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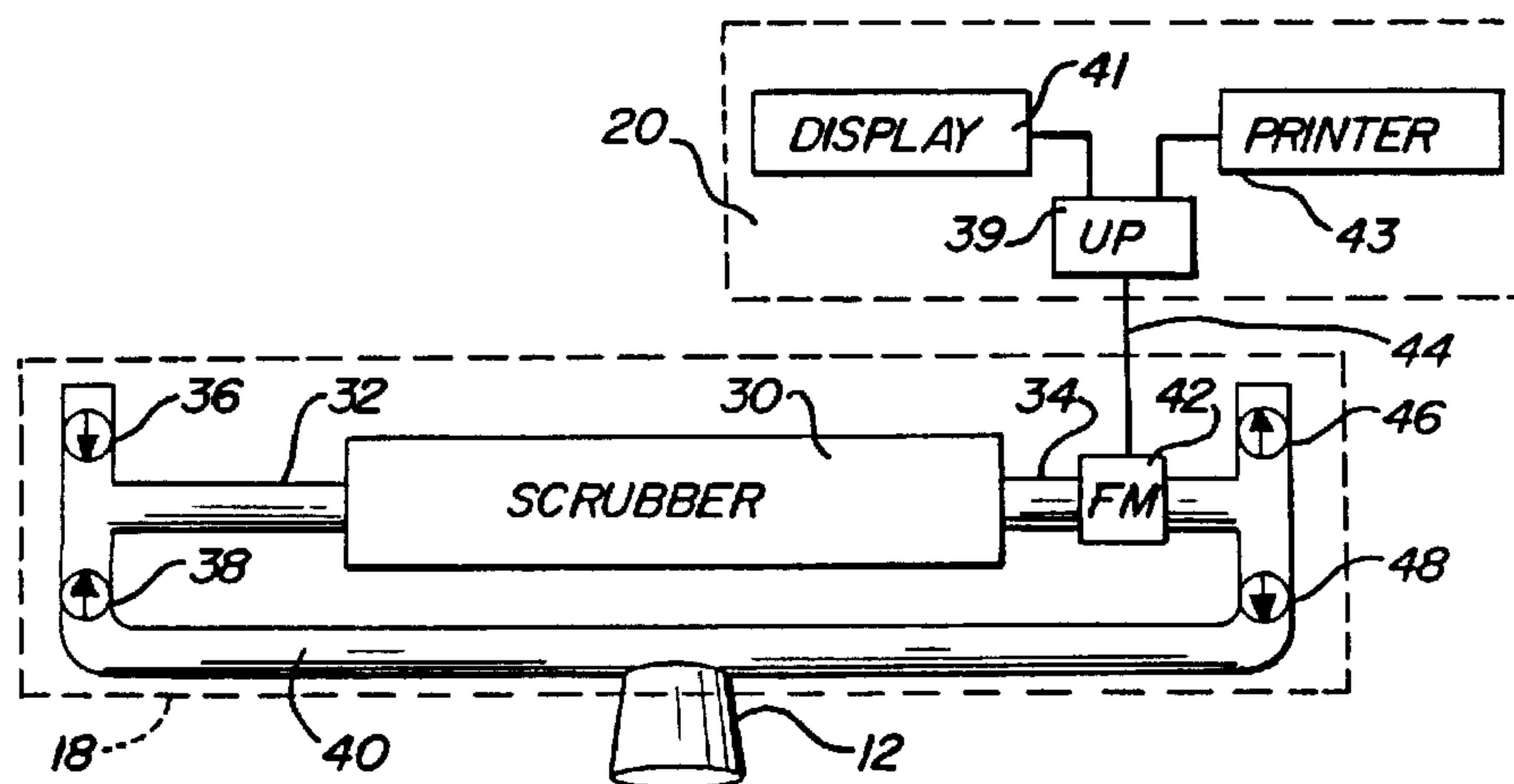
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(57) Abrégé/Abstract:

An indirect calorimeter for calculating the metabolic rate of a subject by measuring the oxygen consumption during respiration over a period of time includes a gas flow meter (42) providing output electric signals to a microprocessor (20) which drives a display and printer. The output of the flow meter (42) is connected to a mouthpiece (12). The exhaled gas passes through a CO₂ scrubber (30) and then through the flow meter (42). The difference in volume between the inhaled gas and the exhaled gas is proportional to the oxygen consumption of the subject and the microprocessor (20) integrates that signal over the time of the test, and multiplies it by a constant to provide a metabolic rate display. The temperature and water vapor content of the inhaled air are adjusted to that of the exhaled air either by passing both the inhaled and exhaled gases through the scrubber (30) before their volume is measured, or by preheating the inhaled air and employing a water absorbent member to add moisture to the inhaled air and remove it from the exhaled air.



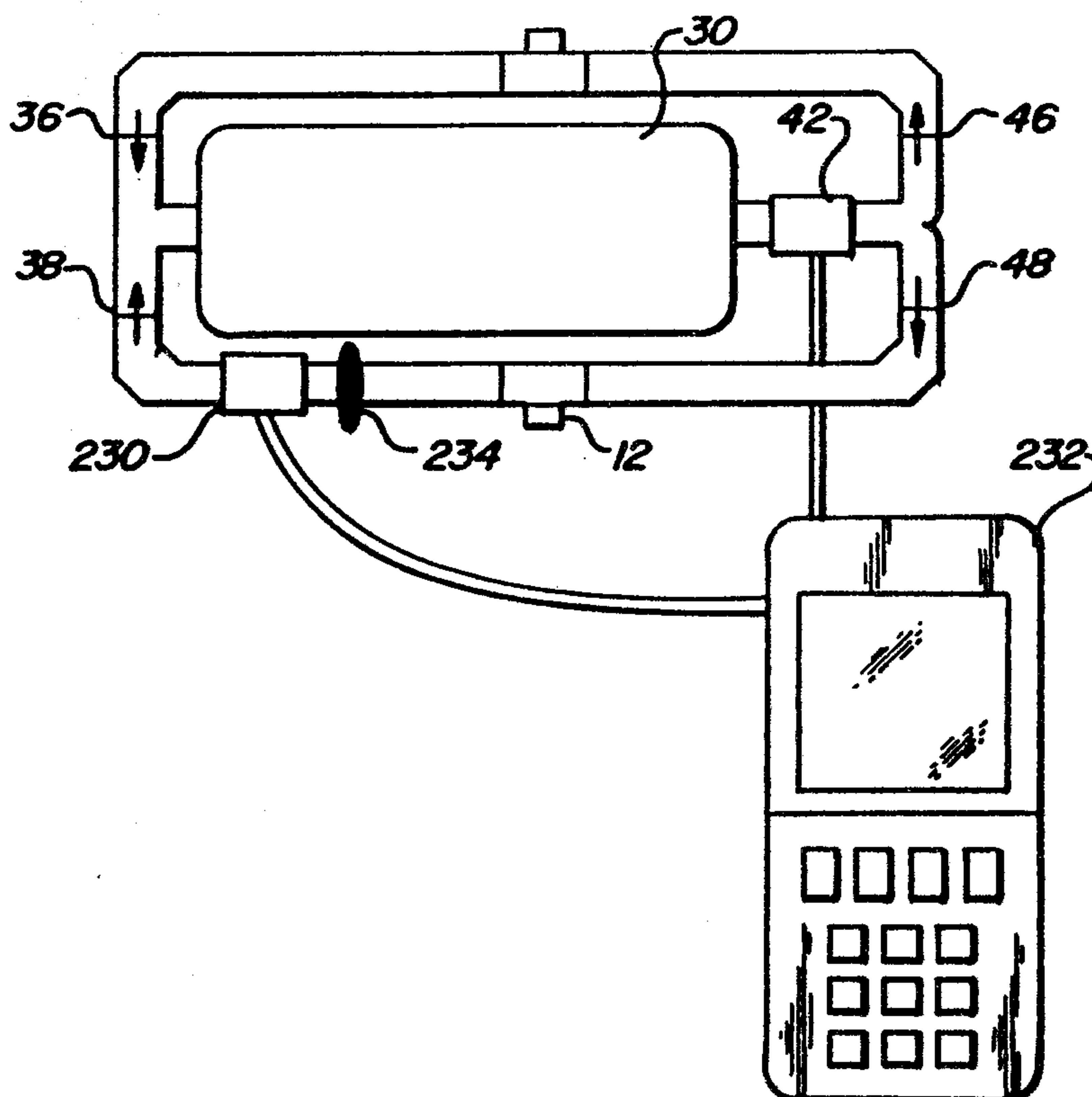
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(57) Abstract

An indirect calorimeter for calculating the metabolic rate of a subject by measuring the oxygen consumption during respiration over a period of time includes a gas flow meter (42) providing output electric signals to a microprocessor (20) which drives a display and printer. The output of the flow meter (42) is connected to a mouthpiece (12). The exhaled gas passes through a CO₂ scrubber (30) and then through the flow meter (42). The difference in volume between the inhaled gas and the exhaled gas is proportional to the oxygen consumption of the subject and the microprocessor (20) integrates that signal over the time of the test, and multiplies it by a constant to provide a metabolic rate display. The temperature and water vapor content of the inhaled air are adjusted to that of the exhaled air either by passing both the inhaled and exhaled gases through the scrubber (30) before their volume is measured, or by preheating the inhaled air and employing a water absorbent member to add moisture to the inhaled air and remove it from the exhaled air.



