26 which preferably traps particles of about 5 microns in size or larger. The conduit 28 connects the bacterial filter to a bidirectional flow meter 30 preferably of the same type as flow meter 15. Alternatively, other forms of bidirectional flow transducers might be used such as differential temperature types.

The other end of the flow sensor 30 is connected via conduit 32 to a resistance heater 34 which raises the temperature of air passing through it to approximately 37° C. Alternatively, the flow sensor might include means for measuring the temperature of the air exhaled by the subject and controlling the incoming air to that precise temperature.

The other end of the heater 34 is connected to an air intake/outlet 36 which may receive room air or may be connected to a positive pressure ventilator in the manner described in my United States Patent No. 5,038,792.

The electrical output signals from the flow meters 15 and 30 are provided to a microprocessor-based computation and display unit 38. The unit 38 converts the

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signal from the flow meters to digital form, if they are analog signals as employed in the preferred embodiment of the invention. Unit 38 is a computation and display unit of the general type disclosed in my United States Patent 4,917,718.

5 Like that unit, it acts to integrate the difference in the signals from flow meter 30 during inhalations and exhalations to generate a signal proportional to the volume of oxygen consumed during the test. Additionally, it integrates the difference between the signal from flow
10 meters 15 and 30 during exhalations to develop a signal proportional to the volume of carbon dioxide generated by the subject (V_{CO_2}). Essentially, considering the volume of inhaled air entering the calorimeter during a patient inhalation, as measured by the flow meter 30 as V_1 ; the
15 volume of the full exhalation passing through the flow meter 15 during an exhalation as V_2 ; and the volume of exhaled air after the CO_2 has been scrubbed, as measured by flow meter 30 during an exhalation as V_3 , the system makes two following computations:

20
$$VO_2 = V_1 - V_3$$

$$V_{CO_2} = V_2 - V_3$$

The keyboard 40 associated with the unit 38 allows storage and display of various factors in the same manner as the system of my previous patent.

25 In operation, assuming that room air is being inhaled, an inhalation by the subject on the mouthpiece 14 draws room air in through the intake 36 where it is first heated to essentially the temperature of the exhaled air by

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the heater 32. It then passes through the flow meter 30, generating a signal to the computation unit 38. After passing through the bacterial filter 28 and then the artificial nose 22, the inhaled air passes through the CO₂ scrubber 18. Since there is a negligible carbon dioxide content in room air the scrubber will have little effect upon inhaled air initially, but after prolonged use may add some water vapor to the incoming air by virtue of chemical reactions which occur when the subject exhales through the scrubber.

The inhaled air is then passed through the flow meter 15 and then the mouthpiece 14 to the subject. When the subject exhales, the exhaled air is again passed through the flow meter 15 and scrubber 18 in the opposite direction. The chemicals in the scrubber react with the carbon dioxide in the exhaled breath, producing water vapor and raising the temperature of the scrubber. The exhaled air is then passed through the artificial nose which tends to equalize the moisture vapor content of the exhaled air with that of the inhaled air. The exhaled air then passes to the flow meter 30 through the bacterial filter 26. The exhaled air will at this point have a water vapor content and temperature roughly comparable to that of the inhaled air so that the flow meter measurements of the inhaled and exhaled gases are on a comparable basis. The exhaled air then passes through the heater 34 to the air source.

The volume of exhaled air passed through the flow meter will be lower than the volume of inhaled air because of the absorption of the carbon dioxide by the scrubber 18.

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This difference in volume is a function of the oxygen absorbed from the inhaled air by the subject's lungs and the signals provided by the flow meter 30 to the unit 38 allow the integration and calculation of the resting energy expenditure in the manner described in my previous patent. The volume of CO₂ produced by the subject is similarly calculated.

The system 12, unlike the devices disclosed in my previous patent, requires no one-way valves and is accordingly lower in cost and more reliable in operation than the previous devices. Its costs may be sufficiently low that the entire unit may be disposed of after a single test. Alternatively, since the bacterial filter 26 prevents bacterial contamination of the flow meter, the flow meter might be reused and the other components, to the right of the flow meter in Figure 1, discarded after a single use.