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OXYGEN CONSUMPTION METER

Field of the Invention

This invention relates to indirect calorimeters for measuring metabolic rate on the basis of respiratory oxygen consumption and more particularly to such a
5 calorimeter which scrubs the CO₂ from the exhaled gas and computes the difference between the inhaled gas volume and the volume of the scrubbed exhaled gas to calculate oxygen consumption.

10 Background of the Invention

Measurement of the energy expenditure of humans is important for a number of reasons. For nutritional purposes, measurement of the resting energy expenditure is important for determination of the proper caloric
15 content for feedings of hospitalized patients in view of the fact that certain diseases and traumas may cause the resting energy expenditure to vary substantially from normal values. In burn patients the metabolic rate may increase by as much as 300%. Other hospital situations in
20 which the measurement of rate of metabolic oxygen consumption is important include the adjustment of

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parental feedings for infants, and the control of respiratory gases during surgical operations. The resting energy expenditure may also decrease substantially in the course of a weight loss diet, and knowledge of this basal energy requirement is important to the adjustment of caloric inputs in order to achieve a target loss. Similarly, knowledge of caloric expenditure and oxygen consumption during exercise are useful for cardiac rehabilitation and athletic training.

10 A variety of indirect calorimeters for measuring oxygen consumption during respiration have been devised and are available commercially. These broadly include closed circuit devices wherein oxygen depleted during respiration is replenished from an oxygen source and the volume of replenishing oxygen is measured to determine respiratory oxygen consumption. A device of this type is disclosed in U.S. Patent No. 4,753,245. Open circuit devices generally measure the volume of inhaled gas and the proportions of carbon dioxide and oxygen in exhaled gas to determine the respiratory oxygen consumption. Devices of this class are disclosed in U.S. Patent Nos. 3,523,529, 4,619,269, 4,221,224 and 4,572,208.

25 All of these devices are relatively complex and expensive and require specially trained technicians for their operation. Their use has largely been limited to hospital settings for the adjustment of nutritional requirements for critically ill patients in intensive care units.

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A potentially simpler and less expensive form of calorimeter would measure the inhaled gas volume, pass the exhaled gas over a carbon dioxide scrubber to remove the lung contributed CO_2 from the exhaled gas and then measure the remaining gas volume. The difference between the two measured volumes would be a direct function of the respiratory oxygen consumption. However, because the exhaled gas has substantially different temperature and water vapor content than the inhaled gas, the volume measurements may grossly misestimate the actual oxygen consumption. Additionally, because such a device would measure variations in the relatively small differential between two large measurements, design of the device to attain a reasonable accuracy presents a problem.

My U.S. Patent No. 4,917,108 discloses a system which implements this concept. In that design, both the inhaled and exhaled volumes were directed to pass through the carbon dioxide scrubber, flow meter, and connecting tubing of the calorimeter. The intent of this orientation was to condition the inhaled and exhaled gases to a similar temperature and pressure. However, this configuration also resulted in a dead space (rebreathing) volume in which the final portion of gas from exhalation became the initial portion of the next inspired gas. While the carbon dioxide was removed by the scrubber prior to inspiration, the oxygen concentration of the inspired gas was diluted by the lower oxygen concentration of the exhaled gas that remained in the dead space volume. After a period of several breaths, the inspired oxygen concentration would re-

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equilibrate to a lower value that can be predicted by the following variables: 1. Concentration of Oxygen Source (FaO_2); 2. Tidal volume (V_t) of the inspired breath; 3. Dead space volume (V_{ds}); 4. Oxygen consumption per breath (VO_2); 5. Respiratory quotient, the ratio of CO_2 produced to oxygen consumed per breath (RQ). For example, if the subject was breathing room air ($FaO_2=20.9\%$) with $V_t=800ml$, $VO_2=25ml$, $RQ=1.0$, and the calorimeter $V_{ds}=200ml$, the actual oxygen concentration of the inspired gas would equilibrate to 19.9% after 5 breaths. Further, if the $V_{ds}=400ml$, with all other variables unchanged, the oxygen concentration inspired by the patient would stabilize at 17.9% after 7 breaths. While this effect is not a significant factor as the FaO_2 is increased, or as the ratio of V_t to V_{ds} is decreased, it nevertheless substantially limits the size, efficiency and longevity of the carbon dioxide scrubber.

Summary of the Invention

The present invention is accordingly directed toward a simple and low cost indirect calorimeter, or oxygen consumption meter that overcomes the deficiencies of the prior art and may be used by relatively untrained personnel so that it is adapted to use in a wide variety of situations for measurement of oxygen consumption and energy expenditure. The calorimeter of the present invention can operate from atmospheric air or any other oxygen source, such as a mechanical ventilator, and utilizes a chemical carbon dioxide scrubber, and inhaled and exhaled air volume flow meter means. The scrubber,

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the flow meter, a source of gas to be inhaled and a respiratory connector such as a mask, endotracheal tube or

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mouthpiece are interconnected with conduits and one-way valves so that inhaled air is first conditioned to adjust its temperature to a level comparable to that of exhaled air, its volume is then measured and it is then passed to
5 the mouthpiece, and exhaled air is passed through a CO_2 scrubber before its volume is measured. The flow meter means preferably provides pulsed signals with each electric pulse representing an increment of flow volume, and the system includes a microprocessor-based computation
10 and display unit which receives the pulse signals, distinguishes inhalations from exhalations, and generates integrals of their differences over a period of time. The microprocessor preferably stores these integrated different signals for short periods of time representing
15 increments of use of the calorimeter during the test and at the conclusion of the test displays the value representing the oxygen consumption over the latter portion of the test, multiplied by a constant to arrive at the display of kilocalories per 24 hour time. This
20 arrangement discards the initial readings which may be inaccurate until the scrubber chemicals have built up a stable temperature and water vapor level. The integration of a large number of respiration cycles minimizes error resulting from limited repeatability of the flow sensor.

25 A preferred embodiment of the invention, which will subsequently disclosed in detail, employs a single flow meter for measuring both the inhaled and exhaled volume, thereby eliminating a possible differential of accuracy between separate meters as an error source. The

flow meter, may be of the differential pressure type or may take other forms such as turbine, ultrasonic or electromagnetic meters. The flow meter is connected to receive the air to be inhaled, after its temperature has been conditioned either by passing it through the scrubber or otherwise warming it, and also receives the gas output from the scrubber. Conduits and one-way valves connect the mouthpiece to both the inlet of the scrubber and the output of the flow meter. When the user inhales, atmospheric air or air from a mechanical respirator ventilator is drawn into the calorimeter, heated, and passed through the flow meter, to the mouthpiece or other patient interface. Exhaled air passes through the scrubber and the flow meter to the atmosphere or back to the ventilator. The microprocessor analyzes the train of pulses it receives from the flow meter to distinguish inhalations from exhalations. In an alternative embodiment, the system includes a flow direction sensor disposed in one of the conduits and connected to the microprocessor so that the microprocessor can distinguish inhalations and exhalations from the flow direction of the air that passes over the direction sensor.

The present calorimeter may also be used in positive pressure ventilation systems using any concentration of oxygen source. This includes intensive care mechanical ventilators and closed loop anesthesia. The present invention may also be applied to exercise stress testing. In an alternative embodiment of the invention separate flow sensors may be provided for the

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inhaled and exhaled volume, eliminating the need for the microprocessor to distinguish pulse trains associated with the inhaled and exhaled breaths.

The present invention employs either of two alternative arrangements for adjusting the temperature and water vapor content of the inhaled air to substantially that of the exhaled air so that the inhaled volume and the exhaled volume, as measured by the flow meter, may be directly compared to determine the oxygen volume utilized by the patient. In one embodiment, the inhaled air is passed through the same CO₂ scrubber through which the exhaled air passes. As the exhaled air passes through the scrubber, the chemical reaction between the carbon dioxide and the absorber substance raised the temperature and water vapor content of the scrubber. After a short period of operation the inhaled and exhaled air will have substantially the same temperature and water vapor content so that their volumes, as measured by the flow sensor, may be directly compared without the need to temperature/water vapor measurement adjustment. However, in this arrangement some of the inhaled air volume includes some small proportion of the air remaining in the scrubber from the last exhalation, which has a lower oxygen content than the ambient air. Minimizing this rebreathed volume by minimizing the size of the scrubber limits the length of the test that may be conducted by the calorimeter.

In order to relieve this limitation on the scrubber size an alternative embodiment of the invention employs a heater to raise the temperature of the inhaled

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air to substantially the temperature of the exhaled air and passes this heated air directly to the flow meter so that only the exhaled air passes through the scrubber. This embodiment also incorporates means to essentially equalize the water vapor content of the air to be inhaled and the exhaled air. This device preferably takes the form of a water absorbent filter media, such as a sponge, which absorbs the moisture vapor in the exhalation and has its moisture content reduced by the relatively dry air during inhalation. Such devices are used in other respiratory products and are termed "artificial noses". This device may act as a filter for the mouthpiece, passing the inhaled volume to the patient and accepting the exhaled volume for passage to the other apparatus.

Another alternative embodiment of the invention provides a capnometer sensor in the flow path of exhaled air, between the mouthpiece and the scrubber, to measure the concentration of CO_2 in the exhalation, and to generate an electrical signal proportional to this value for provision to the microprocessor. This allows the microprocessor based computer to calculate the flow volume of CO_2 per unit time as well as the respiratory quotient (RQ) which equals the CO_2 generated per unit time divided by the oxygen consumption per unit time. The computer can use this data to calculate the resting energy expenditure (REE), which is an important respiratory indicator. The artificial nose acts as a filter in front of the mouthpiece, passing the inhaled air volume to the mouthpiece and accepting the exhaled air volume from the

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mouthpiece. The artificial nose absorbs air vapor from the exhaled air to effectively remove it from the exhaled volume passed to the flow meter. The dry incoming air absorbs the moisture from the artificial nose piece to maintain its capacity for absorbing water vapor from the exhaled volume. Alternatively, the artificial nose may be positioned at the input to the flow meter. Either of these arrangements removes the engineering limitation on the volume of the scrubber, allowing use of the sufficiently large scrubber to ensure the removal of all CO_2 from the exhaled air over an extended breathing cycle.

Another alternative embodiment of the invention incorporates a capnometer sensor in the conduit which carries the exhaled breath to the scrubber in order to determine the carbon dioxide concentration in the exhaled breath. The electrical signal from the capnometer is provided to the microprocessor base controller for the unit which uses a signal to compute the volume of CO_2 exhaled per unit time. By calculating the ratio between the exhaled carbon dioxide volume per unit time and the oxygen consumption volume per unit time, the system calculates the respiratory quotient which is an important indicator of energy metabolism. The system thus provides the analyst with an indication of oxygen consumption, carbon dioxide production and the respiratory quotient enabling a rigorous assessment of energy metabolism.

For use of the calorimeter in a clinical setting it is desirable that those portions of the apparatus which may be contaminated in use be made disposable. These

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include the mouthpiece, the CO₂ scrubber, the interconnecting tubing and valving. The flow meter and the capnometer are relatively expensive and economics may prohibit their disposal. Accordingly, in one embodiment of the present invention, one or more disposable bacterial filters are interposed between these disposable elements, which are contaminated by a patient's breath, and the non-disposable elements, which are protected from contamination by the filters.

10 The device of the present invention is thus simple, inexpensive, easy to use, and has excellent accuracy.

Brief Description of the Drawings

Other objectives, advantages, and applications of the present invention will be made apparent by the following detailed description of a preferred embodiment of the invention. The description makes reference to the accompanying drawings in which:

FIGURE 1 is a perspective view of a preferred embodiment of the indirect respiratory calorimeter of the present invention being used by a subject;

FIGURE 2 is a schematic illustration of the gas flow circuitry of the embodiment of FIGURE 1;

FIGURE 3 is a flow diagram illustrating the manner of operation of the microprocessor used with the present invention;

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FIGURES 4A and 4B are schematic illustrations of two alternative embodiments of the invention employing separate flow sensors for inhaled and exhaled gas;

FIGURE 5 is a partial schematic view of a section of an alternative construction of a single flow meter indirect calorimeter of the type illustrated in Figure 2 but incorporating a mechanical sensor for flow direction to generate an electric signal distinguishing flow associated with exhalations from flows representative of inhalations;

FIGURE 6 is a schematic illustration of an alternative embodiment of the invention designed for use with a positive pressure respiratory ventilator;

FIGURE 7 is a schematic illustration of another alternative embodiment of the invention also designed for use with a respiratory ventilator;

FIGURE 8 is a schematic diagram of an alternative embodiment of the invention in which only the exhaled air and not the inhaled air is passed through the scrubber and the inhaled air is preheated to a temperature comparable to that of the exhaled breath; and

FIGURE 9 is a schematic diagram of another alternative embodiment of the invention employing a capnometer sensor to allow determination of the carbon dioxide concentration in the exhaled breath and the resultant calculation of respiratory quotient and resting energy expenditure.

Detailed Description of the Preferred Embodiment

Figure 1 illustrates a preferred embodiment of the present invention in use. A user 10 inhales and exhales air from and into a user respiratory interface 5 taking the form of a mouthpiece 12 adapted to engage the inner surfaces of the user's mouth so as to form the sole passage for inhaled and exhaled air passing through the mouth. A nose clamp 14 of conventional construction may be employed in connection with the mouthpiece 12 to assure 10 that all respiratory air passes through the mouthpiece. In alternative configurations a mask that engages the nose as well as the mouth might be employed. In embodiments such as those illustrated in Figures 6 and 7, intended for use with mechanical ventilators, an endotracheal tube may 15 be employed rather than a mouthpiece or mask.

The mouthpiece 12 is directly connected to a small instrument housing 18 that is manually held by a handle 19 fixed to the housing. The instrument housing 18 contains the other components of the system and is 20 connected to a microprocessor-based computation and display unit 20. The unit 20 includes an ON/OFF switch 22 and a pair of LED signal lights 24 and 26. The signal light 24 is illuminated when the switch is first thrown to the ON position to indicate that the test is underway. At 25 the end of a predetermined time, the light 24 is extinguished and the signal light 26 is illuminated, signaling that enough time has elapsed and that the subject may quit at any time. In the preferred embodiment

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of the present invention, the housing 18 and the mouthpiece 12 are intended for one use and are disposable.

The unit 20 also includes a first digital display 28 which displays the value VO_2 , the volume of inspired oxygen consumed per minute, and a second display 29 which exhibits the value of Kcal/24 hours, i.e., the value arrived at by multiplying the integral of the difference between the scrubbed inhaled volume and the scrubbed exhaled volume by a constant.

Figure 2 provides a schematic of the circuitry in the instrument housing 18 of the preferred embodiment. The housing includes a carbon dioxide scrubber 30. The scrubber 30 is a container having an inlet and an outlet and a central passageway filled with a carbon dioxide absorbent material such as sodium hydroxide or calcium hydroxide. Such absorbers are well-known to the art. Sometimes they include sodium hydroxide and calcium hydroxide admixed with silica in a form known as soda lime. Another absorbent material used is "Baralyme" which comprises a mixture of barium hydroxide and calcium hydroxide.

Preferably the scrubber 30 employs a carbon dioxide absorbent media in the form of a fiber structure in which there is absorbed and retained in liquid a solution of one or more substances capable of chemically binding carbon dioxide, such as aqueous sodium hydroxide solution. The scrubber 30 becomes saturated with CO_2 after some period of use. The preferred embodiment of the present invention uses a small scrubber 30. In an

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alternative embodiment, the instrument housing 18 of Figure 1 is of a table top configuration and utilizes a large scrubber 30 that has a longer useful life. In this embodiment, the scrubber is preferably removable from said system so that after becoming saturated, a user may replace it with a new scrubber cartridge. In this table top configuration, the mouthpiece is also removably attached to the system. The microprocessor unit 20 of this embodiment may further include means for keeping track of the number of uses of the scrubber and indicating to the user when it should be replaced.

The circuitry in the instrument housing 18 further includes conduits 32 and 34 connected to the inlet and outlet of the scrubber 30, respectively. The opposite end of the conduit 32 is also connected to two one way valves 36 and 38. One way valve 36 allows the passage of air from the atmosphere into conduit 32. One way valve 38 is connected to one end of another conduit 40 that is directly connected to a mouthpiece 12. The valve 38 allows for air exhaled into the mouthpiece to pass into conduit 32.

Conduit 34 is connected to a flow meter 42, of the pressure differential type, that measures the volume of air passing through it. Such flow meters are well known in the art. In the preferred embodiment, the flow meter is removably attached to the system so that the housing 18 and the mouthpiece 12 may be disposed of after usage, while the flow meter is retained. Alternatively, the entire structure may be designed for a single use and then

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disposed. An opening in the instrument housing, indicated at 21 in Figure 1, functions to allow the user to connect and disconnect a flow meter to the system. The flow meter may be calibrated by providing a known volume of gas to the system and analyzing the number of pulses generated by the flow meter.