An alternative form of the invention, in which the inhaled gases are not passed through the carbon dioxide scrubber, is illustrated in Figure 2. Again, a connection to an air source 44 passes inhaled air through a heater 46 and then to a bidirectional flow sensor 48. The electrical output of the flow sensor is provided to a microprocessor-based computation and display unit 50. The inhaled air passes from the flow meter 48 through a bacterial filter 52 and then through a water vapor-absorbent artificial nose 54. It is then carried through conduit 56, through a one-way valve 58, to the subject mouthpiece 60.

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The exhaled gases pass from the mouthpiece 60 through another one-way valve 62, which provides an exit from the mouthpiece, and through a second flow sensor 64. The electrical signal from the flow meter 64 is provided to the microprocessor-based computer 50. In addition to calculating the oxygen consumption of the subject, VO_2 , and the resting energy expenditure in kilocalories per unit time, the computer 50 generates a display of the exhaled CO_2 volume per unit time, the Respiratory Quotient (RQ), which equals VCO_2 divided by VO_2 , and the resting energy expenditure. The Resting Energy Expenditure (REE) is preferably calculated from the Weir equation:

$$REE \text{ (KC/24 hours)} = 1440 (VO_2 * 3.341) + (VCO_2 * 1.11)$$

where VO_2 and VCO_2 are both measured in milliliters per minute.

The output of the flow meter 64 is provided to the CO_2 scrubber 66 which removes the CO_2 from the exhaled gases in the same manner as the scrubber 18 of the embodiment of Figure 1 and provides its output to the flow passage 56. Since the flow path through the artificial nose 54, the bacterial filter 52, the flow meter 48, the heater 46, and the air inlet/outlet 44 has a lower resistance than the passage through the one-way valve 58, particularly during an exhalation, the output from the scrubber takes this low resistance flow path and the exhaled volume again passes through the flow meter 48, in the reverse direction from the inhalation, and its output signal is provided to the computer 50. Since the passageway from the output of the scrubber 66 has a higher

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resistance to flow than the passage through the unidirectional valve 58, the inhaled air passes through the valve 58 to the mouthpiece rather than through the CO₂ scrubber in the reverse direction.

5 The embodiment of Figure 2, by avoiding passage of the inhaled air through the scrubber, eliminates problems caused by the volume of exhaled air that remains in the scrubber after an exhalation and is necessarily inhaled before air from the source 44 is inhaled, thereby
10 removing any limitation on the size of the scrubber.

Having thus described my invention, I claim:

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Claims

1. An indirect calorimeter operative to measure the respiratory oxygen consumption and carbon dioxide production per unit time of a subject breathing respiratory
5 gases comprising:

a respiratory connector operative to be supported in contact with the subject so as to pass inhaled and exhaled gases as the subject breathes;

means for connecting to a source of said
10 respiratory gases;

a first pass-through bidirectional flow meter adapted to generate electrical signals as a function of the volume of gases which pass through it in either direction;

a second flow meter adapted to generate
15 electrical signals as a function of the gases that pass through it;

a pass-through carbon dioxide scrubber operative to absorb carbon dioxide from gases which pass through it;

conduits interconnecting said respiratory
20 connector, said means for connecting to a source of respiratory gases, said scrubber and said first and second flow meters so that upon inhalation by the patient gases are passed from the source of respiratory gases, then through the first flow meter, and finally to the subject
25 through the respiratory connector and upon exhalation by the subject the exhaled gases are passed first through the second flow meter, then through the scrubber, and finally through the first flow meter in a direction opposite to the inhaled gases; and

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means for receiving the signals from the first and second flow meters and for generating a first signal proportional to the integrated differences between the inhaled and exhaled gas volumes after passage through the scrubber over a period of time to calculate the oxygen consumption and a second signal proportional to the integrated differences between the exhaled gas volumes before and after being scrubbed to calculate the carbon dioxide production.

10 2. The indirect calorimeter of claim 1 wherein at least one of the flow meters is of the pressure differential type.

 3. The indirect calorimeter of claim 1 wherein at least one of the flow meters is of the temperature
15 differential type.

 4. The indirect calorimeter of claim 1 wherein said conduits are operative to cause the inhaled gases to be passed through the carbon dioxide scrubber after passing through the first flow meter and before passing to the
20 subject through the respiratory connector.