The end of the flow meter 42 opposite the end connected to conduit 34 is connected to two one way valves 46 and 48. Valve 46 allows exhaled air passing through the flow meter to exit to the atmosphere. Valve 48 is connected to the other end of the conduit 40 and allows inspired air that has passed through flow meter 42 to enter conduit 40 and exit through the mouthpiece 12. In an alternative embodiment, illustrated in detail in Figure 5, a flow direction sensor may be disposed between valves 46 and 48 and connected to the microprocessor in order to more accurately distinguish between inhalations and exhalations. Such a sensor may comprise a lightweight resilient flap 47 having one end fixed to the conduit wall between the valves 46 and 48 so that in the absence of flow it extends normally across the conduit. When the user breathes the resultant air flow moves the free end of the flap 47 to one of two different positions depending on whether air is exiting through valve 46 on an exhale, or passing through valve 48 on an inhale. These alternative positions are illustrated by phantom lines 47a and 49b. Two contact sensors 51 and 53 are used to sense the position of the flap and provide signals to the microprocessor.

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The flow meter 42 is connected to the microprocessor unit 20 via a connection wire 44. The meter 42 provides the microprocessor unit with pulsed signals, each electric pulse representing an increment of flow volume. The microprocessor unit 20 includes a microprocessor 39 connected to a display 41 and, in the preferred embodiment, a printer 43. The microprocessor receives signals which allow it to distinguish pulse signals representing inhalations and exhalations. In the preferred embodiment, the microprocessor stores the integrated signals for short periods of time representing increments of use of the calorimeter during the test. At the conclusion of the test, the microprocessor sums the values representing the oxygen consumption over the latter portion of the test, and multiplies this by a constant to arrive at the display of kilocalories/24 hours.

Alternatively, the flow direction could be sensed by directional switches (not shown) integrated with the unidirectional valves 36, 38, 46 or 48.

The mouthpiece 12 is directly connected to the conduit 40 and allows a subject to breathe air into and out of the conduit. The system functions as follows: When a user inhales through mouthpiece 12, atmospheric air is drawn into valve 36, through conduit 32, through the scrubber 30, into conduit 34, through the flow meter 42, into valve 48, through conduit 40, to the mouthpiece 12 and into the lungs of the user. Exhaled air passes through the mouthpiece, into conduit 40, through valve 38, into conduit 32, through the scrubber 30 and the flow

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meter 42, exiting through valve 46 to the atmosphere. The conduits and valves used in the instrument housing 18 are well known to the art and are preferably very short in length in order to minimize the error created by
5 extraneous air in the conduits and valves.

Figure 3 provides a flow diagram illustrating the general flow of operation of the microprocessor in the preferred embodiment of the present invention. The algorithm uses five registers to store values of integrals
10 of the volumes as generated by the flow meter 42 during five successive intervals.

First, the LED signal light 24 of Figure 1 is illuminated in order to indicate to the user that the test is underway. The boolean variable SWITCH is then
15 initialized to true and the integer variable REG, for keeping track of the current register in use, is initialized to 0.

Next, the main timer is started. This timer expires after the minimum time required for the test has
20 passed. In the preferred embodiment, this time is 10 minutes.

Next, at the step indicated at 60, an interval timer is started. This timer keeps track of short increments of the total time. In the preferred embodiment
25 this time is 1 minute. The microprocessor finds the integrated difference between the exhaled and inhaled gas volumes for each increment of time and stores these values at memory locations designated REG 1, REG 2... The processor only stores the most recent 5 periods, so that

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the initial readings that may be inaccurate due to temperature differences between the inhaled and exhaled gas are discarded. Next, the counter variables Vol 1 and Vol 2 are initialized to 0, and REG is incremented by one.

- 5 At 62 a check is made as to whether the current register is greater than 5. If not, the algorithm goes to the step indicated at 64. If $REG > 5$, then REG is set back to 1 and the algorithm continues at step 64.

At 64, the boolean variable WAIT is set to true.

- 10 This variable is used to indicate whether the microprocessor is waiting for a pulse signal from the flow meter. Next, a wait timer is started. This timer is used to create a maximum time in which the microprocessor will wait for a pulse signal. Next, the algorithm goes to the
15 step indicated at 66.

At 66, a check is made as to whether a pulse signal has been received from the flow meter. If not, the algorithm goes to the step indicated at 68. If a pulse has been received at 66, WAIT is set to false and at step
20 70 a check is made as to whether SWITCH is true. If it is, Vol 1 is incremented. If it is not, Vol 2 is incremented. In either case, the algorithm then goes back to step 66. In the alternative embodiment of Figure 5 utilizing the flow direction sensor switches 51 and 53, no SWITCH
25 variable is needed for the algorithm. In this embodiment the microprocessor may check the signal being received from the flow direction sensors 51 and 53 and then increment Vol 1 if the user is inhaling or Vol 2 if he is exhaling. Similarly, when separate flow meters are used to

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sense inhaled and exhaled volume, as in the embodiment of Figure 4, the algorithm is appropriately modified.

At 68, a check is made as to whether both WAIT is true and the wait timer has not expired. If either of these conditions are not true, the algorithm goes to the step indicated at 72. Else, the algorithm continues at step 66.

At 72, SWITCH is complemented. Next, a check is made as to whether SWITCH is set to true. If so, the algorithm goes to the step indicated at 74. If SWITCH is false, the algorithm goes back to step 64.

At 74, a check is made as to whether either the interval timer has expired or WAIT is set to true. IF either of these conditions is true, the algorithm continues to the step indicated at 76. Else, it goes back to step 64.

At 76, the absolute value of the difference between Vol 1 and Vol 2 (the difference between exhaled and inhaled oxygen volumes) is stored in the current register. Next, a check is made as to whether the main timer has expired. If so, the algorithm continues to the step indicated at 78. Else, the algorithm goes back to step 60 and goes through the routine another time, loading the integrals of the volume signals for the next interval of time (preferably one minute) into the next register. At 78, the LED signal light 26 of Figure 1 is illuminated in order to indicate to the user that he may quit at any time. The microprocessor senses that the user quit when

no pulse signal is received from the flow meter for an entire period of the wait timer.

Next, a check is made as to whether WAIT is set to true. If so, the algorithm continues at the step indicated at 80. IF WAIT is false, the algorithm goes back to step 60. At 80, the five registers are summed together to arrive at an integral of the difference between exhaled and inhaled oxygen volumes over the latest portions of the test. Next, the volume of the oxygen inspired per minute, VO_2 , is displayed on the digital display 28 of the microprocessor unit 20, as shown in Figure 1. Finally, the sum is multiplied by a factor to arrive at the number of kilocalories that the subject expends during a 24 hour period. This factor is arrived at as follows: Approximately 5 kilocalories are expended for every 1 liter of oxygen consumed in a minute. In the preferred embodiment of the present invention, the volumes of oxygen are measured in millimeters. Therefore, the resting energy expenditure (REE) may be calculated from the Weir equation, set forth subsequently. This result is displayed on the digital display 29 of the unit 20, and a report of the test results is outputted to the printer 43, as shown in Figure 2. An alternative algorithm may also display the volume of oxygen inspired per minute after the main timer has expired and continue to update it after each interval period.

The disclosure of the algorithm depicted in Figure 3 is not intended to limit the present invention. Many different algorithms may be implemented to achieve

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the same results. For the purposes of illustration, well-known housekeeping functions, such as error checking features, were omitted from the algorithm of Figure 3.

Figures 4A and 4B depict alternative embodiments of the present invention which include two flow meters. The embodiment of Figure 4A utilizes a carbon dioxide scrubber 90 that is connected at one end to a conduit 92, and at the opposite end to a conduit 94. Conduit 92 is connected to a one way valve 96 at one of its ends. The valve 96 allows air to pass from the atmosphere into conduit 92. The other end of conduit 92 is connected to a flow meter 98. A one way valve 93 is disposed between the conduit 92 and the meter 98 that allows air to flow from the conduit to the flow meter. The meter 98 is connected to the microprocessor unit 100 via connection line 102. Air may pass from conduit 92, through flow meter 98, and exit to the atmosphere.

Conduit 94 is connected at one end to a one way valve 104. The opposite end of valve 104 is connected to a conduit 106. Valve 104 allows for the passage of air from the conduit 106 into the conduit 94. The opposite end of conduit 94 is connected to a flow meter 108. Flow meter 108 is connected to the microprocessor unit 100 via connection line 110. The end of the flow meter 108 opposite the end connected to conduit 94 is connected to a one way valve 112. The valve 112 connects the meter 108 to the end of conduit 106 that is opposite the end connected to valve 104. Valve 112 allows for the passage of air from meter 108 into conduit 106.

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Conduit 106 is also directly connected to a mouthpiece, indicated at 114. The mouthpiece is removably attached to the conduit. Furthermore, the scrubber 90 is also removably attached to the system and is preferably a large one of the type that may be used a plurality of times before becoming saturated with carbon dioxide.

The system operates as follows: When a user inhales through mouthpiece 114, atmospheric air is drawn into valve 96, through conduit 92, through the scrubber 90, into conduit 94, through flow meter 108, through valve 112, into conduit 106, through the mouthpiece and into the user's lungs. Exhaled air passes through the mouthpiece, into conduit 106, through valve 104, into conduit 94, through the scrubber 90, into conduit 92, through valve 93 and through flow meter 98, exiting to the atmosphere.

This embodiment requires calibration of the two flow meters in the manner previously noted and, obviously, a different algorithm for the operation of the microprocessor than the one shown in Figure 3. In this embodiment, the microprocessor need not distinguish inhalation pulse signals from exhalation signals because it receives two inputs, one for each flow meter. The algorithm may also be further extended to include means for keeping track of the number of times that the installed scrubber is used, and then indicating to the user that the system is due for a new scrubber after a certain limit is passed.

In the embodiment of Figure 4B, the incoming air is not passed through the scrubber 90 before being measured

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by the flow meter. Rather, the incoming air is first passed through a preheater 109 which raises its temperature to that of the exhaled air. It then passes through an input flow meter 108, a one-way valve 112' and a moisture
5 absorbent artificial nose 111 to the mouthpiece 114'. Exhaled air passes through the nose 111, a one-way valve 104', the scrubber 90' and an output flow meter 98'. Both of the flow meters 108' and 98' provide electrical signals to the microprocessor-based computer 100'.

10 Figure 6 illustrates an embodiment of the invention useful with a respiratory ventilator 100 having a conduit 102 for inspired air and a conduit 104 for expired air. The ventilator 100 may of the positive pressure ventilation type which incorporates a sensor (not
15 shown) either in the line 102 or the line 104 to control the ventilator to provide a positive pressure outflow through line 102 to force breathing of the patient. Rather than a mouthpiece or a mask, the embodiment of Figure 6 employs a connector 106 adapted to be connected to an
20 endotracheal tube passed through the patient's throat. The indirect calorimeter is otherwise the same as that of Figure 2 with a scrubber 108 receiving either inhaled gas through a valve 110 or exhaled gas through one-way valve 112. The scrubber passes its output through a single flow
25 meter 114 which is connected to a microprocessor and display unit 116. A pair of one-way valves 118 and 120 direct the gaseous output from the flow meter either to the patient on inspiration, or back to the patient on expiration. Both inspired and expired gasses are exchanged

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between the calorimeter and the ventilator through the connection 122.

The calorimeter is thus transparent to the ventilator, that is the ventilator operates as if it were
5 connected directly to an endotracheal tube rather than indirectly to that tube through the calorimeter.

Another alternative embodiment of the invention suitable for use with a positive pressure ventilator 130 of the type having separated inspiratory tubing 132 and
10 expiratory tubing 134 is illustrated in Figure 7. The indirect calorimeter, generally indicated 136, is substantially identical to that of Figure 2 other than in providing a connection 138 for an endotracheal tube rather than the mouthpiece 12 of Figure 2. The inspiratory tubing
15 output of the ventilator 132 is passed to CO₂ scrubber 140 through a one-way valve 142 forming part of the calorimeter. Scrubber 140 also receives expired gases from the patient through a one-way valve 144. The output of the scrubber is passed through a flow meter 146 which provides
20 an electrical output to a microprocessor and display unit 148. The gaseous outputs of the flow meter are either provided to the expiratory tubing 134 through a one-way valve 150 during exhalation or to the patient through a one-way valve 152 during inhalation.

25 This arrangement is suitable for use with mechanical ventilators that do not assist the patient's breathing after sensing his initial direction of breathing.

In an alternative embodiment of the invention, illustrated in Figure 8, the inhaled air is not passed

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through the CO₂ scrubber prior to provision to the patient's mouthpiece. The CO₂ scrubber only receives exhaled air.

Referring to Figure 8, an air source 200, which may represent a connection to ambient air or a positive pressure ventilator, connects to a conduit 202 which passes the air through a preheater 204 which is preferably an electric resistance heater. The heater raises the temperature of the incoming air to approximately 34 degrees Centigrade, which will be within a degree or two of the temperature of the exhaled air. Alternatively, a sensor (not shown) may measure the exhaled air temperature and control the temperature of the preheater 204. The heated inhaled air is then passed through the flow meter 206 which provides its electric output to the microprocessor based computer 208. A pair of unidirectional flow valves 210 and 212 direct the preheated inhaled air through a conduit 214 to a moisture absorbing filter 216 of the type employed with "artificial noses". The filter essentially constitutes moisture absorber, such as a filter formed of fibrous elements or a sponge. The artificial nose 216 directs the inhaled air to the patient's mouthpiece 218.

When the patient exhales through the mouthpiece the exhalation is first passed through the artificial nose 216. This adjusts its water vapor content to a level comparable to that of the inhaled air. The artificial nose thus absorbs moisture from the exhaled breath and has its moisture level reduced by the incoming breath. The result is to effectively reduce the moisture vapor content of the exhalation. After passing through the artificial nose, the

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exhaled air passes through a CO₂ scrubber 220 and the output of the scrubber is directed to the flow meter 206 by a one-way valve 222. The output of the flow meter is returned the air source 200 by the one-way valve 212.

5 In this configuration, on an inhalation, the patient receives a fresh breath of air. In the previous configurations, since the inhaled air came from the CO₂ scrubber, there was a need to minimize the volume of the scrubber to in turn minimize the rebreathing of the
10 previously exhaled air on a subsequent inhalation. The removal of this constraint allows the use of a substantially larger CO₂ scrubber.

Figure 9 illustrates an alternative embodiment of the invention in which a capnometer sensor 230 is disposed
15 between the mouthpiece 12 and the scrubber 30. The calorimeter which is otherwise substantially identical to previous embodiments. Accordingly, the numerals associated with the embodiment of Figure 2 have been utilized for the other components. The capnometer is operative to generate
20 an electrical signal which is a function of the percentage CO₂ concentration of the exhaled air volume which it passes. The capnometer may be of a conventional type such as those described in U.S. Patents 4,859,858; 4,859,859; 4,914,720; or 4,958,075. The electrical signal from the capnometer as
25 well as the signal from the flow meter 42 are provided to a microprocessor based computer 232. In addition to calculating the oxygen consumption VO₂, and the resting energy expenditure in kilocalories per unit time, the computer 232 generates a display of the exhaled CO₂

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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:

5 $REE \text{ (KC/24 hours)} = 1440 (VO_2 * 3.341) + (VCO_2 * 1.11)$

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

The embodiment of Figure 9 illustrates another feature of the invention which is useful in connection with
10 any of the other embodiments. A bacterial filter 234 is interposed in the flow line between the mouthpiece and the capnometer 230. The bacterial filter may be of any commercial variety having an air passage of 5 microns or lower. Effectively, it protects the capnometer and the
15 flow meter from bacterial contamination from the exhaled air. The protected components may therefore be used for a succession of measurements by different patients without any special sterilization or the like. The mouthpiece 12 may be made disposable as is the CO_2 scrubber 30. The
20 bacterial filters could similarly be employed in the previous embodiments of the invention to protect the flow meter, which is relatively expensive from bacterial contamination so it need not be disposed between uses.

Having thus described my invention, I claim:

WHAT IS CLAIMED IS:

1. An indirect calorimeter operative to measure the respiratory oxygen consumption from respiratory gases per unit time of a subject, comprising:

a respiratory connector operative to be supported in contact with the subject so as to pass said respiratory gases as the subject breathes into said respiratory connector;

a scrubber having a gas inlet and a gas outlet and constructed to absorb carbon dioxide from said respiratory gases passing between its inlet and outlet;

flow meter means operatively connected to said respiratory connector for generating signals as a function of the gas volume of said gases passed through said meter means;

valves and conduits interconnecting said respiratory connector, scrubber, and flow meter means, and constructed such that upon the subject inhaling, gas is caused to pass through the scrubber, then through the flow meter means, and then to the subject's respiratory system through the respiratory connector, and upon the subject exhaling to pass the exhaled gas from the respiratory connector first through the scrubber, then through the flow meter means;

means for receiving the resultant signals from the flow meter means and for generating a signal proportional to the integral of the differences between the inhaled and exhaled gas volumes over a period of time; and

means for connecting said conduits to a mechanical ventilator so that the ventilator may provide respiratory gas to the calorimeter and receive exhaled gas from the calorimeter.

2. The indirect calorimeter of claim 1 wherein the mechanical ventilator includes a single passage adapted to pass both inflow to the ventilator and outflow from the ventilator and said means for connecting said conduits to said mechanical ventilator includes a single conduit interconnecting said single passage to said respiratory connector, scrubber, and flow meter means, and constructed to pass respiratory gasses through said single passage of the ventilator.

3. The indirect calorimeter of claim 1 wherein said ventilator includes a first tube for passing gasses to be inhaled by the subject and a second tube to pass gasses exhaled by the subject, and said first and second tubes constructed to connect to separate sections of said conduits of the indirect calorimeter interconnecting said respiratory connector, scrubber and flow meter means.