 5. The indirect calorimeter of claim 1 including valve means connected to the conduits operative to pass inhaled gases directly to the subject through the respiratory connector from the first flow meter and to pass

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exhaled gases through the carbon dioxide scrubber before they pass through the first flow meter.

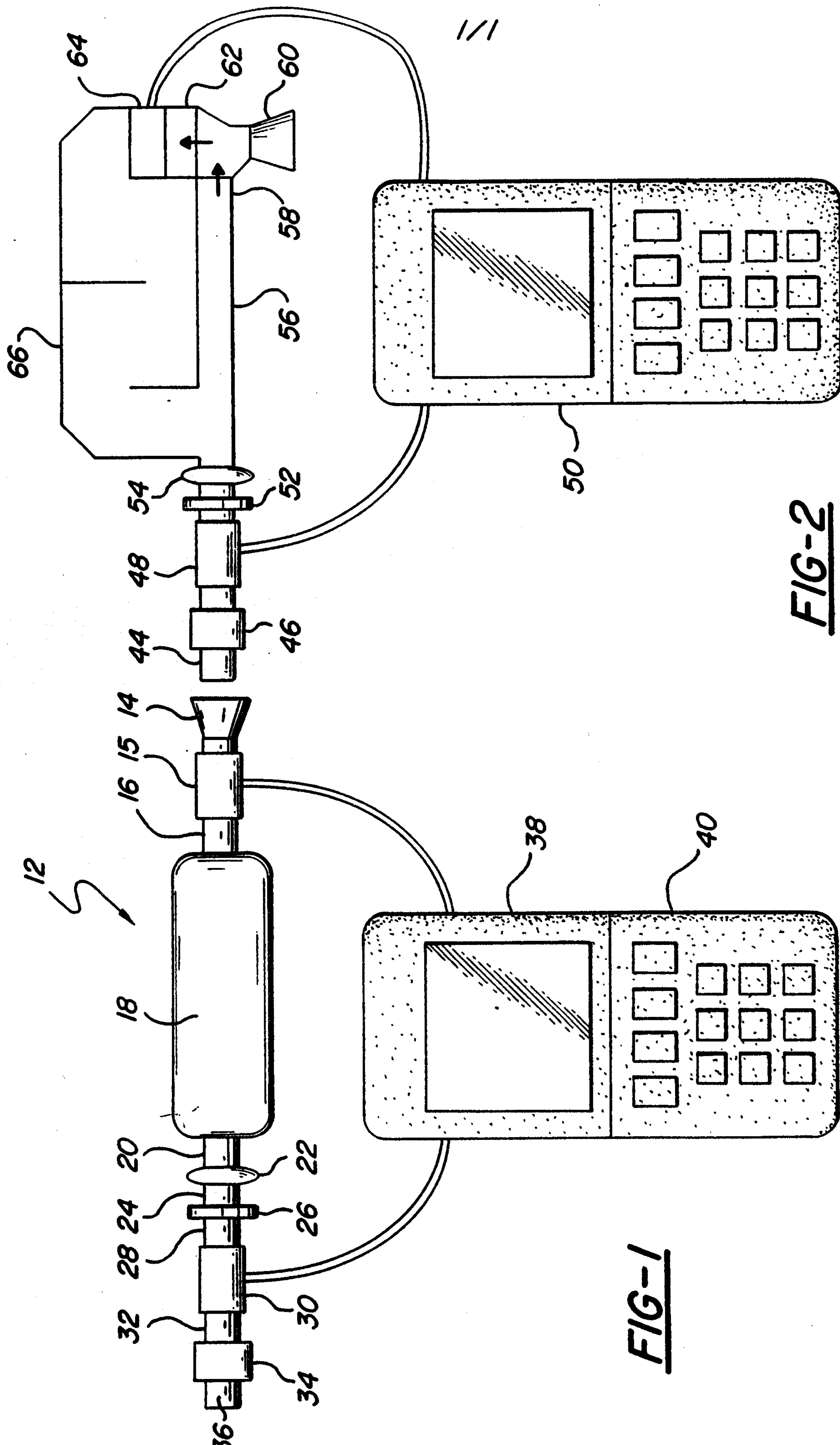


FIG-1

FIG-2