4. The indirect calorimeter of claim 3 including a first one-way valve means for interconnecting said first tube of the ventilator with the conduits of the indirect calorimeter and a second one-way valve means for interconnecting the second tube of the ventilator to the indirect calorimeter.

5. The indirect calorimeter of claim 1 wherein said conduits have disposed therein a first pair of valves operably connected to said inlet side of the scrubber and adapted to connect the scrubber to a respiratory connector and a second pair of valves operably connected to said outlet side of the scrubber and adapted to connect the scrubber to a source and sump of respiratory oxygen.

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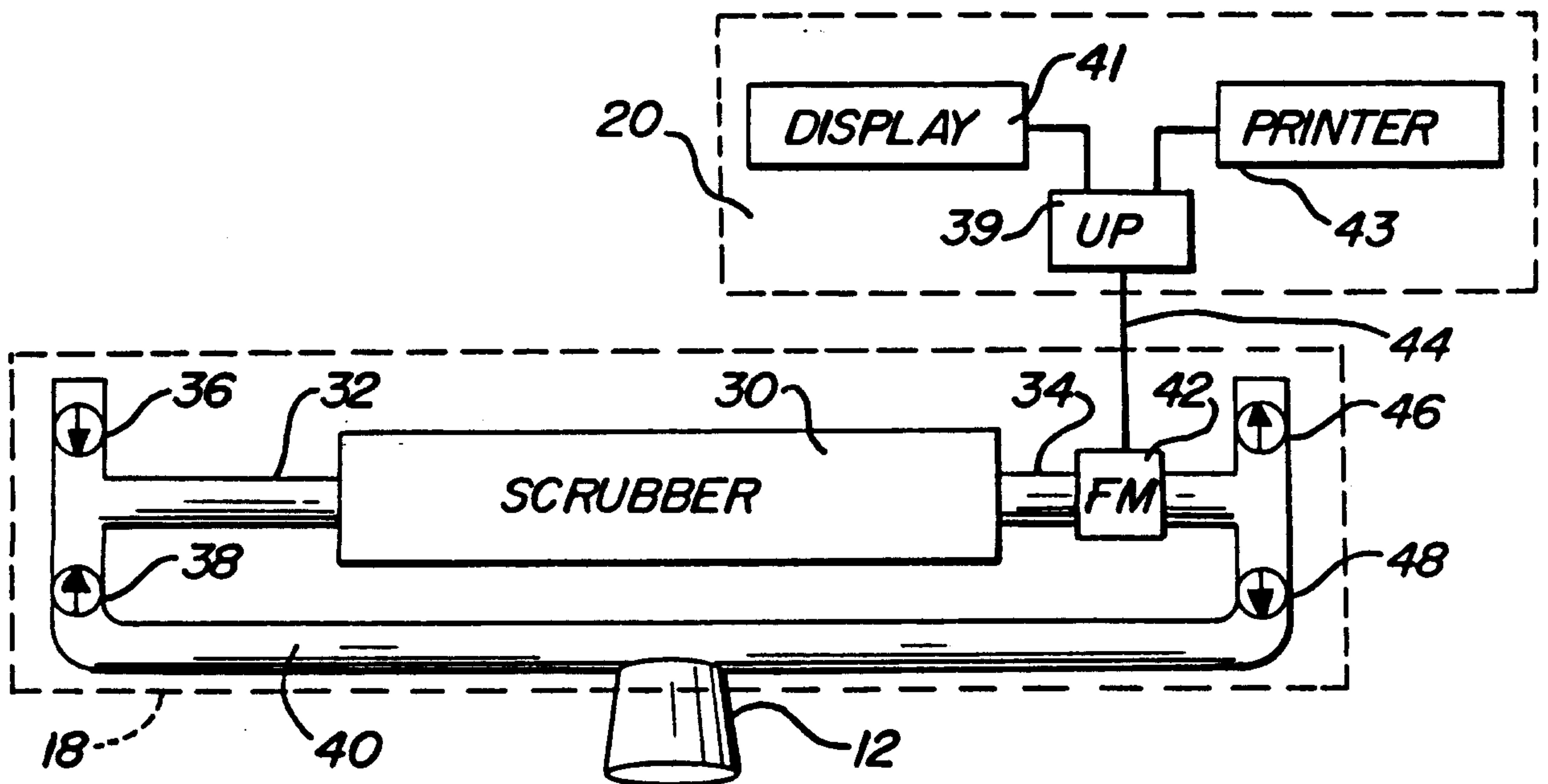
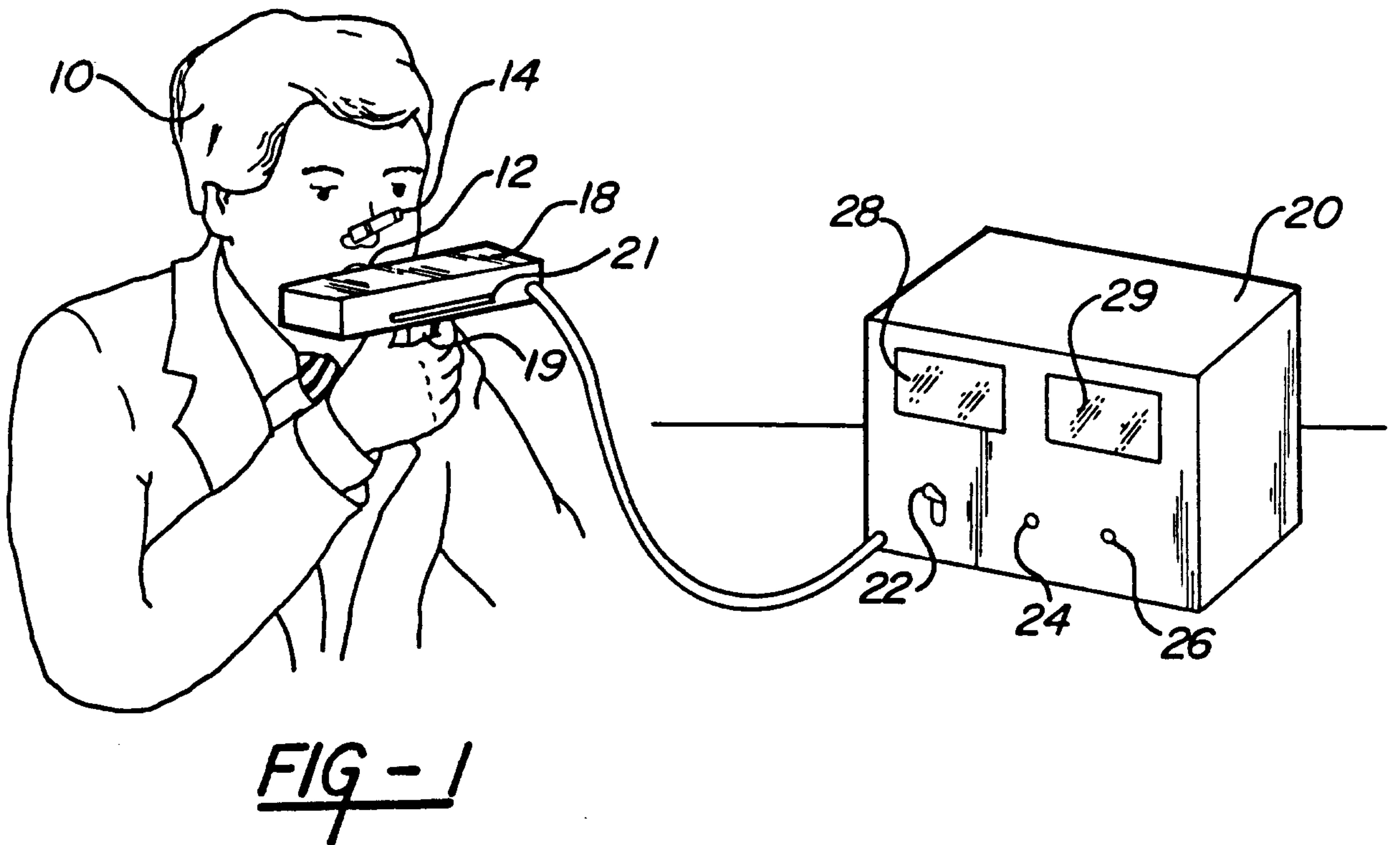
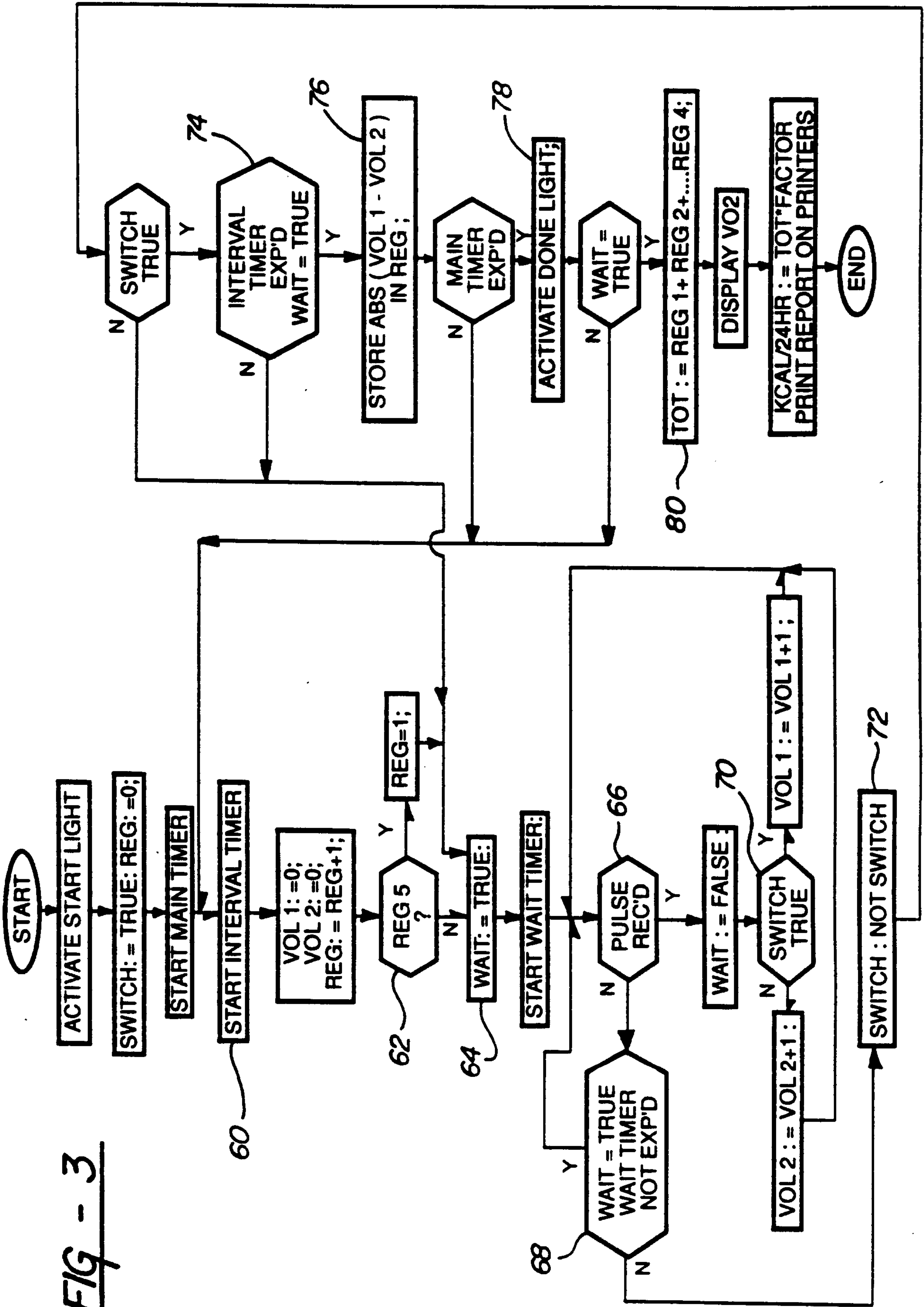


FIG - 3



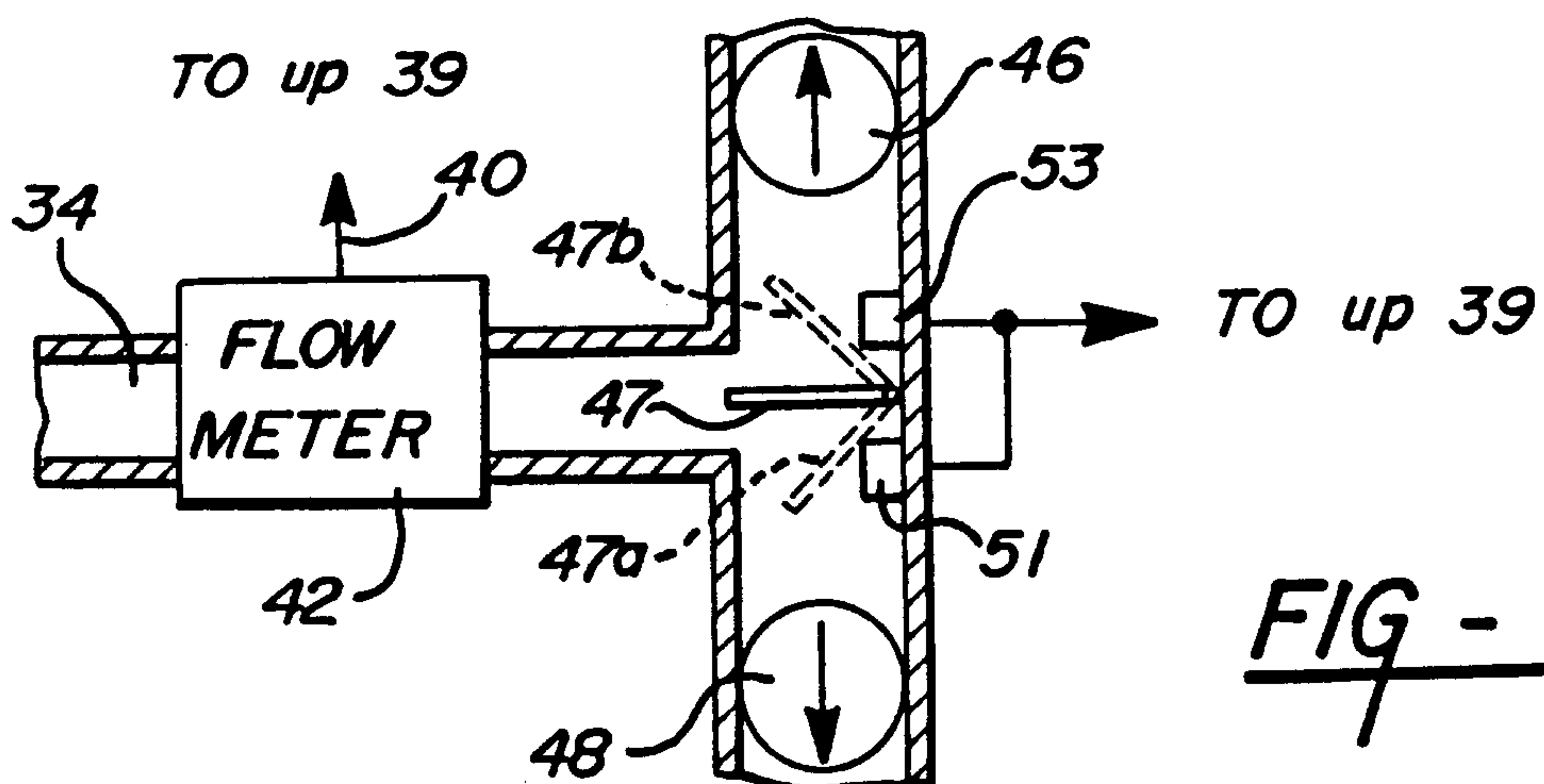
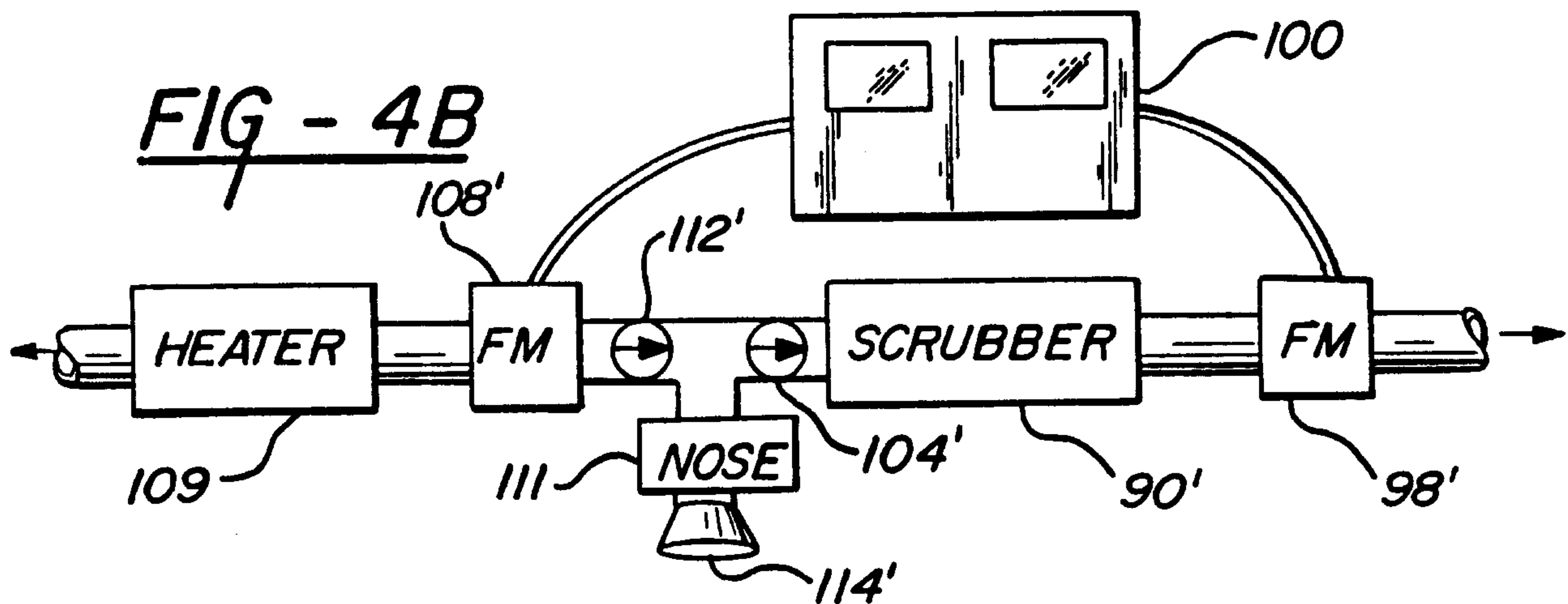
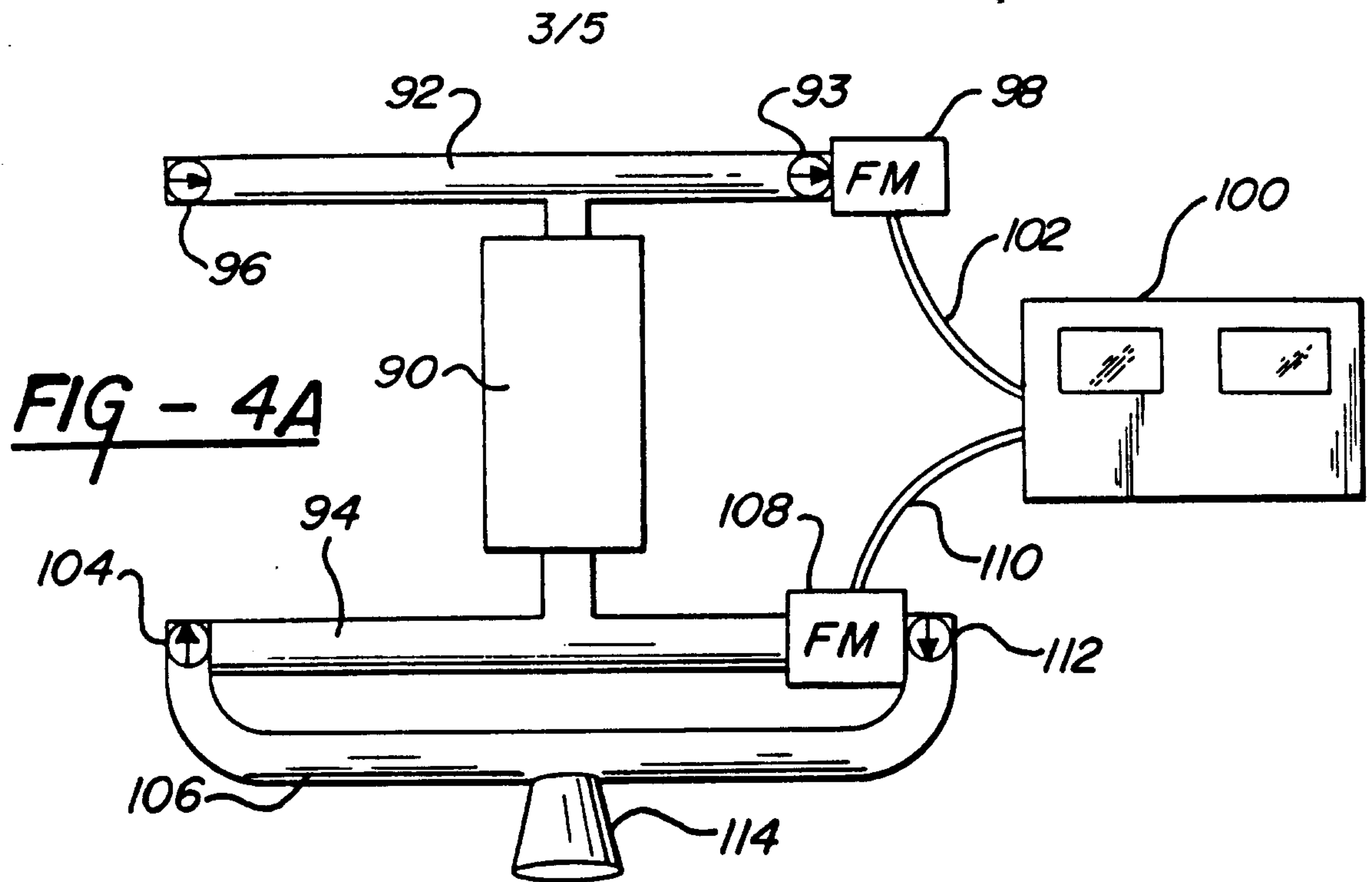


FIG - 6

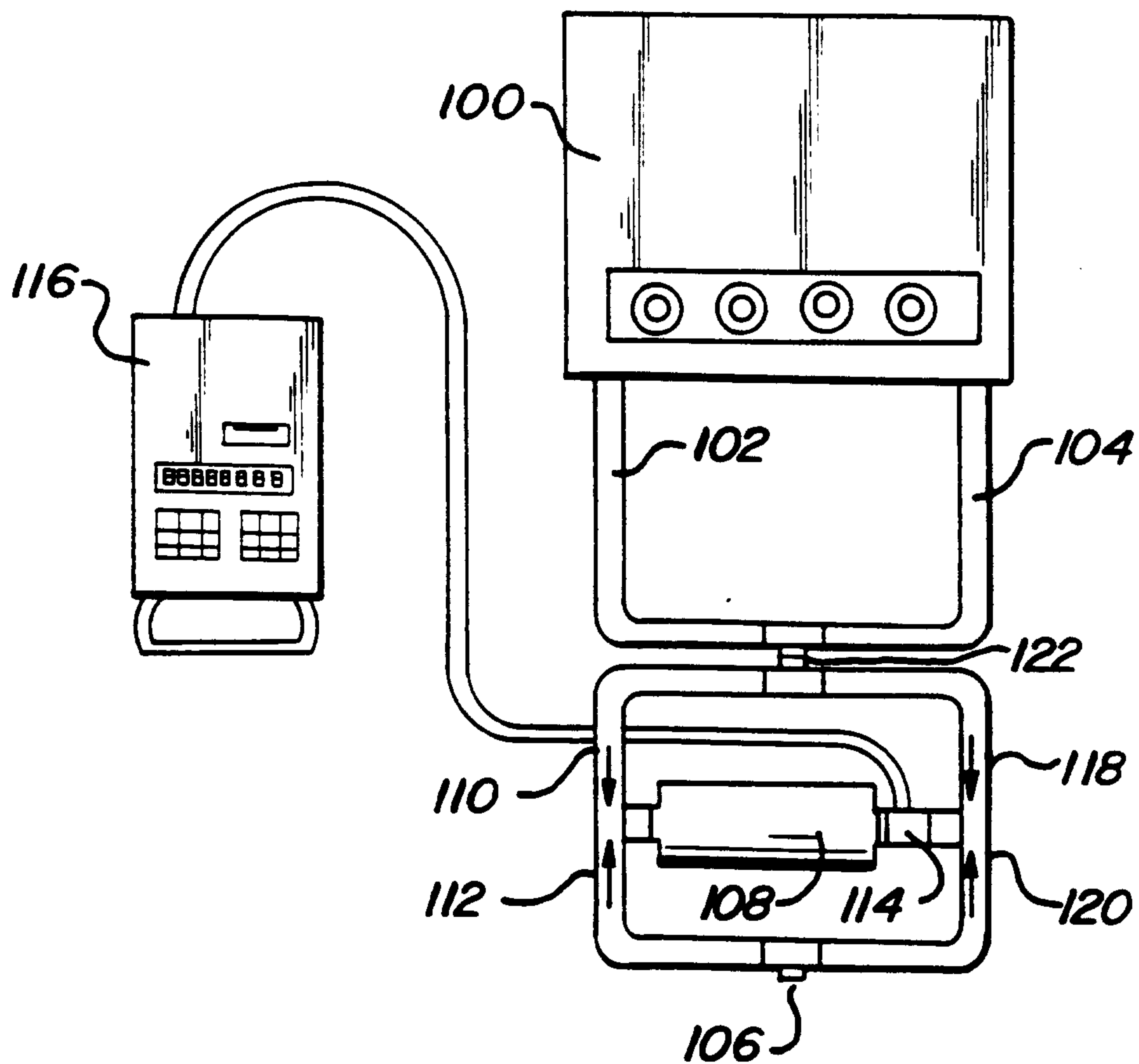


FIG - 7

